# Master Thesis

# Understanding Irrigation-based Agricultural Systems:

# Factors' Influencing Agricultural Performance in Khuzestan Province, Iran

By

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## List of Abbreviations

| | |
|---|---|
| APSIM | Agricultural Production Systems Simulator |
| BMP | Best Management Practice |
| CSIRO | Commonwealth Scientific and Industrial Research Organization |
| CLD | Causal Loop Diagram |
| DPSIR | Driver-Pressure-State-Impact-Response model |
| DSSAT | Decision Support System for Agricultural Technology |
| EC | Electric Conductivity |
| EPA | United States Environmental Protection Agency |
| FAO | Food and Agriculture Organization of the United Nations |
| GDP | Gross Domestic Product |
| GHG | GreenHouse Gas |
| GIS | Geographic Information System |
| GIZ | German Corporation for International Cooperation |
| ICID | International Commission on Irrigation and Drainage |
| IPM | Integrated Pest Management |
| IRR | Iranian Rial |
| IUCN | International Union for Conservation of Nature |
| KWPA | Khuzestan Water and Power Authority |
| MENA | Middle Eastern and Northern Africa |
| MoE | Iranian Ministry of Energy |
| MoJA | Iranian Ministry of Jihad Agriculture |
| N | Nitrogen |

| | |
|---|---|
| NA | Network Analysis |
| O&M | Operation and Management |
| OECD | Organisation for Economic Co-operation and Development |
| PSR | Pressure-State-Response model |
| RISE | Response-Inducing Sustainability Evaluation |
| SAIP | Sustainable Agriculture Initiative Platform |
| SDA | System Dynamics Approach |
| SF | Stock-Flow model |
| SWM | Sustainable Water Management |
| UN | United Nations |
| UNEP | United Nations Environmental Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USDA | United States Department of Agriculture |
| WB | World Bank |
| WCED | United Nations World Commission on Environment and Development |
| WP | Water Productivity |

**Certification Page**

I, Ulrike KIRSCHNICK (Student ID 51216602), hereby declare that the contents of this Master's Thesis are original and true, and have not been submitted at any other university or educational institution for the award of a degree or diploma.
All information derived from other published or unpublished sources has been cited and acknowledged appropriately.

KIRSCHNICK, Ulrike

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## Abstract

Irrigation-based agriculture in arid regions causes and also faces several environmental challenges that will be aggravated in the future due to climate change. To outline measures that improve the sustainability of these systems, an understanding of the system, and the environmental, economic and social factors influencing its performance a needed. This research synthesizes quantitative and qualitative elements of previous system modeling research to develop a new method using DE and Gotvand irrigation schemes in Khuzestan Province, Iran as a case study. The evaluation of factors influencing farmers' performance results from a comparison of the respondants of the questionnaire, and of the two irrigation schemes to determine structural effects. The evaluated farmers are embedded in a strong given structure, the analysis of these conditions is crucial to understand system functioning. The farmers show great variance in environmental and economic factors, such as irrigation frequency, fertilizer and pesticide use, and profit per hectare, results that are strongly correlated to farm size, harvests per year and education. The most important social platform for farmer cooperation particularly in Dez is the gate community. This local organization can serve to realize further internal and external performance potentials, such as knowledge transfer, optimization of irrigation schedules and contracting with buyers to secure sales. The comparison of different farmers, and of the two irrigation schemes, helps to understand the system and result in recommendations for the involved stakeholders. Nevertheless, a bigger sample and future research on international standards of sustainability in irrigation-based agriculture are needed.

**Keywords:** Agricultural system modeling, sustainability, factor interaction, irrigation, farming performance

# 1. Introduction

Irrigated agriculture in arid regions is often referred to as unsustainable, even though this notion of sustainability is only observational and undefined. As a nation with 65% of its landmass considered arid and 20% categorized as semi-arid, the Islamic Republic of Iran faces various challenges in water management from the recent past up until today (Madani, 2014), which will be aggravated due to an increase in temperature and reduction in precipitation as effects of climate change (United Nations Framework Convention on Climate Change (UNFCCC), 2007).

While Iran used to be internationally recognized for "significant success in water resources management over thousands of years in an arid area of the world", the water sector is currently facing a looming crisis (Madani, 2014). The agricultural sector uses 92% of the total annual water withdrawal, whereof irrigation regimes are the main consumer of water. On the national level, 46% of the cultivated area is equipped for full or partial control irrigation, with wheat and barley being the most important crops in terms of water consumption, accounting for 39% of all irrigated crops on a surface area of 3.24 million ha in 2003. 57% of the water originates from groundwater resources and 43% from surface water reservoirs (Food and Agriculture Organization of the United Nations (FAO), 2008). Despite the declining importance of the agricultural contribution to Iran's overall economic performance in the face of industrialization and an oil-export oriented economy, the agrarian sector remains a key sector to national survival and sustainable development (Khorami & Pierof, 2013), providing employment, food, and livelihoods for rural communities. In Iran, agriculture accounted for 9.3% of the Gross Domestic Product (GDP) and provided approximately 20% of the jobs in 2014 (World Bank (WB), 2016).

The agricultural sector does not only cause the water crisis and decreasing groundwater levels due to overexploitation and inefficient water use, but is also affected by water shortages and droughts as well as soil degradation and salinization, which damages ecosystems and agricultural productivity (Madani, 2014). Policies and economic incentives failed to address the major issues of overexploitation, mismanagement, and injustice in water distribution. On the contrary, the centralization of governmental water management land reforms "have exacerbated water scarcity in Iran" (Lehane, 2014). Nevertheless, water scarcity and pollution problems are high on the political agenda (Madani, 2014).

## 1.1 Objectives and Significance

Some research has been conducted in the water and agricultural sector and the Iranian government recognizes the significance of water and water related problems as crucial to the country's socio-economic development (Madani, 2014; Bozorg-Haddad et al., 2016). Nevertheless, only a few scientific works and legislations target the agricultural system and water consumption for irrigation purposes as one of the main reasons for water related issues in Iran, and most research focuses on irrigation scheduling and water use rather than overall system performance (Marques et al., 2005).

A system is a "regularly interacting or interdependent group of items forming a unified whole" (Merriam-Webster, 2017). The agricultural system, being an open system rather than closed, consists of natural and man-made components which interact with each other and their environment outside of the system boundary "to determine overall system behavior" (Wallach et al., 2013). Agricultural systems processes a certain input (earth's resources) within this network of components in order to produce the desired output (crops and livestock). Significant differences between natural and anthropogenic systems is the occurrence of wastes and pollution as undesired by-products of a production process in man-made systems, whereas natural systems are coordinated and organized in a way that all components are organized in closed cycles (Zhang, 2013). In system analysis and assessment of irrigation-based agriculture the agricultural production and also the water management are the two main sub-systems which are merged together.

Additionally, sustainability requires systemic thinking and modeling of agricultural production; and systems thinking is gaining importance in the field of sustainability (Walters et al., 2016; Jones et al., 2016; Marques et al., 2005). “Models are necessary for understanding and predicting overall agro-ecosystem performance” (Jones et al., 2016). Furthermore, as agricultural systems consist of various components and complex interaction among them, modeling systems requires interdisciplinary thinking (Broto et al., 2012).

As pointed out by the International Commission on Irrigation and Drainage (ICID) (2017), more local research is needed to analyze existing practices in irrigation-based agriculture and understand chances and challenges of the adoption of sustainable practices. The definition of sustainable agriculture and water management (SWM) in the agricultural sector is vague and observational, lacking standardized methods to quantify the degree of sustainability; especially in the case of combining agricultural and water management aspects.

In regards to these challenges, this research aims to develop a methodological framework which evaluates the degree of sustainability within the two chosen agricultural systems in Khuzestan Province, Iran. The methodological review and synthesis of existing methods to develop a new model contributes to the methodological development in the field of sustainability science. As Jones et al. (2016) and Holzworth et al. (2015)

stated, the future development of methods needs to consider technological advancement, to be transdisciplinary and should provide user friendly models with open source available and harmonized data.

Analyzing differences of agricultural performance and related water consumption on a local level helps to gain a deeper understanding of the system. It enables one to identify crucial components influencing sustainable performance in order to outline opportunities for the adoption of more sustainable practices across space and time. As Turner et al. (2016) state, it is important to understand the system and embedded problem first, before "jumping to conclusions", which might have adverse effects on the system rather than improvements. System understanding then facilitates the development of political, economic, and technical mechanisms which support system transformation towards more sustainability. Thus, this research can offer valuable insights and outline recommendations for sustainable agriculture within the chosen systems as well as other areas under irrigation schemes with similar climate and geographical conditions.

## 1.2 Research Structure and Questions

As a first step, this research reviews different methods to model agricultural systems and their economic, physical, and social dimensions in regards to which sustainability can be measured. The second part of the literature review analyzes previous research on sustainable agricultural practices to refine the concept of sustainability in agriculture. By combining aspects of these tools and best management practices (BMP), a new method is developed with the goal to not only understand the system performance, but also draw conclusions on the system's degree of sustainability. Sustainability in this context is not an ultimate goal, but a gradation of overall performance by comparing different farmers regarding their achievements in terms of economic profitability, regionalism, Water Productivity (WP), environmental impact, and social welfare.

The resulting part serves to test and adapt the method within the chosen system. To understand the system farmers are embedded in, primary information from interviews and in-field observations as well as complementing literature serve to outline framework conditions. The focus lays on institutional and administrative organization and water resource management. The data collected by questionnaires are interpreted after findings on sustainability from the literature review, and statistically analyzed in regards to variance and correlation, as well as qualitatively in regards to farmers' perceptions. Following the structure of the thesis, the discussion deals with the evaluation of the adopted method throughout the research process. Furthermore, the results and findings on factors influencing farmers' performances and drawbacks on sustainability will be discussed. Finally, the conclusion will sum up the main findings to answer the following research questions and give recommendations for future development:

- Which factors determine the performance of irrigation-based agricultural systems in regards to economic factors, environmental impact, water resource usage, and formal and informal cooperation?
- How do these factors correlate with each other?
-

## 1.3 Scope

Being the second largest country by area and economy (after Saudi Arabia) and the second most populated nation (after Egypt) in the Middle East and Northern African (MENA) Region (WB, 2016), the Islamic Republic of Iran constitutes diverse topographical zones, large spatial and temporal climatic variability, and economic and social diversity.


**Figure 1: Surface water sources, irrigation schemes and location of Khuzestan province in Iran (FAO, 2008)**

Khuzestan Province in South-Western Iran serves as the case study for the developed methodology because of its importance for agricultural production, its problems in regards to water management, and its diversity of irrigation schemes. Within Khuzestan, Dez and Gotvand are the two irrigation systems being analyzed due to their similar framework conditions yet differences in agricultural performance.

Khuzestan province has the highest percentage usage of area for agricultural purposes (11.77 million ha of agricultural land, 8.59% of the total surface area) producing nearly one third of all agricultural products in Iran (Ministry of Jihad Agriculture (MoJA), 2017). At the same time, it has one of the lowest irrigation efficiencies at 27-37% compared to the 17 main agricultural provinces of Iran (Keshavarz et al., 2005). As the MoJA states, the biggest challenge in Khuzestan agricultural water use is the absent systems thinking on political, economic, and community levels (Ommani, 2011).

The area is especially interesting because it is the country's second largest wheat producer with approximately 62% of the cultivated area under irrigation (United States Department of Agriculture (USDA), 2012), where the gap between water consumption and production relation is especially noticable.

Nevertheless, this ratio is different among the four irrigation schemes that are located in Khuzestan province (see Figure 1). These four irrigation schemes are differentiated due to their geographical location and source of water and include Dez, Gotvand, Karkheh-Shavorr and Maroon irrigation schemes. They are characterized by high discrepancies in regards to their comparative water use efficiency or global WP, which calculates the yield production rate for wheat per water unit used, taking into consideration the delivered water, cultivated area, and crops water requirement. Among these four, Dez has the highest global WP with 0.81 kg $m^{-3}$ whereas Gotvand represents one of lowest global WP rates in whole Iran with 0.43 kg $m^{-3}$ (Montazar, 2009). The ones located in Khuzestan are marked in yellow.

**Table 1: Water productivity of wheat in different command areas (Montazar, 2009)**

| Location | Irrigation scheme | Water productivity kg/m$^3$ |
|---|---|---|
| Khuzestan Province | Dez | 0.85 |
| | Gotvand | 0.43 |
| | Karkheh Shavoor | 0.62 |
| | Maroon | 0.68 |
| North-Western Iran | Moghan | 0.70 |
| | Qazvin | 0.72 |
| | Varamin | 0.52 |
| | Abshar | 0.55 |
| | Borkhar | 0.48 |
| | Mahyar | 0.49 |
| | Nekooabad | 0.50 |
| | Roodasht | 0.60 |

# 2. Literature Review

In order to develop a new method for system modeling, approaches to decide on a methodology and different established methods will be reviewed first. These methods include Driver-Pressure-State-Impact-Response (DPSIR) Models, the System Dynamics Approach, Network Analysis and modeling software. Secondly, to assess sustainability in agriculture, literature on recommended practices and management will be analyzed.

## 2.1 Methodological Choices for Modeling and Sustainability Assessment of Agricultural Systems

There are different approaches to system modeling, sustainability, and sustainability assessments which depend on the focus and scope of the study, the available and collectable data, and expected results and target audience (Beloin-Saint-Pierre et al., 2016). In the following sections, existing literature on system modeling and sustainability assessment will be reviewed and synthesized in order to develop a new methodology in chapter 3. The reviewed literature has been derived from scientific databases such as Scopus, Science Direct, and Ritsumeikan Asia Pacific University Runners database and library using the keywords “agriculture”, “system” and “modeling”. Additional literature comes from the field of industrial ecology and urban metabolism, which can also give useful insights for the modelling of agricultural systems.

### 2.1.1 Data Input and Indicators

Data collection to “quantify and identify actual use and inefficiencies” imposes the biggest challenge to accurate and reliable system modeling to evaluate the degree of sustainability and draw possible solutions for SWM (Nolasco, 2013). As Beloin-Saint-

Pierre et al., (2016) stated, not only data availability, but also the type and quality of data need to be sufficient and fit the chosen indicators within the geographical and temporal scope. The type of data can be categorized in regards to the dimension analyzed within the system into physical (e.g. material, energy, and water), economic and social data and different types of data can be translated into other forms by using intensity factors (Zhang et al., 2014). Top-down data, such as statistical yearbooks, might be available and accessible, but need to be disaggregated to fit the local context, which is challenging. Bottom-up data might be more useful to describe local specificities, but collection requires sufficient financial and temporal resources.

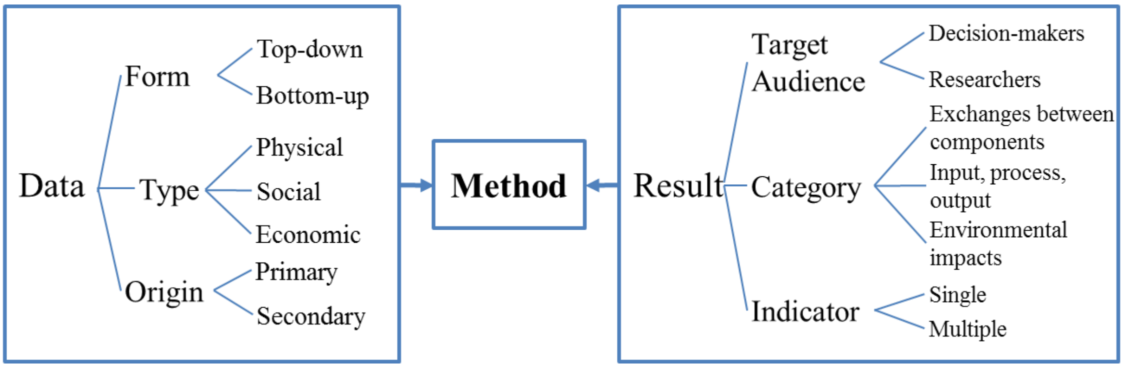



**Figure 2: Influence of input data and expected result on the choice of method**

Furthermore, the chosen data should match the desired format of results, which reflects the needs and characteristics of the targeted audience to ensure a reasonable level of comprehensiveness. This requires the categorization and classification of input data into useful indicators such as water reuse and crop production economics (Pereira et al., 2012). This choice is also influenced by the author's motivation (Beloin-Saint-Pierre et al., 2016). The three main different categories of results are either to describe exchanges between compounds of a system, to quantify inputs entering and outputs exiting a system and the processing between both, and the calculation of environmental impacts. The indicators can focus on one specific (e.g. GHG emissions) or multiple criteria assessment.

Beloin-Saint-Pierre et al. (2016) recommend the use of a functional unit that indicators are related to in order to facilitate a comparison of different cases and gain information on the intensity of resource use.

The majority of reviewed studies use bottom-up as well as top-down data and most indicators and data used in previous modelling of agricultural systems are of physical and economic nature. Almost all studies, such as Balali & Viaggi (2015), Marques et al. (2005), Salazar et al. (2012), Liu (2009), Pereira et al. (2012), Ghahroodi et al. (2015), Sassenrath et al. (2010), Walters et al. (2016), Martinzadeh et al.(2017) and Rao & Rogers (2006) include:

- Farm characteristics, such as land area and livestock data, such as farm size and number and type of livestock and crop;
- Soil quality, such as information on water and nutrient (organic matter) content, temperature, and erodibility;
- Climate data, such as temperature and precipitation as well as air quality;
- Water data, such as groundwater extraction, water consumption and waste water or drainage discharge as well as specific water demands of different crop types;
- Economic data, such as prices for various cost and revenue positions;
- Population data, such as projected population, spatial distribution, and fertility rates.

Some studies also aim to include information on management practices retrospective to seasonality and environmental conditions, such as cropping patterns and technology use (Marques et al., 2005; Jones et al., 2016). As an environmental indicator, several researchers calculate system-related GHG emissions (Čuček et al., 2012), which is only partly applied in agricultural production. The calculation for emissions from energy use on farm level, such as conducted by Sugden (2010), is straightforward and requires less data, whereas the consideration of emissions from land use change requires a larger amount of data and “a standard guideline addressing carbon footprinting specially for agriculture” is missing (Pandey & Agrawal, 2014).

Only few studies, such as Sassenrath et al., (2010) and Rao & Rogers (2006), consider social and institutional indicators equally to economic and environmental factors in the system modeling. Other system modeling approaches focus solely on these social aspects without considering physical and economic data such as Hauck et al. (2016), Cadger et al. (2016), Hashemi et al. (2015), Dowd et al. (2014), Marzban et al. (2016) and Janssen et al. (2006). Most of the social data is collected through questionnaires and interviews as well as secondary literature on socioeconomic structure and statistics and reflects different structural elements, farmers’ attitudes, and opinions, which are interpreted to estimate social factors, such as resilience, vulnerability and adaptation to environmental change. Collected data include socioeconomic information, standard of living through variables such as energy consumption, sense of heritage, inter-generational active participation, commitment to local community, responsiveness, social capital, institutional organization, and land tenure, degree of economic independence, attitudes towards large scale production, environmental attitudes and commitment to environmental protection, and information transfer and networks.

### 2.1.2 Methods for System Modeling

The choice of method and the depth of system analysis are predefined by the data availability and expected results (Beloin-Saint-Pierre et al., 2016), and can be selected through three major decisions concerning type, approach and scale (Jones et al., 2016).

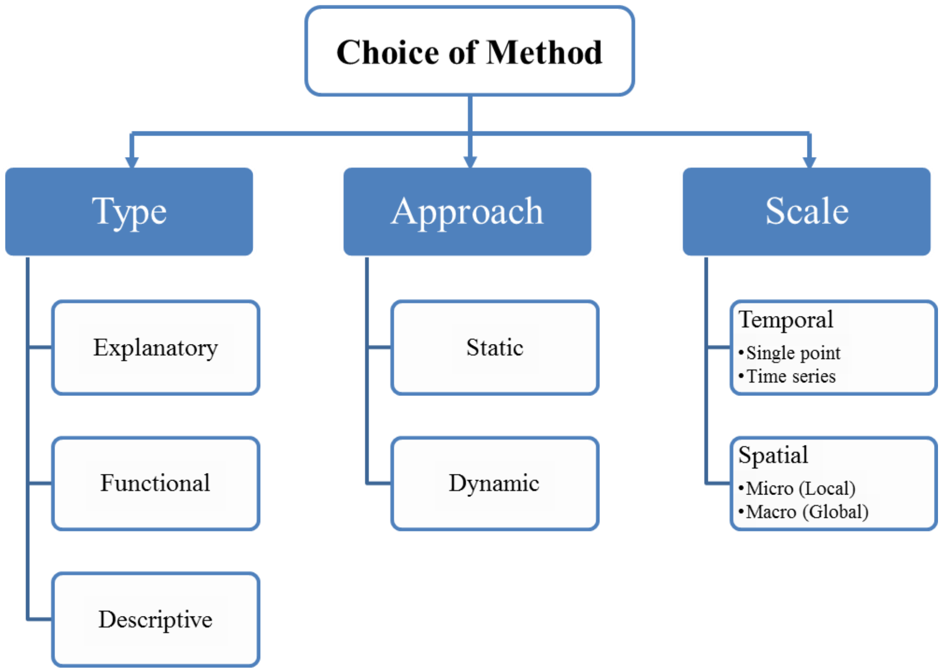



**Figure 3: Methodological choices for system modeling**

Explanatory models aim to identify crucial components of systems and how these interact and contribute to the overall system performance, which requires the consideration of a large number of parameters and thus encounters problems of balancing between complexity and simplification, and problems of uncertainty (van Ittersum et al., 1998). In contrast, functional types offer higher certainty in the results because they empirically assess fewer parameters and are typically applied to simulate crop production (Ritchie & Alagarswamy, 2002). Both types of models aim to deepen the scientific understanding of system functioning and are useful for decision-makers only to a limited extend. Policy makers are less interested in insights on system functioning but in systems' reactions to external environmental drivers and policies and, therefore, require descriptive models (van Ittersum et al., 1998). Whether this modeling increases scientific understanding or not is secondary, as the main goal of these models is to "provide reliable system response information that decision and policy makers need" (Jones et al., 2016).

Static models are useful to understand the inner functioning of a system and are practicable as they require less financial and temporal resources, but they do not consider changes in environmental factors such as climate change, they do not give insights on a system's evolution, and they do not allow extrapolation and identification of trends. For this reason, and in regards to holistic sustainable thinking, Beloin-Saint-Pierre et al. (2016) recommend the use of dynamic models, which can describe systems' responses to external drivers and changing framework conditions (Wallach et al., 2013). The main challenge of dynamic modeling is increasing complexity and difficulty in modeling due to the high amount of data requirements.

Similar as in regards to advantages and disadvantages of approaches, the temporal scope needs to balance between data requirement and available resources, and quality and adequacy of output. Furthermore, the scope "is important in determining what type of model is needed and what users are being targeted" (Jones et al., 2016). An overview of different scopes of models is visible in **Figure 4**.

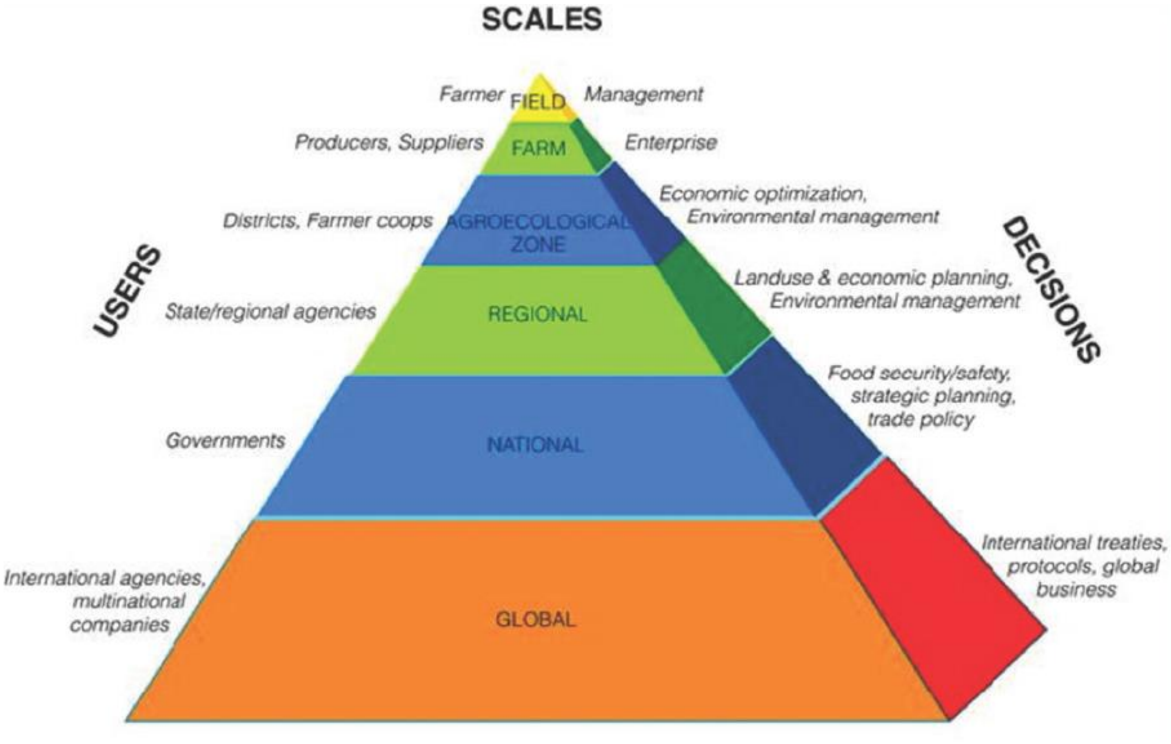



**Figure 4: Spatial scales with users and decisions on each level (Jones et al., 2016)**

The smallest geographical scope is the field level, which enables the identification of BMP for crop and livestock production, profitability, and environmental protection from the farmers' perspective (He et al., 2012). The other levels provide analysis on a wider scope, which deepens the understanding of regional systems and allows outlining effects of changes in framework conditions such as weather, management, and socioeconomic conditions in a certain area. Beloin-Saint-Pierre et al. (2016) define this scope differently, which is nevertheless in line with the mentioned findings: System modeling should reflect a global scope in a way that not only mechanisms within a local (or regional) area are considered, but also all relevant influences from outside the primary system boundary.

#### *Driver-Pressure-State-Impact-Response (DPSIR) Models*

The DPSIR framework has been developed from the Pressure-State-Response (PSR) framework and is helpful to model ecological and social processes within a system simultaneously and to predict system changes in reaction to drivers. These static or dynamic descriptive models provide an overview of a system's main challenges "link science to […] policy and management" (Lewison et al., 2016). As such, DPSIR models require a high level of data aggregation and can have issues of constructional validity, but they offer the advantage of high level comprehensiveness and suitability for decision-makers, whom need to be actively engaged in the modeling process, and concurrently improve "scientific understanding of policy and planning for sustainable agricultural development" (Rao & Rogers, 2006). For this reason, governmental agencies and other political institutions such as the FAO, the WB, the UN, the European Environment Agency (EEA), and the US Environmental Protection Agency (EPA, 2016) favor and recommend the use of DPSIR schemes. Several researchers have also applied them to coastal and river water monitoring (Song & Frostell, 2012; Kristensen, 2004; Lewison et al., 2016) to assess agricultural systems (Rao & Rogers, 2006) and to analyze land and soil degradation in response to changes in land use (Porta & Poch, 2011).

The system is modeled through five steps of causal links, starting in a logical order with the drivers which cause the pressure on and within the system and can be measured through efficiency indicators and emission factors (Smeets & Weterings, 1999). These lead to a certain state of environment, society and economy which impacts the quality of components within the system, such as health, ecosystem, and resources and can be measured through dose-response-indicators. These impacts then stimulate responses in the form of policies, targets, and management practices which aim to influence not only the direct impact, but also drivers, pressures, and state. Responses are chosen in regards to risks, costs, and benefits of the action and can be evaluated in regards to their effectiveness. An example of a DPSIR for water systems is visible in Figure 5. Typically the construction of a DPSIR model starts with the analysis of the state (or problem), from which then pressures and impacts are investigated.

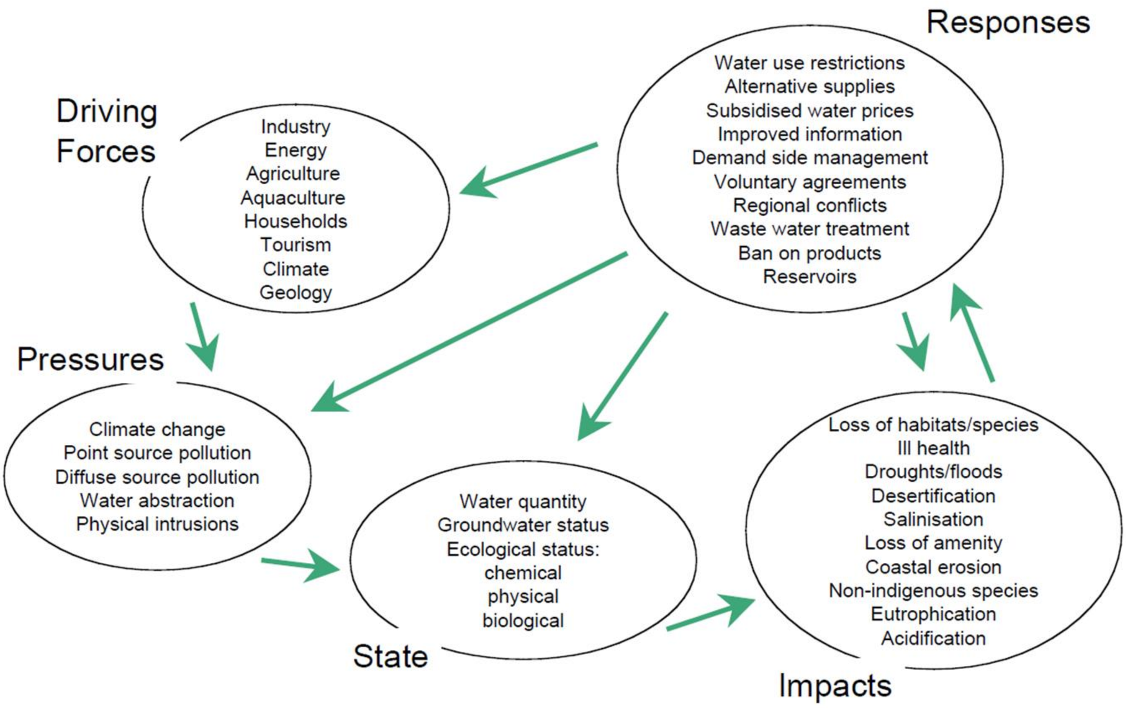



**Figure 5: A generic DPSIR framework for water (Kristensen, 2004)**

Next to this macro scale of system modeling through logical considerations, other researchers such as (Porta & Poch, 2011) use a finer scale to consider context-related specificities. To assess the drivers and pressures of soil degradation, they compared the soil in a high quality state from one site with an eroded and degraded soil from another site and then observed impacts on the overall system from these different states. Based on this comparison, they outlined policies and measures to reach the good state of the first site.

***System Dynamics Approach (SDA)***

The SDA "attempts to represent both bottom-up (physical) and top-down (biological) forces interacting in an ecosystem" and is applicable in various fields, such as fisheries, water and nutrient cycles, and agriculture (FAO, 2007). In agricultural systems, multidimensional factors and their interlinkages are modeled to elaborate interdependencies of factors, their interconnected, dynamic feedback loops, and resulting behaviors from this connection and feedback (Walters et al., 2016). The advantage of applying the SDA in an agricultural sustainability assessment lies within the strength "to include the dynamic interactions between factors at play in an interconnected system" (Meadows, 2008; Walters & Javernick-Will, 2015; Walters et al., 2016). While the SDA attempts to reflect system interconnections and dynamics and, therefore, system complexity, the modeling itself still requires simplification and reductionism which inherits several challenges to the "comprehensiveness of holism" (Wu & David, 2002).

The SDA modelling consists of two main parts to be able to assess sustainability: the qualitative modelling of Causal Loop Diagrams (CLD) that "represent dynamic factor interaction" (Walters et al., 2016), and the translation of these into quantitative stock-flow (SF) modelling (Pruyt, 2013). The procedure to conduct a SDA can be seen in Figure 6 (Walters et al., 2016).

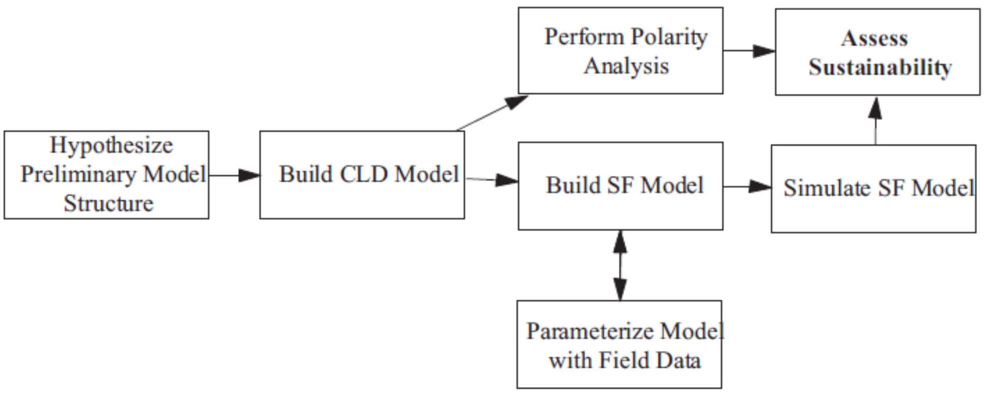



**Figure 6: Framework for modelling agricultural systems under the SDA (Walters et al., 2016)**

"CLDs are composed of arrows (causal influences) between factors and pair-wise factor polarities represented as positive (+) (i.e., an increase or decrease of one factor causes an increase or decrease in the other factor) or (−), which is the opposite of a positive influence: (i.e., an increase or decrease of one factor causes a decrease or increase in the other)" (Walters et al., 2016). In the transformation of CLD to the SF model, the factors are transformed into functional parameters, namely stock (squares) and flows (valves) (ibid). An example of a CLD for an analysis of agricultural systems in the eastern United States is given in Figure 7 and the derived SF models are displayed on the following figure.

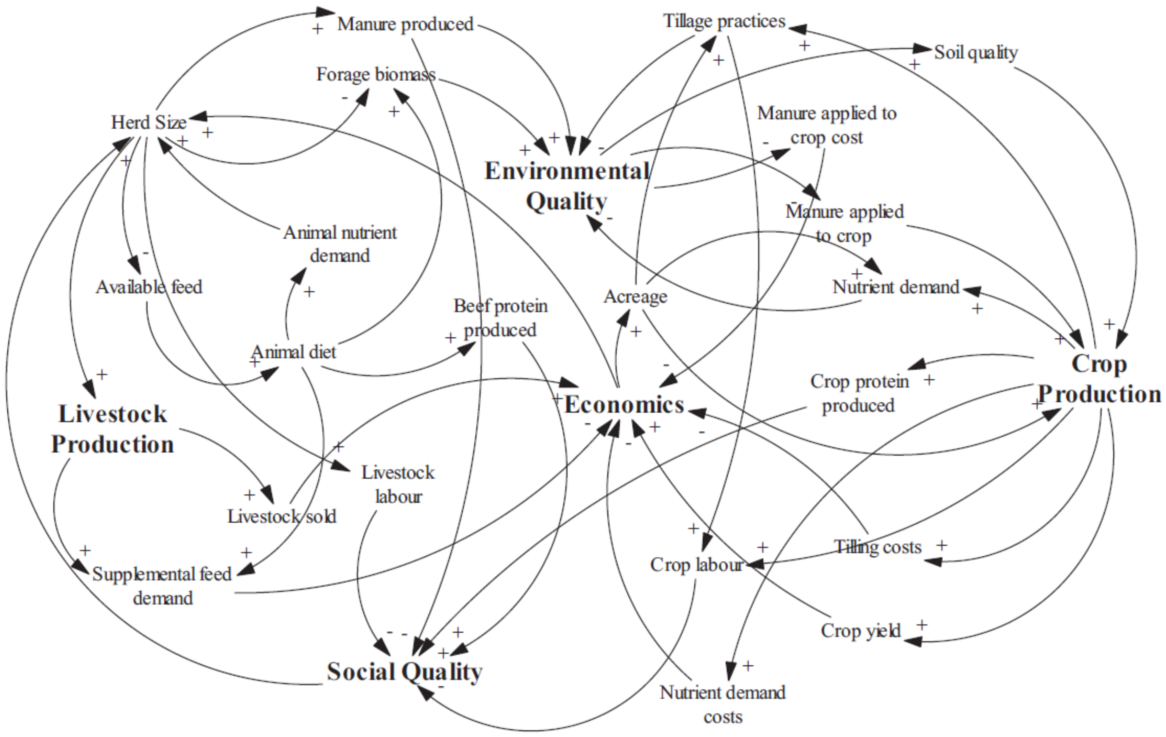



**Figure 7: CLD of production drivers (Walters et al., 2016)**

**Principle drivers in larger bolded font, positive (+) or negative (−) impact of a practice on a factor is indicated at the head of the arrow linking the two parameters**

The SF is built upon various parameters from initial stock conditions. These include crop area, yield, standard deviation and harvest index; livestock characteristics; economic and social factors, such as several costs and revenues; and tillage and environmental indicators, for example the effect of tillage on yields, variations of yields, machinery and pesticide costs, and on labor intensity as well as soil erosion.

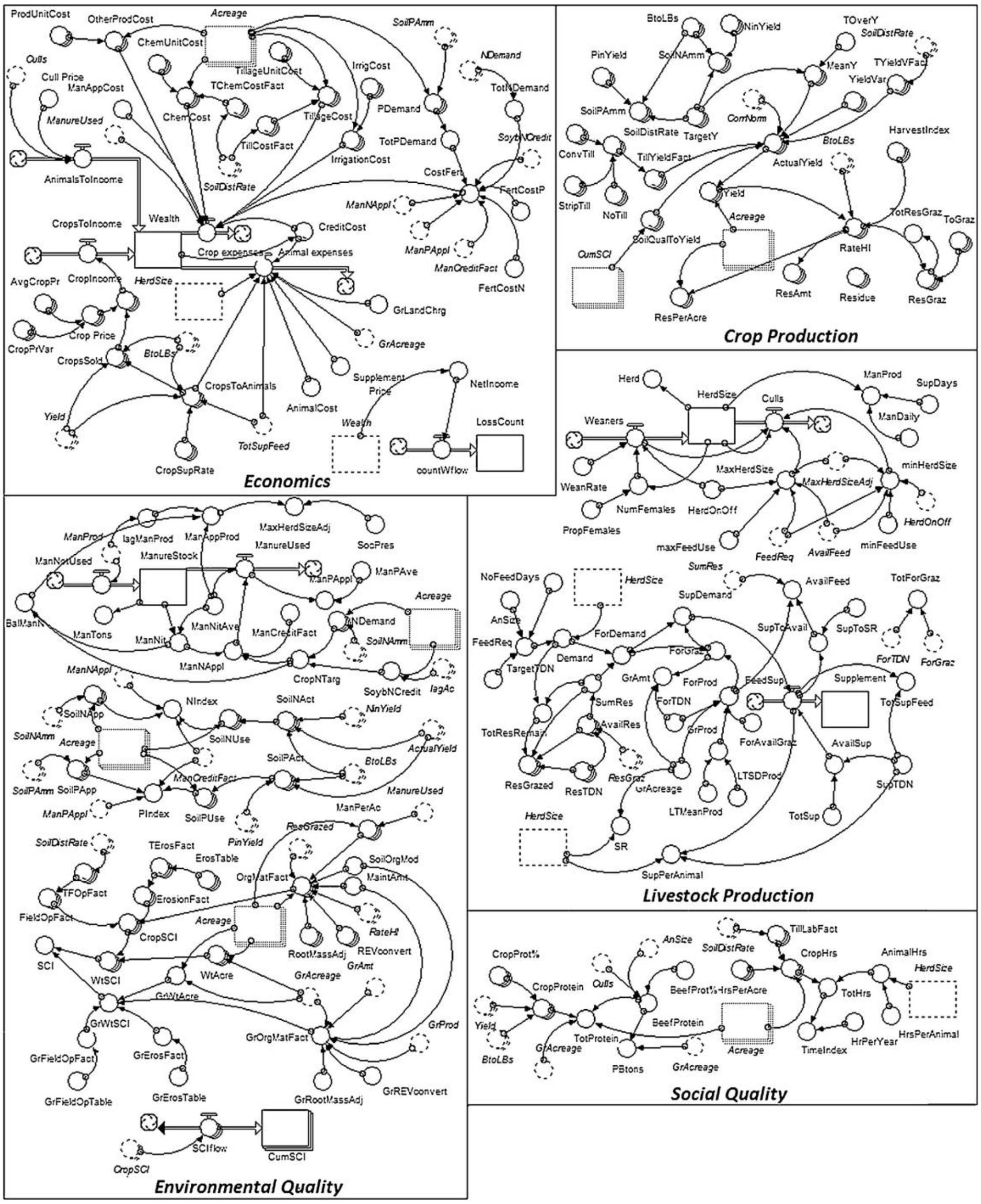



**Figure 8: SF model with each sector labelled (Walters et al., 2016)**

The initial factors that drive the farming practice have to be determined by data collection either from producers (in this case, farmers on their evaluation of factors influencing their production pattern) or from literature and previous studies. The danger and therefore disadvantage of the SDA is inherent in this decision on crucial factors that determine system performance as there might be a gap between modeled problem and real model (construct validity). Also concerns of internal validity arise, when the influence of these variables is inaccurate (Olivia, 1996; Barlas, 1996).

### *Network Analysis (NA)*

NA is another dynamic modeling tool especially used to model social aspects within agricultural systems, such as interconnections between farmers to facilitate knowledge transfer (Cadger et al., 2016), involvement and social pressures of stakeholders in agricultural governance (Hauck et al., 2016) or resilience, or vulnerability and adaptation in regards to environmental change or political drivers (Janssen et al., 2006; Hashemi et al., 2015). To describe the network, NA uses quantitative data, such as size, density, and composition, (Cadger et al., 2016) and predominantly qualitative data ("network narratives") mostly gathered through participation and/or interviews from the stakeholders to identify relationships among stakeholders and assess social interactions (Hauck et al., 2016). The high dependency on qualitative interpretation of collected primary data imposes challenges of internal and external validity.

Further than allowing the identification of key stakeholders in agricultural systems, these stakeholders' attitude towards the structure they are embedded in and the modeling of social components and their interconnections, NA also allows for modeling social responses, such as vulnerability, adaptation, and resilience to a change in framework conditions which can be seen in the following figure.

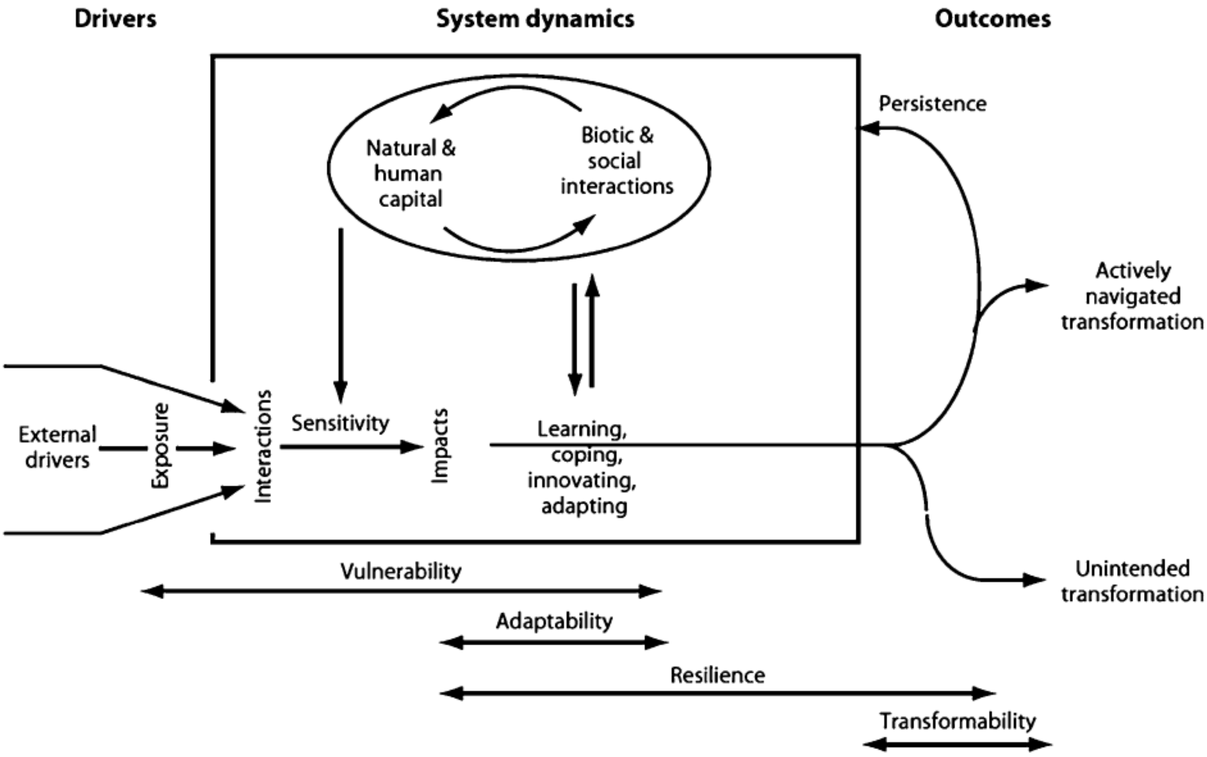



**Figure 9: Conceptual framework linking human adaptive capacity. Vulnerability, resilience and transformability (Chapin III et al., 2009)**

Resilience is "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Kinzig et al., 2006). The application of NA to research interconnections of vulnerability, adaptability and resilience is especially useful for decision-makers, as external drivers and resulting changes in structure and function can be simulated (Dowd et al., 2014). From the social, economic, and environmental perspective, an advantage of NA is the possible estimation of climate change influences on farmers' livelihoods and agricultural production.

***Modeling software***

With the rise of computing technology there exists several software which help to model systems through computer graphics, statistics and geographic information systems

(GIS) (Liu, 2009). Decision Support Systems (DSS) are software programs used by specialists in the agricultural sector that give out specific recommendations for management of livestock, crops, land, and pests, as well as financial planning, based on system modeling (Jones et al., 2016). A lot of models exist and are used in regards to the scope and focus of the model. Most models focus on a specific crop and management aspect, such as Integrated Pest Management (IMP), which is also promoted by the FAO. As Holzworth et al. (2015) criticized, while agricultural system modeling expanded rapidly, the improvement of modeling software lagged behind due to inefficient "interaction between the software industry and the agricultural modeling community".

Most software is only applicable in developed countries due to high technology requirements and being available for a certain price, but there are open source models. The Decision Support System for Agrotechnology Transfer (DSSAT) currently focuses on production models for 42 different crops and simulates "growth, development, and yield as a function of the soil-plant-atmosphere dynamics" (Hoogenboom et al., 2015). The Agricultural Production Systems Simulator (APSIM) extends the scope of DSSAT by adding livestock to the soil, climate, and management interactions (Cichota et al., 2016). Both software operate on a small scale farm level, considering different plant (and animal) types, environmental indicators, which focus mainly on soil properties, and management aspects, such as sowing, harvest, fallow and tillage practices, irrigation, and fertilizer. Next to these two software with agricultural production focus, the SWAGMAN Farm modeling system sets the focus on water management and planning on farm-level, compromising hydrological, agricultural, environmental, and economic models to determine agricultural value and environmental conditions improvements relative to business as usual under usage of various crop types and irrigation methods (Khan &

Hanjra, 2008). Furthermore, it pays special attention to water sources and quality (Commonwealth Scientific and Industrial Research Organization (CSIRO), 2001).

Among the purchasable software, several researchers chose STELLA, because it is "low cost, intuitive, user-friendly, and [has a] widely recognized modelling iconography" (Walters et al., 2016). It is also "the leading systems modeling tool for education and research" (Balali & Viaggi, 2015). This software offers next to a dynamic system modeling the development of different scenarios by using different external drivers (ISEE Systems, 2017). Even though these scenarios help to select and evaluate policy options and develop strategies for agricultural management, they also require high amounts of specific data.

### 2.1.3 Definitions of Sustainability

Various definitions of sustainability have evolved with the increasing importance and popularity of the term, with definitions varying according to the background, focus, and goal of the retrospective researchers and institutions. The conceptualization of sustainability depends on the taken approach and understanding of the word; whether it is a standard or ultimate goal an anthropogenic system wants to achieve, or a dynamic process to define a comparative degree of sustainability through a comparison of different management approaches and their resulting overall system performances. Some research aims to define SWM for the field of agriculture, which proves to have some gaps and difficulties of application in practice due to the use of subjective language of qualitative character, lack of detail, and broad conceptualizations (Russo et al., 2014; Larsen & Gujer, 1997).

The most prominent definition of sustainable development is stated by the

Brundtland Report as “meeting the needs of the present generation without compromising the ability of future generations to meet their own needs” (UN World Commission on Environment and Development (WCED), 1987). The triple bottom-line, as the ensemble of environment, economy and society, emphasizes on the holistic and systematic interconnection of these diverse needs (Organisation for Economic Co-operation and Development (OECD), 2004). The application of this idea to the agricultural system is visible in Figure 10. Broad and unspecific, especially in regards to water consumption within sustainable agriculture, the Sustainable Agriculture Initiative Platform (SAIP) (2015) defines sustainable agriculture as “the efficient production of safe, high quality agricultural products in a way that protects and improves the natural environment, the social and economic conditions of farmers, their employees and local communities, and safeguards the health and welfare of all farmed species.” The economic dimension emphasizes on long-term orientation under a stewardship approach to conserve and guarantee the good quality of natural resources like soil, water, and air while ensuring also a high quality of life for rural communities.

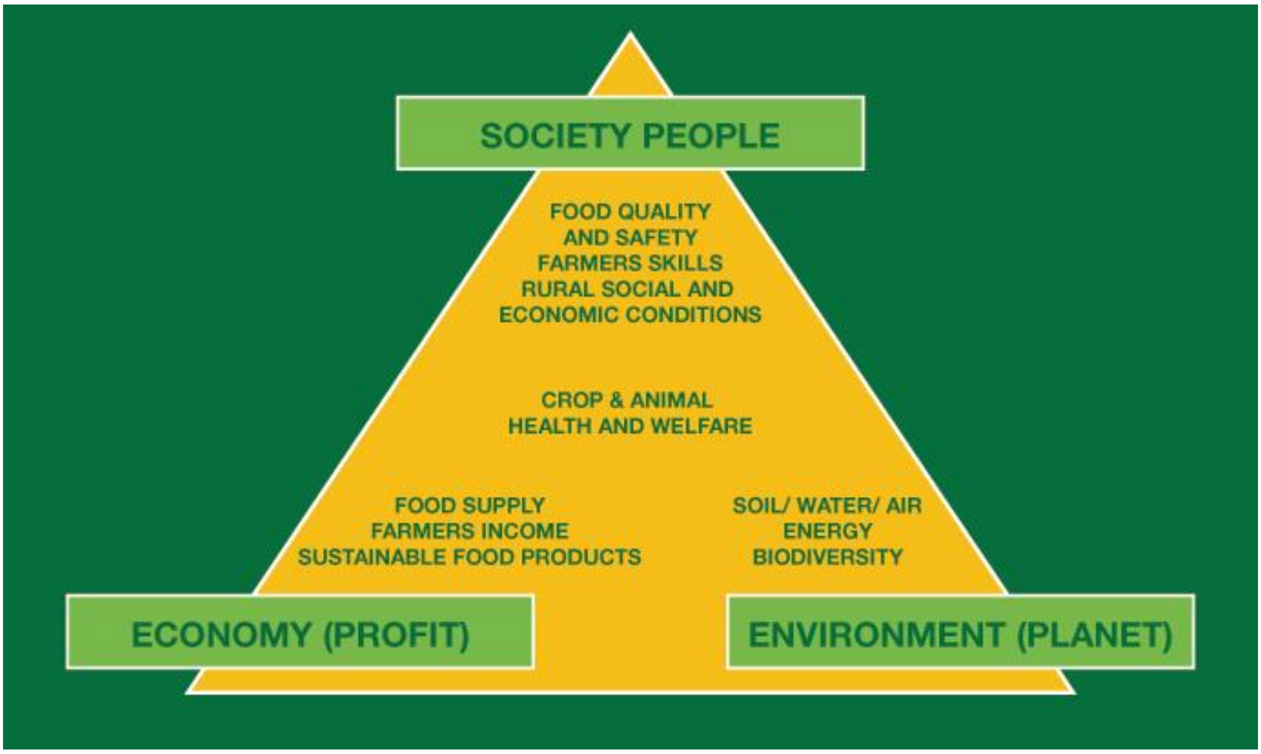



**Figure 10: Dimensions of Sustainable Agriculture (SAI, 2015)**

In regards to sustainability, specifically in water management, (Mays, 2006) and (Alley et al., 1999) relate their definitions similarly close to the initial definition of sustainable development, that the current demand should not impair future supply throughout the dimensions of the sustainability triple bottom-line. Water management should furthermore contribute to the objectives of society, and environmental and hydrologic integrity (Loucks & Gladwell, 1999). Another rather broad and unspecific definition offers the Agenda 21 of the UN (1992), stating that in the course of SWM "adequate supplies of water of good quality are maintained for the entire population of the planet, while preserving the hydrological, biological, and chemical functions of ecosystems, adapting human activities within the capacity limits of nature, and to combat vectors of water-related diseases".

Other than the broad definitions above which conceptualize sustainability as an ultimate goal, some papers use more process-oriented and specific definitions. For example more specific for the agricultural sector, Russo et al. (2014) identify SWM in agricultural systems as the "largest opportunity for reducing total water consumption" and stated, "SWM requires allocating between competing water sector demands and balancing the financial and social resources required to support necessary water systems." Agricultural sustainability as defined by Sassenrath et al. (2009, p.226) is "an approach to producing food and fiber which is profitable, uses on-farm resources efficiently to minimize adverse effects on environment and people, preserves the natural productivity and quality of the land and water, and sustains vibrant rural communities". Also the definition of the FAO (2014) is more useful as sustainability in agriculture can be achieved among five principles:

- Improving efficiency in the use of resources;
- Conserving, protecting and enhancing natural ecosystems;
- Protecting and improving rural livelihoods, equity and social well/being;
- Enhancing the resilience of people, communities and ecosystems; and
- Promoting responsible and effective governance of both natural and human systems.

Similarly, some other research, such as mentioned by Beloin-Saint-Pierre et al. (2016), found that a higher degree of self-sufficiency of a system with system's inputs originating from the system itself (and thus a higher independence of a regional system from external influences) is an indicator for higher sustainability. Zhang (2013) orientates her definition of sustainability in regards to the systems effectiveness to organize its metabolic activities in closed cycles. She suggests in regards to the urban system, artificial and highly aggregated functioning of man-made systems with unsustainable resource use and characterized by the "inefficient nature of the artificial system" need to simulate natural ecosystems in order to become sustainable, incorporating "zero-waste" and "zero-emission" premises.

### 2.1.4 Methods for Sustainability Assessment

Sustainability assessment methods need to elaborate on a variety of issues, as they need to be context-specific and comprehensive even though the agricultural system is complex with various interconnections between environment, society, economy, and technology (Clark & Dickson, 2003). Furthermore, they depend on data and implementation methods, which impose challenges in regards to availability and quality of data, and indicator consistency. To better picture the holistic thinking of systemic sustainability, multiple criteria and their changes through time should be considered (Beloin-Saint-Pierre et al., 2016). Sustainability can be measured either within the system model through an explicit indicator of environmental quality, such as the soil conditioning index in the SDA (Walters et al., 2016), the state of environmental indicators (Rao & Rogers, 2006) through merging several Sustainable Environmental Performance Indicators (SEPI) (Krall, 2015; Čuček et al., 2012), or through intensity factors of resource consumption, such as footprint models and WP (Salazar et al., 2012; Liu, 2009; Ghahroodi et al., 2015). In regards to the emphasis that many sustainability definitions put on the efficient use of resources, intensity factors are especially significant and allow comparison of different systems.

SDA and DPSIR models are able to assess sustainability directly from influences of the different variables on the environmental quality indicators through measurements of criteria influencing soil, water, and air quality, for example (Walters et al., 2016; Rao & Rogers, 2006). An example of the choice of indicators and causal connections with pressures and responses can be seen in following figure.

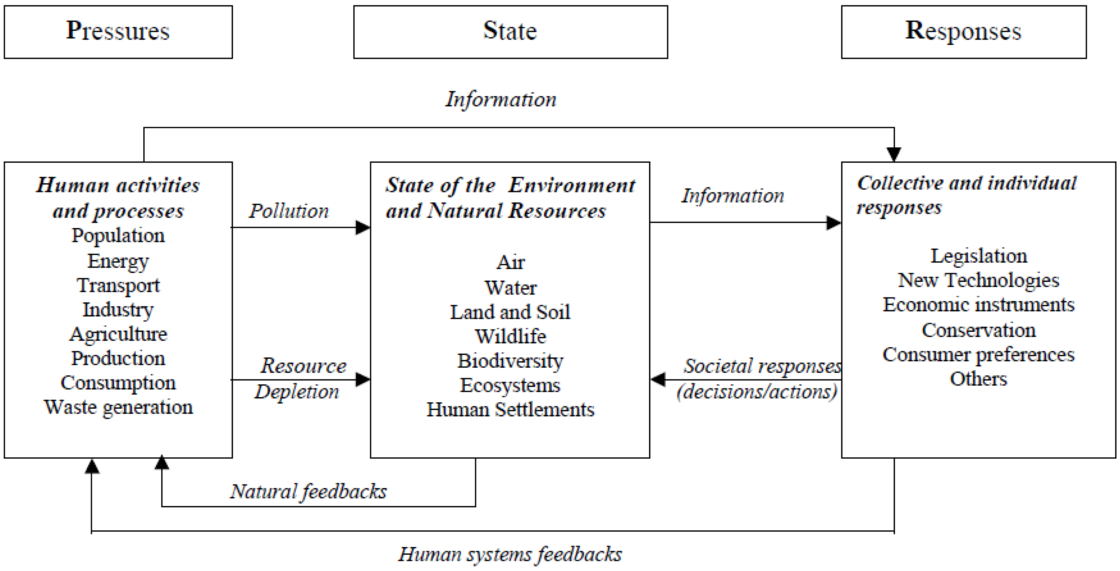



**Figure 11: General PSR framework including indicators to assess the state and sustainability of environment and natural resources (Rao & Rogers, 2006)**

The measured absolute values of the state of environmental and natural resources are then interpreted, and the system's sustainability is evaluated in regards to goal values and comparison with other values of similar conditions or defined desired conditions and impacts. This assessment is useful for decision-makers as it generates an output of changes in sustainability under external drivers, and it is helpful to organize the sustainability assessment of systems in a sophisticated empirical design (Lewison et al., 2016).

While the sustainability assessment in SDA and DPSIR models aims to analyze indicator change as a reaction to external or internal drivers, other models emphasize on a variety of different indicators and interactions among them. The graphical use of spider diagrams helps decision-makers to easily identify crucial components determining the system performance and illustrate these interconnections (Čuček et al., 2012). In order to make sustainability in agriculture measurable, the German Corporation for International Cooperation (GIZ) uses the Response-Inducing Sustainability Evaluation (RISE) method from the Switzerland School of Agricultural, Forest and Food Sciences in Bern. The ten indicators taken into account are visible in Figure 12, which are interpreted on an ordinal scale from 0 (lowest sustainable performance) to 100 (highest sustainable performance).

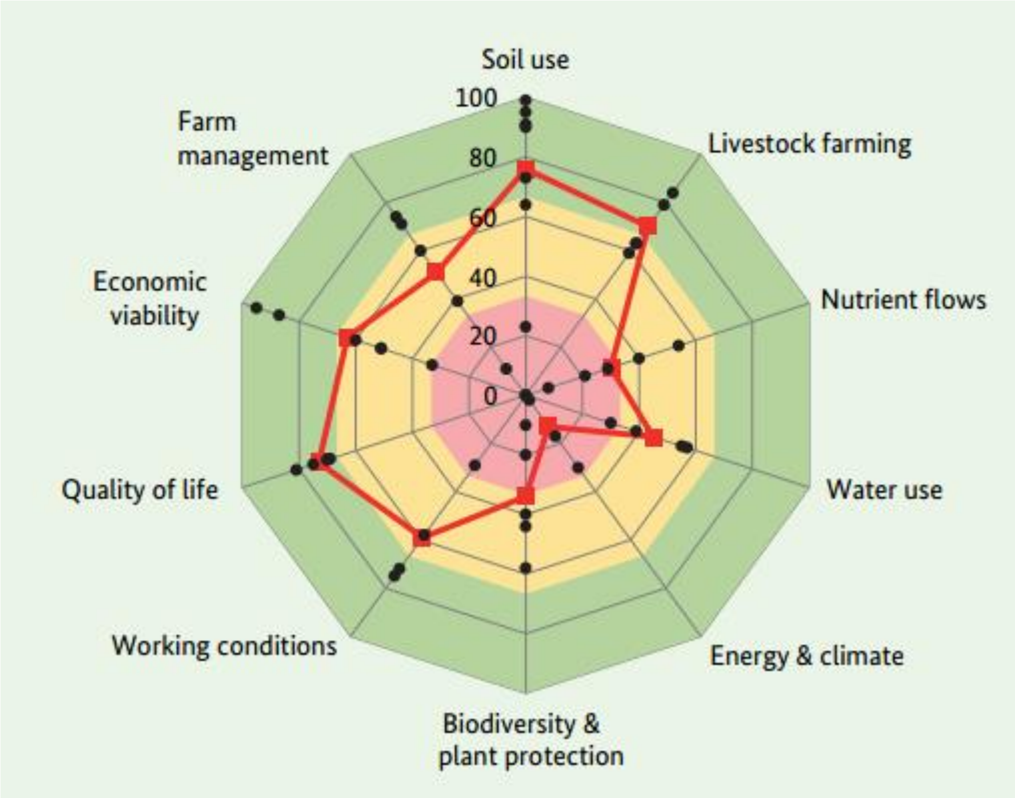



**Figure 12: Measuring Sustainable Agriculture with RISE software (Krall, 2015)**

The software examines water use among the total consumption and existence of water saving measures, which are specified in regards to the type of crop and practice (Krall, 2015). Weaknesses of this approach to evaluate the sustainability of the agricultural practice are the missing information on the source of water supply and intensity of use comparatively with a functional unit, such as production or area. This imposes challenges for the comparison of different units or systems for data harmonization, as the interpretation of the degree of sustainability in water consumption is dependent on context-specific framework conditions.

To meet these challenges, intensity factors, which measure resource use efficiency referenced to a functional area or time unit, are helpful (Čuček et al., 2012). In regards to agricultural productivity and water use, the water footprint and WP measurements are especially popular among researchers. The water footprint measures consumed or polluted water volumes per functional or time unit (Galli et al., 2012), while WP evaluates the efficiency of produced unit of output (yield or revenue) per unit of water used (or wasted), which is aimed to be maximized (Montazar, 2009; Ghahroodi et al., 2015). Another way of calculating the WP in order to assess the comparative degree of sustainable use of resources is through dividing the produced unit of output with the overall water losses (waste) (Ghahroodi et al., 2015) which is the sum of actual season evapotranspiration, leaching fraction and non-beneficial water use, such as evaporation or wind drift in sprinkling (Pereira et al., 2012). This offers the advantage of more insights into specific reasons for low WP.

## 2.2 Sustainable Agricultural Practices

As mentioned before, next to quantitative data on physical and socio-economic factors, some management practices require a high level of qualitative interpretation in order to estimate their influence on the overall system performance and sustainability. The three main fields to improve agricultural performance include integrated agricultural production, irrigation and drainage technology upgrades, and the integration of traditional and local knowledge.

### 2.2.1 Integrated Agricultural Production

Next to water, soil is especially crucial to agricultural production and ecosystem health. In rural areas, unsustainable agricultural practices, including the overuse of water resources (including saline water aquifers), increase of chemical fertilizers application, monoculture plantations, and ineffective irrigation practices, lead to soil degradation, visible in high levels of salinity, wind and water erosion, and diminished agricultural productivity as well as loss of biodiversity and ecosystem damage (Emadodin et al., 2012). Integrated agricultural production, which uses system-inherent inputs and outputs such as crop and livestock resources, can serve to maintain economic productivity while benefitting the environment (Hendrickson et al., 2008). Also, the UN water report, which elaborates on water resources management, emphasizes on an integrated approach, outlines investment and finance opportunities, and suggests management instruments to meet challenges of (agricultural) water management (UN Environment Programme (UNEP), 2012).

Integrated agricultural production is comprised of a set of management practices, such as contour tillage, terracing, no-tillage to keep crop and plant residues longer on the surface, inter planting, crop rotation and, the planting of natural windbreakers, which also provide shading, helping to reduce soil erosion (Eskandarie, 2012). Furthermore, a permanent vegetation cover and permaculture methods enhance soil stability and moisture content (Albaji et al., 2012). The increase in soil organic matter furthermore improves water retention and infiltration and can be reached through applying methods such as (sheet) mulching, basins and swales (Nolasco, 2013). Mulching increases soil productivity and decreases surface evaporation (McMillen, 2013), while swales and basins facilitate water capture and help to recharge groundwater. Additionally, in regards to water, risks can be decreased and productivity can be increased by expanding water availability through water reuse (especially greywater from households) and rain and storm water harvesting for supplemental irrigation in rainfed agricultural regions, as well as choosing crop types with a lower specific water demand and higher drought resilience

(Pereira et al., 2012; Biazin et al., 2012; Nolasco, 2013). The substitution of chemical fertilizers and pesticides with organic ones as well as the overall reduction of application furthermore increases sustainability of agricultural management, as excessive use in intensive agriculture is likely to be harmful for the environment (Tilman et al., 2002).

### 2.2.2 Irrigation and Drainage Technology and Practices

The expansion of irrigated areas and supplemental irrigation are a core objective of SWM as crop yields (productivity) are increased while risk is minimized under irrigation regime (Rockström et al., 2003; UN Educational, Scientific and Cultural Organization (UNESCO), 2009). Water use efficiency in rainfed agriculture reaches 10 to 30%, while irrigated agriculture makes use of 40 to 95% of the system's water depending on irrigation technique and evaporation (Causapé et al., 2006; Falkenmark & Rockström, 2006; Laraus, 2004). Therefore, most irrigation practices focus on water use efficiency, reduction of salinization, and conservation practices to reduce water consumption through technological upgrading (Nolasco, 2013).

Drip irrigation, which ensures a slow and accurate distribution, consumes half as much water as sprinkler technology to achieve the same output (Christian-Smith et al., 2012) and reduces water loss from canopy interception, wind drift, and evaporation (Lazarova & Bahri, 2005). Kumar et al. (2013) found that, complementary to drip irrigation, micro-irrigation using an auxiliary reservoir enhances the reliability of the irrigation system and increases WP. Micro-irrigation often includes fertigation, which is the resolution of fertilizers, pesticides, and herbicides in the irrigation water and allows a higher efficiency of plants' nutrient uptake (Andrezejewski, 2014). Thus, this technological upgrade can help to reduce emissions and costs related to water, energy, and fertilizer and pesticide consumption.

Even though more efficient and thoroughly planned irrigation would minimize the need for drainage, most of agricultural systems still require drainage to remove excess water from the field (Kumar et al., 2013), to prevent adverse effects of waterlogging on plant growth and increasing soil salinity (Vlotman, 2017). Albadji et al. (2012) emphasize the importance of a well-maintained and functioning drainage system in order to establish an irrigation-suitable production pattern. In Khuzestan Province, the major problem in regards to drainage is that "drains are installed deeply, which brings more [mined] saline drainage water out of the underlying strata into the environment" and contributes to low irrigation efficiencies and thus WP on farm and cause environmental damage downstream due to increasing salinity (Akram et al., 2013). Deeper drainage systems have been chosen "based on highest water-consuming crop in the cropping pattern", which is often sugarcane, and operate a longer time (ibid). As such, this drainage is a disadvantage for crops with different (lower) water demands. To conduct adequate water management in agricultural production, the dimensioning and usage of irrigation and drainage should be based on local weather and climate circumstances and regularly checked by visiting the field. "Regardless of [the] technological advances, nothing beats going out when it rains to assess what is really happening in the field" (Vlotman, 2017).

Furthermore, simple techniques, such as natural drainage systems and straw layers under the soil surface, can help to isolate salts as well as the cultivation of plants, which can take up salts to remove them from the soil (phytoremediation) (Bai et al., 2015).
The adoption of these measures is nevertheless not so common. Low water use efficiency, subsidies promoting irresponsible uses of water and (investment) cost for irrigation infrastructure and maintenance (Russo et al., 2014) impose challenges for its realization.

Price mechanisms do not reflect the full cost accounting also for environmental and public health (Horrigan, Lawrence, & Walker, 2002) and give little incentive to farmers to cut down their water consumption. Additionally, practices vary in complexity and may require high personal commitment and knowledge on the farmer's part (Nolasco, 2013).

### 2.2.3 Integration of Local and Traditional Knowledge

Some research emphasizes on the importance of local "traditional" knowledge and practices, which farmers applied over generations in order to meet the challenges imposed by their environment. Learning from these local BMPs can help to find cost-effective and sustainable solutions. These knowledge systems are usually very different from scientific ones, as they are based upon naturalistic epistemologies and belief systems (International Union for Conservation of Nature (IUCN), 1997). The emotional attachment to the natural environment and deep understanding of nature (Kazmi et al., 2014) can contribute to farmers' motivations to adopt sustainable farming methods, but might also harm farmers' receptivity for new and innovative practices and technologies. Researched as well as (yet) undiscovered traditional practices can influence the system performance significantly and can also have positive effects on the sustainability assessment.

Iran gained fame in the past for its success in water management despite being an arid region mainly due to qanat irrigation systems (Madani, 2014). These qanats are "water prospecting with underground horizontal galleries". Due to the "natural gradient the collected groundwater flows out of the galleries without the use of pumps" (Röttcher, 2013). A schematic figure of the functioning of a qanat is visible in the following figure.

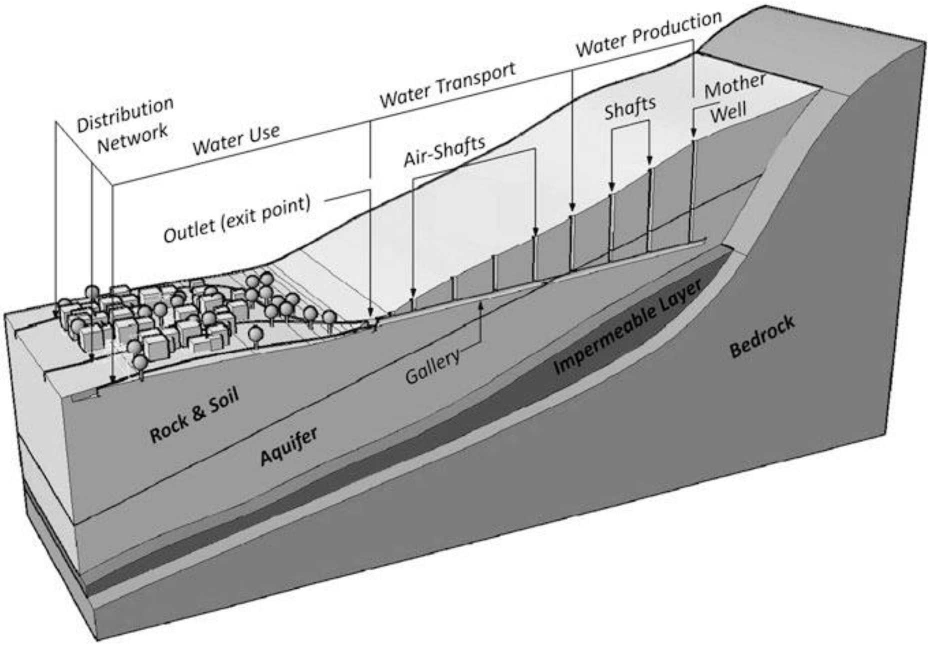



**Figure 13: Cross section of a qanat (Estaji & Raith, 2016)**

An advantage is that due to their design and stable extraction level, groundwater resources are not in danger of being overexploited, but simultaneously the flow of water cannot be controlled, which requires reservoirs for water storage, and the tunnels need continuous maintenance (Yazdi et al., 2010). Another example for the significance of local and traditional agricultural practices is the dry drainage in Gamsar. Farmers there historically divide the land in a way that there are unused strips between the cultivated areas, where drainage water accumulates and evaporates and therefore serve as sinks of salts (ICID, 2017).

# 3. Methodology

Given the exploratory nature of this research, it combines quantitative and qualitative elements from various primary and secondary sources in order to provide a triangulated view of factors influencing irrigation-based agriculture. The expected result is to qualitatively define framework conditions as the underlying structure of the system the farmers' are embedded in, as well as quantitatively analyze factors influencing farmers' performance. The Geographic Information System (GIS) software QGIS serves to illustrate, organize and geographically represent the collected data in order to produce a spatial reference, and to represent the agricultural structures and characteristics of Dez and Gotvand irrigation schemes. The quantitative analysis of agricultural parameters uses statistical methods, such as significance-testing, variance and a correlation analysis. Limitations arise especially from personal constraints and bias as well as problems of constructional internal and external validity. These are common problems of research on systems using a case study, which need to be described in a transparent and explicit way and need to be reflected on in order to outline useful results.

## 3.1 Data Sources and Collection

Information and data used to answer the research questions derive mainly from observations, interviews and questionnaires conducted during the two field trips to Khuzestan province in July 2017 and February 2018, as well as from literature and previous research. Most primary data are originally in Farsi and are translated into English. During the field work, the main partner for organization and supply of information on framework conditions is the Khuzestan Water and Power Authority (KWPA), the state body in charge of electricity and water distribution within the province operating under the Iranian Ministry of Energy (MoE).

The information gathered through observations and interviews on both field trips helps to define system boundaries and framework conditions and to modify the farmer questionnaire for the quantitative analysis of factors influencing farming performance. The semi-structured interviews are conducted with authorities involved in the management of water resources and the provision of financial assistance as well as community-based organizations, such as farmer cooperatives and farmers. Furthermore, the interviews complement the description and explanation of the findings from the analysis parts.

**Table 2: Interviews conducted in Khuzestan province**

| Stakeholders interviewed | Number of interviews | Topics covered |
|---|---|---|
| **Divisions at KWPA** | **8** | **Framework conditions** |
| Economic | 3 | Water allowances and pricing<br>Administrative procedures |
| Distribution | 2 | Distribution of water<br>Infrastructure development |
| Research | 2 | Water accounting<br>Planning and operation of irrigation channels |
| Management | 1 | Challenges of water supply and distribution |
| **Scholars** | **2** | **Political context and challenges of Iranian agriculture**<br>**Water supply system** |
| **Bank** | **1** | **Conditions and eligibility of loans** |
| **Water distribution companies** | **2** | **Framework conditions** |
| Dez | 1 | Information on administrative conditions and infrastructure<br>Support for farmer questionnaires |
| Gotvand | 1 | |
| **Farmers** | **7** | **General information on agricultural organization and attitudes** |
| Dez | 4 | Irrigation system and technology<br>Cropping pattern, processing and sale of crops<br>Role of farmer cooperative<br>Social organization |
| Gotvand | 3 | |

The main source of bottom-up data reflecting the farm level and being locally specific to evaluate factor interaction quantitatively is the questionnaire, which consists of a personal disclosure and six subcategories, which are visible in the following table. In total, 17 questionnaires feed into the quantitative analysis of the result section, comprised of nine farmers from Dez and eight farmers from Gotvand. The farmers have been randomly selected among small and medium farms in the Dez and Gotvand irrigation schemes with the help of Dez water company and Gotvand water company. All data gathered through the questionnaire represent the farming activities during the Iranian agricultural year 2016-2017, which spans from month seven (Mehr) of the year 1395 to month six (Shahrivar) of the year 1396. The full questionnaire is available in the appendix.

**Table 3: Structure of the questionnaire and collected data**

| Subcategory | Indicator | Unit |
|---|---|---|
| **Personal disclosure** | | |
| **Demographic** | Age | years |
| | Gender | m/f |
| | Place of residence | |
| **Education** | Highest educational diploma | ordinal scale |
| | Schooling years | years |
| | Source of agricultural knowledge | years |
| **Agricultural land & properties** | | |
| **Size** | Leased and own land in 2016-17 | ha |
| | Leased and own land in 2015-16 | ha |
| **Location** | Irrigation scheme | |
| | Closest village | |
| | Commuting distance | km |
| **Workforce** | Position and tasks | ordinal scale |
| | Time period | months |
| | Commuting distance | km |
| **Soil fertility** | Own evaluation | likert scale |
| **Cropping pattern & livestock** | | |
| **Cultivated crops** | Crop types and area | ha |
| | Planting period | months |
| | Yield | t/ha |
| **Fertilization** | Types and amounts | kg or l/ha |
| | Prices | Toman/l or kg |
| | Regionality | likert scale |
| **Pesticide and herbicide use** | Types and amounts | kg or l/ha |
| | Prices | Toman/l or kg |
| | Regionality | likert scale |
| **Livestock** | Type and amount | Heads |

| | | |
|---|---|---|
| | Accomodation | Yes/no |
| **Upgrading facilities** | Existance | |
| **Water & irrigation system** | | |
| **Water allowance** | Amount per crop type | $m^3$/a or ha |
| | Price | Toman/$m^3$ or a |
| | Regionality | likert scale |
| | Estimation on actual water usage | yes/no |
| | Method of payment | ordinal scale |
| **Irrigation** | Technique per crop | ordinal scale |
| | Time period or frequency | months or times |
| **Elecrticity consumption** | Amount | kWh/a |
| | Source | ordinal scale |
| **Drainage** | Existance | yes/no |
| **Cooperation & formal organization** | | |
| **Farmer cooperative** | Membership | yes/no |
| | Position and tasks | |
| | Meeting | times/a |
| | Attitude | likert scale |
| **Informal knowledge transfer within the community** | | |
| **Role of family** | Involvement in agricultural activities | occurence |
| **Community activities** | Participation and type of community activities | |
| | Frequency | ordinal scale |
| **Exchange with other farmers** | Discussion with other farmers | occurence |
| | Frequency | ordinal scale |
| | Mutual help | likert scale |
| **Influence of religion** | Attitude about mosque as communication platform | likert scale |
| | Attitude about religion as information media | likert scale |
| **Income diversity** | | |
| **Additional source of income** | Attitude | likert scale |
| | Existance | yes/no |
| | Usage of additional income for farming | yes/no |
| **Governmental help** | Existance and type | ordinal scale |
| **Loan** | Existance and usage | |
| | Attitude | yes/no |

Secondary, top-down data retrieved from previous research available on scientific databases and statistical data from the MoE and Iranian Ministry of Jihad Agriculture (MoJA) on climate and geographic characteristics, legal framework conditions, water management, farm organization, and production patterns complement the methodological development and result section. The literature research is conducted after the snowball system, and concentrates on information specifically on Khuzestan and the Iranian agricultural system. GIS data as another type of secondary data used to answer the research questions are either open-source data, retrieved from various GIS forums and databases, or are provided by the KWPA.

## 3.2 Format of Results

The desired results are first a descriptive part of the system and its structure, followed by a second quantitative part comprised of variances of factors influencing farmers' performance. The final part of the results analyzes factor interaction and effects in regards to multiple criteria assessment.

The four categories of factors influencing farmers' performance that are evaluated are demographic and agricultural factors; economic factors; environmental factors, comprising the use of regional potentials and water usage; and social factors, elaborating on the role of farmer cooperatives and the influence of informal cooperation. Their interpretation reflects the reviewed theories on systemic sustainability and take social, economic and environmental dimensions into account. In order to be comprehensive for a wider public; e.g. external stakeholders, such as political decision-makers and banks; the impact of different factors on the farming system is highlighted, notably which factors influence the performance significantly.

As sustainability and performance evaluation is the result of comparing farmers within Dez and Gotvand irrigation schemes, all quantitative economic evaluation is in regards to the functional unit, which is per hectare. Also environmental aspects use the functional unit and are evaluated as a weighted deviation from the average of the retrospective criteria. Social and demographic factors use absolute values and their variance, e.g. age, and Likert scales for attitudes, opinions and the frequency of social interaction, e.g. in community activities.

Especially useful formats to transport the content and results are figures and tables, such as maps, created with QGIS, and graphs, figures and tables, created with Excel. To sum up factor interaction and evaluate sustainability, a spider graph is used. This evaluation includes two factors from each category, notably:

- Demographic factors: Age and educational level;
- Agricultural properties: Physical size and cumulative size;
- Environmental factors: Irrigation frequency evaluation as well as fertilizer and pesticide use evaluation;
- Economic factors: Profit and additional income; and
- Social factors: Frequency of participation in community activities and attitude towards farmer cooperatives.

Even though the SDA is a powerful way of modeling systems, also reflecting dynamic factor interaction, this research will not include CLDs as an ultimate result due to time constraints and the required causality of factor interaction, which cannot be determined by a correlation analysis and small sample size. Nevertheless, the SDA and CLDs are a source of inspiration for the development of methodology and interpretation of results and might be subject to future research.

## 3.3 Data Analysis

In order to analyze data, economic and environmental data in particular need to be aggregated to increase their explanatory power, while demographic and social factors already make up the desired format to evaluate a farmer's performance. Regarding environmental factors, water use frequency and fertilizer and pesticide use are evaluated on a scale from one to five, where one represents the lowest comparative performance per crop type and five represents the best comparative performance per crop type. The best environmental evaluation of water is, is accrodingly the lowest water consumption, which equals the lowest irrigation frequency. Also the less mineral fertilizer and chemical pesticides are used, the better the environmental performance. To evaluate the farmer overall, the specific scores of all cultivated crop types are weighted after their area.

To evaluate the water use of a farmer, the irrigation frequency of the specific farmer per crop type, which is the time interval between two irrigations, is divided by the average irrigation frequency per crop type of all farmers. The evaluation classes are then fixed as is visible in the following table. It is assumed that the higher the frequency of irrigation, the less water is used, as all farmers use the same irrigation method. This is interpreted as environmentally friendlier in the face of water shortage and crisis, thus results in a higher score.

**Table 4: Evaluation class for irrigation frequency**

| Evaluation class as deviation from average per crop type | |
|---|---|
| 5 | >130% |
| 4 | 110-130% |
| 3 | 90-110% |
| 2 | 70-90% |
| 1 | <70% |

In regards to fertilizer and pesticides, the lower the amount of fertilizer and pesticides applied, the better for the environment, the interpretation of the deviation from the average is turned around (compare Table 5). As the use of regional and organic fertilizers have a positive influence on the environmental factor evaluation, the crops per farmer using manure as an organic and regional fertilizer are upgraded in their evaluation by a factor of one.

**Table 5: Evaluation class for fertilizer and pesticide use**

| Evaluation class as deviation from average per crop type | |
|---|---|
| 1 | >130% |
| 2 | 110-130% |
| 3 | 90-110% |
| 4 | 70-90% |
| 5 | <70% |

Also, data on economic performance need to be aggregated by calculating the weighted revenue per hectare as well as weighted cost per hectare. To do so, the sum of all revenues or cost positions is divided by the cumulative area of the farmer. The revenue per crop type derives from multiplying the yield (in t/ha) given from the farmer with the revenue (in Toman/t) indicated by the KWPA. To calculate the fertilizer and pesticide costs per crop type, both values (on the amount and the price) derive from the questionnaire. Toman is the widely used unit of the Iranian currency Rial (IRR); one Toman equals 10 IRR.

When boxplots are used to illustrate the variance of the factor evaluated, the first and third quartile, the mean, the minimum, and the maximum values are calculated out of the data set. The spider diagram uses the above mentioned calculated categories from one to five for environmental factor interaction as well as for social factors; and interprets the values for demographic, agricultural and economic factors with the conversion factor mentioned in the following table.

**Table 6: Conversion factors for spider graph**

| Factor | One unit equals | |
|---|---|---|
| Education | 3.2 | Schooling years |
| Size | 3.0 | ha |
| Cumulative size | 5.0 | ha |
| Variable cost | 4,400.0 | Toman/ha |
| Profit | 26,000.0 | Toman/ha |

In regards to the correlation analysis, the correlation coefficient r indicates the positive or negative relation between the variables analyzed. It varies from -1 to 1, and to evaluate the effect size, the following scale applies: If r = +/- 0.5 the effect is large; if r = +/- 0.3 the effect is medium; and if r = +/- 0.1 the effect is small (Gogtay & Thatte, 2017). Correlation is not a significance value, and findings are only related to those farmers who took the survey.

## 3.4 Limitations

"All models are wrong, but some are useful" (Box & Draper, 1987, p. 424).

Limitations to this proposed research result from the researcher's bias towards certain technologies and scientific expectations due to the individual perception and interpretation. As the modeling of the system and its factors mutual influences depend highly on logical constructions, problems of internal validity might occur. Personal restrictions are furthermore the limited language ability, which leads to high dependency of translation, limited financial and temporal resources, and cultural sensitivity. Resulting from these constraints, the main limitation for the comparative evaluation of farmers is the relatively small sample size, especially as some crops are only considered once.

Also, data related challenges, such as the aggregation level of top-down data which need to be disaggregated to fit the local level of analysis, diminish the explanatory power and validity of the results. Data collection and general limited availability as well as accuracy are expected to be incomplete and to some part questionable, which requires the use of proxies. This imposes challenges of uncertainty and would require a control group to verify claims from the system modeling and factor interaction. Due to the design of the case study and limited resources to conduct a case control, this is beyond the scope of this research. Even though the methodological development and choice can be adapted and transferred to similar areas, the focus on a local level and specific context makes the results useful rather for local than general decision-makers encountering case studies' typical problems of external validity.

# 4. Results

In order to understand how different farmers perform in the given system, it is crucial to understand the systems structure that the farmers are dependent on but only able to affect to a limited extent. Thus, this first part of the results describes the framework conditions in regards to the natural, institutional and administrative environment. Furthermore, the factors from the four categories that influence farmers' performance will be statistically analyzed and interpreted. The last part of the result section synthesizes these factors and elaborates on their correlations.

## 4.1 Framework Conditions

The following section describes the framework conditions of Dez and Gotvand irrigation schemes. It is assumed that all farmers evaluated perform under the same circumstances, thus, micro climate and local distinguishing features in the framework conditions are not taken into account. Nevertheless, there exist specific distinctions between Dez and Gotvand, which are important for reflecting on the differences in farmers' performances in regards to their retrospective location.

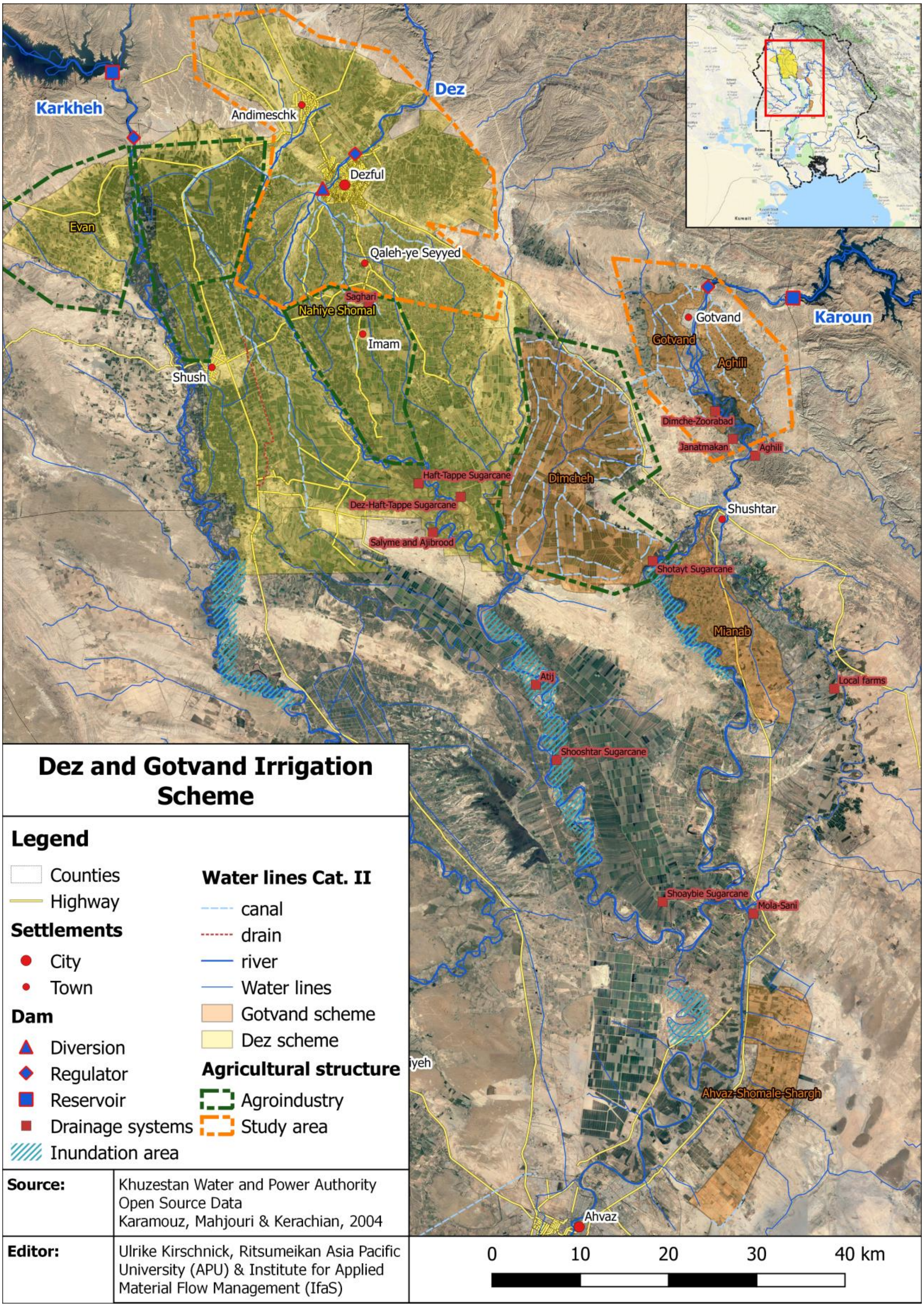



**Figure 14: Overview of Dez and Gotvand irrigation scheme**

### 4.1.1 Water and Soil Resources

The climate and geo-physical conditions in Khuzestan are on one hand favorable for agriculture due to high soil fertility and the climatic possibility to plant more than three times a year. On the other hand, agriculture faces a lot of difficulties due to the limited amount and availability of water as well as soil degradation.

The north of Khuzestan, where the irrigation schemes Dez and Gotvand are located, is characterized by a hot, semi-arid climate, which is visible in the climate diagram of the weather station in Dezful. The average annual temperature is 24.3 °C, whereas during summer temperatures reach a maximum mean daily temperature of 49 °C (Merkel, 2018). The average annual precipitation is 358 mm, opposing an evapotranspiration of 2,044 mm (Shamsaee, 2017).

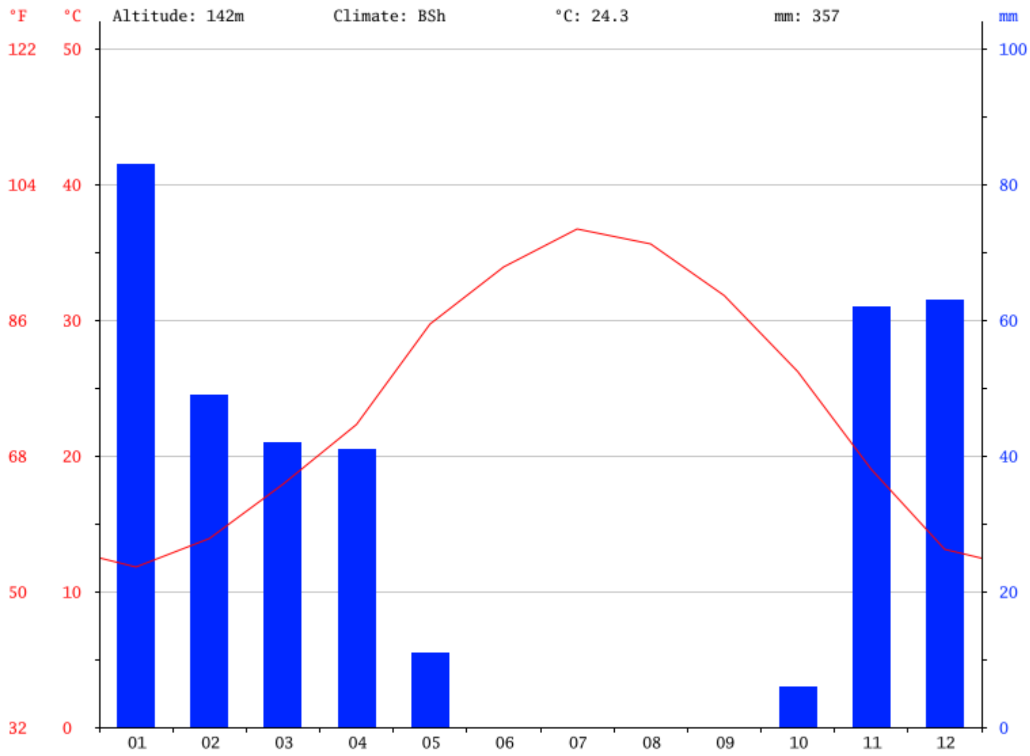



**Figure 15: Climate diagram of weather station in Dezful (Merkel, 2018)**

Due to the little rainfall, especially during the summer months, and high evapotranspiration, most farmers depend on irrigation using surface and groundwater for irrigation purposes. There are different methods of water extraction, some irrigation methods require pumping, other irrigation methods divert the water directly from the river or irrigation channel and use natural slope to distribute the water (Hormozi et al., 2016). The main source of water in Gotvand is Karoun River, and the water in Dez irrigation scheme is mainly extracted from Dez River and direct groundwater usage. From the main dispersion dams, the water is distributed through the irrigation network visible in Figure 14.

While problems on the supply-site include the limited availability of water and competition of different user groups, there are also issues in regards to water quality. While the groundwater has a good and acceptable drinking water quality (Alavi, et al., 2016), surface water quality diminishes the closer one gets to the water mouth. The water quality upstream is high (the water quality of Karoun between Gotvand City and Shooshtar is relatively high and the water quality of Dez River between Andimeshk and Dezful is also high). The water quality downstream varies from intermediate to very low quality levels (Karamouz, Mahjouri, & Kerachian, 2004). The cause of this poor status is mainly due to pollution from large sugarcane productions as well as sewage and industrial waste emitted to the river bodies (The Guardian - Teheran Bureau, 2015).

Additionally, drainage systems are missing in wide parts; therefore, an estimated amount of 2 billion $m^3$ of drainage water re-enters rivers annually (Shamsaee, 2017). The existing drains were designed to fit the most water-consuming crop in the cropping pattern, which is often sugarcane. The drains lay up to 4m deep (Dez water company, personal communication, February 24, 2018), which leads to an increased salinity of the excess water and neglects possibilities of natural drainage and "direct flow towards perforated collectors or open deep drains, and soil water reservoirs" (Akram et al., 2013). There are little official requirements and guidelines for drains and farmers are not obliged to have or maintain them (Dez water company, personal communication, February 24, 2018). Given these circumstances, most farmers mention that excess water just runs off their field and enters a collection pond or drain, but they have no control over drainage and do not know about the existence of sub surface drainage systems in their fields.

Highly discussed among different stakeholders is the issue of water quality, especially in Gotvand irrigation scheme. The water from Gotvand dam reservoir might be too salty to be suitable for irrigation due to the constructional mistake, where the "structure was built on salt beds" (Financial Tribune, 2016). The electric conductivity (EC) supposedly increased from 800 to 1,600 µS/cm since the construction of the dam in 2011 (KWPA, personal communication, February 27, 2018). Contrariwise, Gotvand Water Company (Personal communication, February 24, 2018) states that measurements of the EC show only insignificant changes since the construction of Gotvand reservoir dam. The EC varies seasonally from 800 to 1,000 µS/cm, which is still acceptable compared to the European critical value of 2,500 µS/cm for drinking water at 20°C (European Communities (Drinking Water) Regulations 2007). Scientific investigations on water quality up- and downstream of the dam indicate a "significant reduction of water quality […] downstream; however, it still remains in standard stage" (Mansournejad, Kalantari, & Adeli, 2015).

The Ahvaz plain provides fertile soil (Ommani, 2011) and the overall suitablity of the soil for agricultural purposes is favorable, nevertheless, inefficient irrigation methods lead to "degraded soil conditions such as soil salinity and alkalinity and water logging problems" (Hedayat, 2011). Albaji, Nasad, & Hemadi (2012) evaluated the land suitability for surface, sprinkle and drip irrigation methods in the Ahvaz plain, where Gotvand and Dez are situated, by taking into account the slope, drainage properties, electrical conductivity, calcium carbonate status, soil texture and soil depth. The Dez area is, according to them, mainly favorable for agriculture in regards to slope, soil depth and nutrient content, but show deficiencies regarding salinity and alkalinity, drainage and soil texture. In Gotvand, dominant problems for agriculture are drainage and low calcium carbonate content (Albaji et al, 2014)

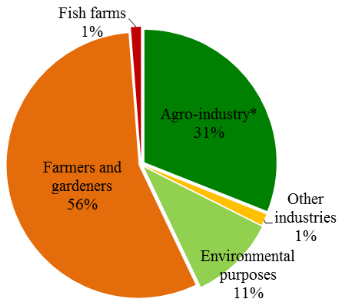
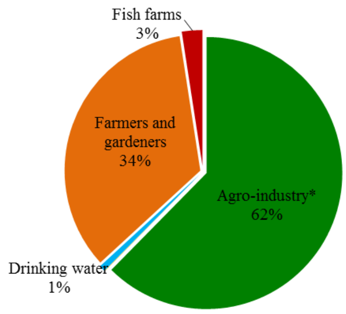
### 4.1.2 Agricultural structure

Even though Dez occupies almost ten times the area of Gotvand, the agricultural structure and farming methods in both are similar. The agricultural structure is characterized by discrepancies between large agro-industrial complexes, that are mostly state-owned, and traditional small-scale farms, which are managed on the family level. These small-scale farmers form gate communities, which are the decisive organizations of cooperation, especially in regards to water consumption. Some farmers are also part of agricultural cooperatives to shift from individual to collective farming, investing their capital into land, machinery and buildings, but these influence the farming activity only indirectly and less so than the gate community.

The main cause of land fragmentation between large agro-industrial complexes and small farmers is the land reform, which led to smaller farmers facing problems of inefficiency and little competitive ability (Hedayat, 2011). Their land consists often of small parcels and is not directly owned by the farmer after the land reform. In some cases, farmers lease land on an annual basis and the prices for lease are characterized by high price volatility (Farmer #5, personal communication, July 25, 2017).

Although the agro-industry consumes 31% of the water in Dez and 63% of the total delivered water in 2016, and although it occupies large areas of the Dez and Gotvand irrigation scheme (compare figure 14), the agro-industry is not a subject of the study, as they are under direct control of the MoJA. In opposition to the domination of sugarcane as the agricultural good for the agro-industrial sugar processing plants, the crops under irrigation cultivated by farmers that are subject to this study are mostly wheat, corn and sugar beets. As it is possible to harvest twice a year, farmers grow additional vegetables, such as cabbage, tomatoes, onions, and potatoes. Small scale farming under irrigation is mostly disconnected from animal breeding in both irrigation schemes, even though some farmers in Gotvand produce fodder, such as alfalfa. The existence of animals for small scale farmers is mostly for subsistence reasons, so for example, farmer #16 (personal communication, February 26, 2018) has two cows and other farmers have some chickens.

**Table 7: Characterization and comparison of agricultural structure and water consumption in Dez and Gotvand irrigation scheme (Albaji et al, 2014)**

| Characteristic | Unit | Dez | Gotvand |
|---|---|---|---|
| Total agricultural area | ha | 120,000 | 13,300 |
| Area under irrigation | ha | 90,000 | 8,000 |
| Number of farms | | | |
| Number of gate communities | | 1,050 | 63 |
| Crops cultivated by interviewed farmers | | Wheat, corn, sugarbeet, colza | Wheat, corn, onion, potato, cabbage, colza, alfalfa, cauliflower, tomato |
| Water distribution company | | | |
| Water consumption | Mm$^3$ | 2,900 | 1,000 |
| Water consumption per user group | |   |   |
| | | * The water consumption includes water for irrigation and processing | |

Even though the produced crops have good export potentials (Hedayat, 2011) and processing facilities exist (e.g. to dry and clean cereals) in Dez and Gotvand irrigation schemes, small and medium farmers have (especially in Gotvand) often no access to these (Gotvand water company, personal communication, February 26, 2018). Farmers also mostly do not have a purchase guarantee, but the produced goods are sold directly after harvest to local shops. In the case that farmers cannot find a buyer, the harvest deteriorates due to a lack of knowledge about and existence of storage facilities (Farmer #12, personal communication, February 26, 2017).

To overcome these issues of small-scale farming, especially in regards to water delivery and consumption, farmers whose lands are situated closely to each other and share water from the same irrigation channel, form gate communities. These are semi-formal organizations with the purpose of allocating water among the farmers after the gate of the local irrigation channel (see figure 17), and often to contract and deal with water distribution companies or the KWPA. The administratively responsible person for this communication is the gate representative, who is the democratically elected head of the gate community.

**Figure 16: Gate of a gate community in Gotvand irrigation scheme. July 26th, 2017.**

Even though the gate community has an administrative function, the internal organization is rather informal, as the distribution of water and control of the actual usage is decided by the members “over a cup of tea” (Farmer #2, personal communication, July 26, 2017) and not subject to regulations or external control. Most farmers are nevertheless satisfied with its functioning, as the “water is strictly distributed according to the size of the agricultural land” (Farmer #3, personal communication, July 26, 2017). The amount of water per farmer is temporally limited and measured after the frequency and time interval of irrigation, thus, the gate is open for a certain time period to flood the furrows of the field. This traditional form of irrigation is described in the following table and leads to excessive water use due to high evapotranspiration rates (Albaji, Naseri, & Nasab, 2010). With every new cultivation of the field, these furrows need to be created manually or with machinery, requiring intensive workforce.

**Table 8: Description of furrow irrigation in Dez and Gotvand irrigation schemes. July 25th, 2017 and February 26th, 2018.**

| Types of furrow irrigation | |
|---|---|
| After every two rows of crop one furrow | Every 5m one furrow of 30 cm depth |
| Potato, onion, corn, cabbage | Wheat, barley, colza |
|   |   |

The formal counterpart on the higher level is the farmer cooperative, which consists of more members. Due to the size and few meetings per year, there is less interaction between farmers, and the cooperatives influence farmers only indirectly and less than the gate community (Famer #5, personal communication, July 27th, 2017). The functions of the cooperatives comprise to enhance communication with institutions, to monitor contracts, to facilitate transactions, and to monitor water consumption. In some cases, the cooperation also serves as the seller of supplies, such as seeds and fertilizer, and buyer of agricultural products (Farmer #9, personal communication, July 27, 2017). Governmental bodies have a positive attitude towards farmer cooperatives and provide financial support, as farmer cooperatives simplify communication with farmers, and also include political power (KWPA, personal communication, July 27, 2017).

### 4.1.3 Legal and Institutional Framework Conditions

Next to natural conditions and agricultural structure, farmers are embedded in an administrative structure, which limits the scope of their own decision-making. Insufficient cooperation between the responsible ministries, fixed prices for wheat and corn, and the water price disconnected from the actual amount of water consumed for irrigation create a strong given structure. This method of water pricing gives little incentives to farmers to reduce their water consumption and the actual water consumption is not measured, even though in Dez a pilot project exists for a more flexible and accountable water delivery system. Furthermore, limited access to capital diminishes farmers' financial scope.

The legal responsibility for water distribution is divided between the MoE and the MoJA, which is rather contested, as institutional responsibilities overlap and information is shared only imperfectly.

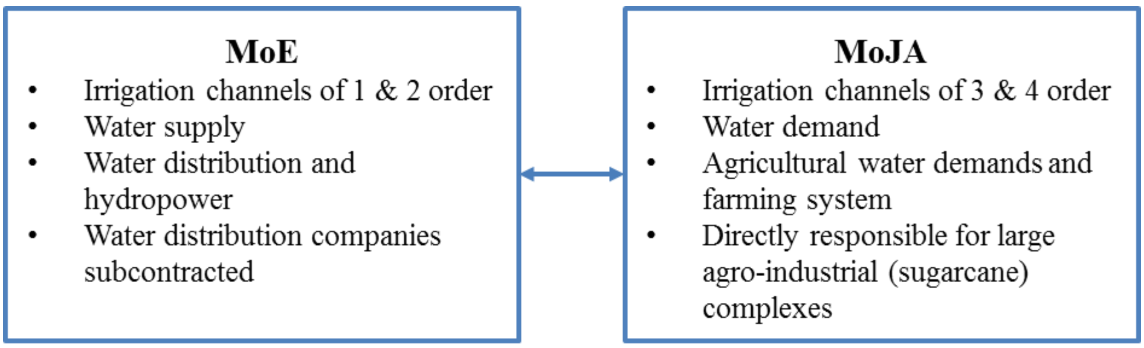



**Figure 17: Responsibilities of the MoE and the MoJA in Khuzestan irrigation schemes**

While the MoE (and under the MoE the KWPA) is responsible for the supply of water and the maintenance of irrigation channels of first and second order, the MoJA controls the demand side of water for irrigation purposes and distribution channels of third and fourth order (KWPA, personal communication, July 23, 2017).

An example reflecting insufficient communication between the two governmental bodies is the different approach to determine agricultural water consumption: While the MoE states that 80-90% of water consumption in Khuzestan is from agriculture, the MoJA assumes the agricultural usage to be around 60% (Scholar #1, personal communication, July 26, 2017). Another institutional conflict exists also within the MoE, as the KWPA and the dam operators compete over water from the reservoir, and thus water storage for hydropower and usage for irrigation (Interview KWPA, 23.07.2017).

Additionally, the calculation of water allowances and pricing reflects administrative issues, as the KWPA would be “urged [by the MoJA] to provide highly subsidized water” (KWPA, personal communication, July 25, 2017). While farmers receive the water allowance, which is the amount of water allowed per hectare and growing season of the crop the farmers register to plant, from the KWPA; the price is determined by the MoJA. It is not a comparative price per $m^3$, but is based on the yield and revenues for the specific crop type in the retrospective area. The water price that farmers need to pay for their water usage per hectare is a percentage of the total revenue. This percentage depends on the status of the irrigation network that the farm is located in. Dez and Gotvand are both categorized as modern irrigation systems and therefore, the water price is 3% from the total revenue (for semi-modern ones it is 2% and for traditional irrigation networks 1%). The yield per crop type reported by the MoJA is the one of the previous year, but this temporal distortion between water consumption and result is relativized, as farmers pay only half of the water price to the KWPA in the beginning of the agricultural year in

February (KWPA, personal communication, July 25, 2017). Nevertheless, the yield, which is the basis of the water price calculation, deviates from the yields farmers retrospectively reported. For example, the yield for wheat varies from 3.2 to 6 t/ha, whereas the yield reported by the MoJA is 3.64 respectively 3.5 t/h. Similarly, the average yield of corn as indicated in the questionnaire is 8.9 t/ha, varying from 6 to 11 t/ha, opposing the yield of 6.2 to 6.3 t/ha used by KWPA to calculate the water fees.

Despite the fixed yields, the resulting water prices vary according to the calculation method as visible in the two following tables. In Dez, it varies by 0.495 Toman/m$^3$ (from 0.054 Toman/m$^3$ for Alfalfa to 0.549 Toman/m$^3$ for Cabbage and Cauliflower). The water price in Gotvand also varies by 0.303 Toman/m$^3$ (from 0.099 Toman/m$^3$ for Colza to 0.402 Toman/m$^3$ for Cabbage and Cauliflower.

**Table 9: Water allowance and price for selected crops in Dez irrigation scheme in 2016**

| Dez irrigation scheme (3%) | Water allowance | Regional yield | Revenue | Water price | |
|---|---|---|---|---|---|
| Crop | m$^3$/ha | t/ha | Toman/t | Toman/ha | $10^{-3}$ Toman/m$^3$ |
| Wheat | 6,429 | 3.64 | 12,705 | 1,389 | 216 |
| Corn | 12,262 | 6.30 | 10,368 | 1,959 | 160 |
| Sugarbeet | 8,976 | 61.13 | 2,004 | 3,675 | 409 |
| Colza | 16,929 | 1.35 | 25,300 | 1,023 | 60 |
| Onion | 10,000 | 32.15 | 2,640 | 2,546 | 255 |
| Potato | 7,571 | 25.73 | 3,960 | 3,057 | 404 |
| Cabbage/Cauliflower | 6,333 | 37.94 | 3,053 | 3,475 | 549 |
| Tomato | 12,238 | 33.33 | 4,029 | 4,029 | 329 |
| Alfalfa | 31,905 | 8.71 | 6,593 | 1,723 | 54 |

**Table 10: Water allowance and price for selected crops in Gotvand irrigation scheme in 2016**

| Gotvand irrigation scheme (3%) | Water allowance | Regional yield | Revenue | Water price | |
|---|---|---|---|---|---|
| Crop | m³/ha | t/ha | Toman/t | Toman/ha | 10⁻³ Toman/m³ |
| Wheat | 6,780 | 3.50 | 12,705 | 1,334 | 197 |
| Corn | 10,634 | 6.20 | 10,368 | 1,928 | 181 |
| Sugarbeet | 9,537 | 43.50 | 2,004 | 2,615 | 274 |
| Colza | 17,341 | 2.26 | 25,300 | 1,718 | 99 |
| Onion | 11,463 | 27.65 | 2,640 | 2,189 | 191 |
| Potato | 8,293 | 17.09 | 3,960 | 2,031 | 245 |
| Cabbage/Cauliflower | 6,488 | 28.50 | 3,053 | 2,610 | 402 |
| Tomato | 13,610 | 35.00 | 4,029 | 4,231 | 311 |
| Alfalfa | 36,878 | 24.35 | 6,593 | 4,817 | 131 |

The water allowances in general are high compared to approximate values of seasonal crop water demands stated by the FAO: For corn the water demand is 5,000 to 8,000 $m^3$/ha (FAO, 2018), whereas in Dez the water allowance is approximately 50% higher and in Gotvand about 33%.

**Table 11: Comparison of crop water requirements**

| Comparison of crop water requirements | Water allowance Dez | Water allowance Gotvand | Upper limit of crop water requirement FAO | Difference Dez | Difference Gotvand |
|---|---|---|---|---|---|
| Crop | m³/ha | | | % | |
| Wheat | 6,429 | 6,780 | 6,500 | -1.1% | 4.3% |
| Corn | 12,262 | 10,634 | 8,000 | 53.3% | 32.9% |
| Sugarbeet | 8,976 | 9,537 | 7,500 | 19.7% | 27.2% |
| Colza | 16,929 | 17,341 | 20,000 | -15.4% | -13.3% |
| Onion | 10,000 | 11,463 | 5,500 | 81.8% | 108.4% |
| Potato | 7,571 | 8,293 | 7,000 | 8.2% | 18.5% |
| Cabbage/Cauliflower | 6,333 | 6,488 | 5,000 | 26.7% | 29.8% |
| Tomato | 12,238 | 13,610 | 8,000 | 53.0% | 70.1% |
| Alfalfa | 31,905 | 36,878 | 16,000 | 99.4% | 130.5% |

For all crop types, except corn, the water allowance is higher in Gotvand than in Dez; a difference that is due to less precipitation and higher evapotranspiration. The yield of most crop types, except for tomato and alfalfa, is also higher in Dez than in Gotvand, despite the revenues being the same in both. Even though the KWPA determines the water allowance and farmers know the amount of water deliverable to them, neither the farmers nor the KWPA measure the actual water consumption (KWPA, personal communication, July 23, 2017).

Additionally, Dez and Gotvand are also different in regards to their water distribution system, since a pilot project started in 2016 in Dez to distribute water more efficiently to supply on -demand (Interview #8, 2018). The farmers can order water short-term any time through a service on the phone. The gate representative fills out the form to request water for their gate community and the Dez water company delivers as fast as possible. Combined with this adjustment to meet more specifically short-term needs in order to increase efficiency of the water distribution system, the Dez water company set a merit-based system, which reimburses farmers the amount that they use that is less than their allowance antiquates. The whole system is based on the reporting and request from the farmer on the amount of water they command; there is no control from the site of Dez Water Company. To the time of the study 290 gate communities are participating in the new adapted distribution system. In Gotvand, a messenger group exists where farmers and Gotvand Water Company can communicate, but the delivery of water is organized in a way that every 48 hours the main channels are refilled (Gotvand Water Company, personal communication, February 26, 2018).

Furthermore, the government fixes prices for corn and wheat, which explains the high cultivation of these crops, even though corn has relatively high water requirements. Nevertheless, some farmers articulated concern of these crops' water demands in face of water shortages in Khuzestan Province, as "[they] know that these crops are not good for the land but [they] have no choice" (Farmer #5, personal communication, July 29, 2017). The fixed prices are also subject to internal discussion, as for the MoJA in Khuzestan food security is of less importance than other aspects (Ommani, 2011).

Nevertheless, both, the MoJA and the KWPA acknowledge the problems that agricultural water usage in Khuzestan is causing and facing. Thus, the MoJA emphasizes supportive policies that enhance the usage of more sustainable methods that increase the knowledge of farmers about these methods. They also support organic farming with the goal to conserve water resources (Ommani, 2011).

In regards to financial framework conditions, farmers in Dez and Gotvand face several challenges. Interest rates are high (at 18% at the time of the study (Farmer #6, personal communication, July 27, 2017)) and credits are not easily accessible, especially for illiterate farmers (Scholar #1, personal communication, July 26, 2017). Additionally, due to the land reform, the farmers mostly do not own the agricultural land, but land tenure is a complex system. As a consequence, the land cannot serve as a mortgage (Keshavarzi bank, personal communication, July 28, 2017). Therefore, in order to be eligible for a loan, farmers need to apply at the bank and an expert visits the farm to evaluate the credibility of the farmer. Among the required criteria of eligibility are water availability, the size of the land and the possessions. According to Keshavarzi Bank, the evaluation can be difficult as farmers borrow possessions from their relatives or neighbors for the time of the inspection to get a higher ranking. The MoJA influences banking policies directly through requiring special loan conditions in political priority areas. For example, loans to change from traditional irrigation to modern irrigation have an interest rate of 12%, of which the governmental pays 3% (ibid).

## 4.2 Factors Influencing Agricultural Performance

Even though farmers act under the same framework conditions, their environmental and economic performance differs as well as their demographic and social characteristics. All factors influencing farmers' performance show high variety. Farmers in Gotvand compared to those in Dez have on average a higher level of education, but smaller farm sizes and economic disadvantages. In regards to environmental performance, farmers in Dez have less crop diversity, but use on average, based on the calculation method of water allowance and comparative irrigation frequency, less water and less fertilizer than those in Gotvand. For all farmers, despite their irrigation scheme, the family is highly involved in agricultural activities. While in Dez the gate community is a more dominant social platform, in Gotvand religious and professional life are more intertwined. The descriptive statistical analysis for all factors is visible in the following table.

**Table 12: Descriptive statistical values for factors influencing farmers' performance**

| Descriptive statistics for factors influencing farmers performance | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Category** | **Factor** | **Unit** | **n** | **Mean** | **Maximum** | **Minimum** | **Standard Deviation** |
| Demographic and agricultural factors | Age | years | 17 | 51.41 | 80.00 | 29.00 | 13.12 |
| | Educational level | years | | 9.94 | 16.00 | 0.00 | 5.01 |
| | Farm size | ha | | 9.29 | 52.00 | 0.60 | 11.37 |
| | Harvest | times/year | | 1.65 | 3.00 | 1.00 | 0.70 |
| Environmental factors | Soil fertility | 1: Very poor<br>5: Very fertile | | 3.88 | 5.00 | 3.00 | 0.78 |
| | Fertilizer & pesticide use | 1: Very little<br>5: Very much | | 3.29 | 4.50 | 2.00 | 0.62 |
| | Irrigation frequency | 1: High frequency<br>5: Low frequency | | 2.80 | 4.71 | 1.40 | 0.94 |
| Economic factors | Revenue | Toman/ha | | 83,055.05 | 151,775.25 | 35,612.50 | 31,778.34 |
| | Profit | Toman/ha | | 67,542.54 | 130,570.36 | 15,152.80 | 32,206.79 |
| | Additional income | 1: Existant<br>2: Non existant | | 1.29 | 2.00 | 1.00 | 0.47 |
| Social factors | Farmer cooperative member | 1: No<br>2: Yes | | 1.71 | 2.00 | 1.00 | 0.47 |
| | Farmer cooperative attitude | 1: Very negative<br>5: Very positive | | 3.53 | 5.00 | 1.00 | 1.18 |
| | Community activities | 1: No participation<br>5: Very frequent participation | | 3.18 | 5.00 | 1.00 | 1.51 |

### 4.2.1 Demographic and agricultural factors

Age and education play an important role, especially in regards to problems of literacy of notably small-scale subsistence farmers. There is little formal and specialized agricultural education as most farmers inherit their skills from the previous generation. Also the land size and ownership influence farmers' performance, with Dez farmers cultivating on average bigger areas than in Gotvand, especially in regards to cumulative size. Gotvand farmers mostly plant only one time per year, and have therefore a smaller cumulative land size, but have the advantage to consume less water especially in the hot summer months, when they leave their land bare.

All farmers in Dez and Gotvand are men, with farmers in Dez being mostly in their 50's. The age of Gotvand farmers shows greater variety and ranges from 29 to 80 years.

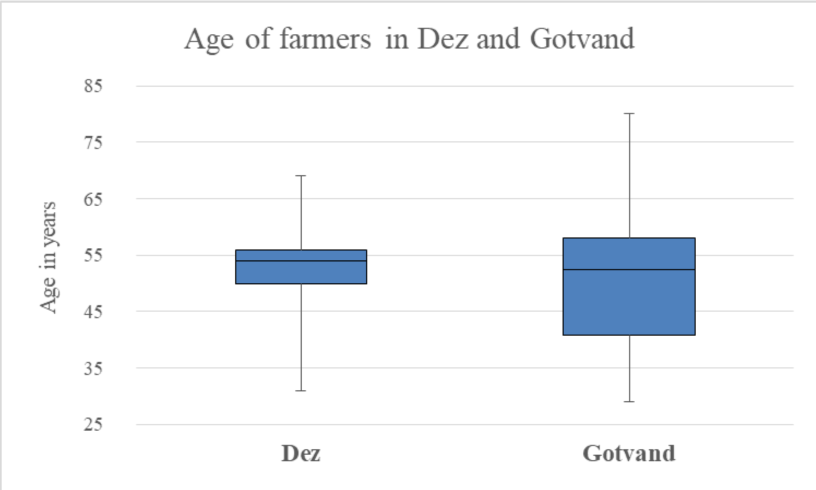



**Figure 18: Variance of farmers' ages in Dez and Gotvand**

Education level is also strongly connected to the age of the farmer. While from the participating farmers two in both irrigation schemes mention primary school with a total of 4 years of education as the highest educational diploma, farmers in Gotvand have on average a higher educational level, as four (out of eight) farmers also have university degrees, which equals to 16 years of education. Junior Highschool covers nine years of schooling and highschool 12 in total.

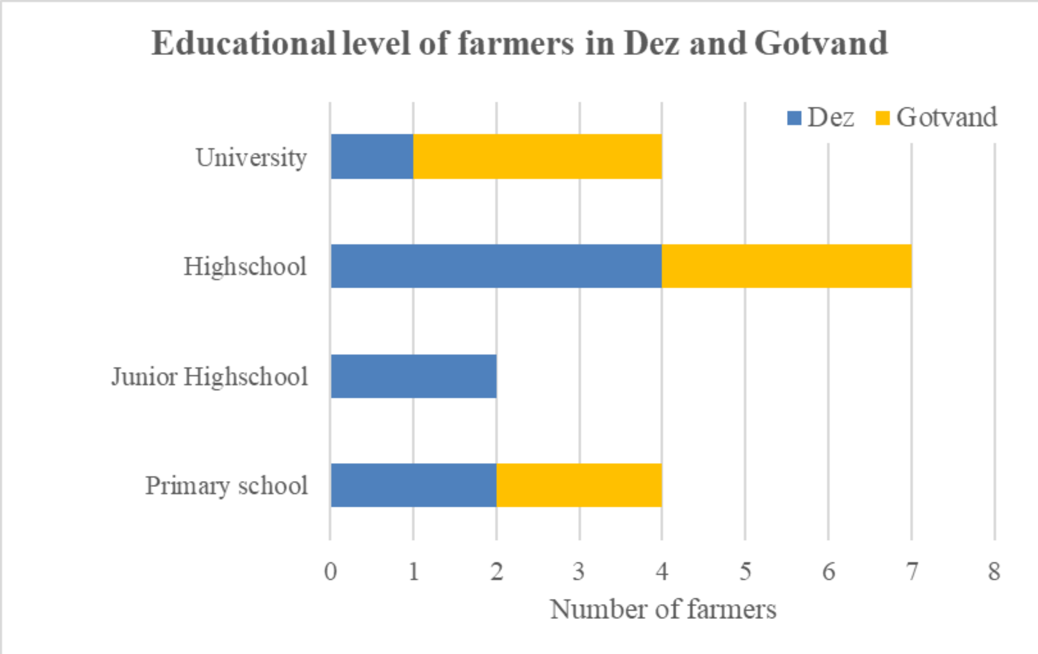



**Figure 19: Educational level of farmers in Dez and Gotvand**

The level of education in general does not necessarily translate into the level of agricultural knowledge, as the formal education from school or university covers only few agricultural aspects. Only two out of the four farmers in Gotvand with a university degree also studied agriculturally related subjects. Therefore, most farmers in Dez and Gotvand obtain their knowledge on farming from the previous generations or through self-study. Furthermore, farmer #8 and farmer #10 (personal communication, February 25 and 26, 2018) mention that instead of following one given path of agricultural knowledge, "[they] discuss with other farmers and just experiment with whatever works well for [their] land".

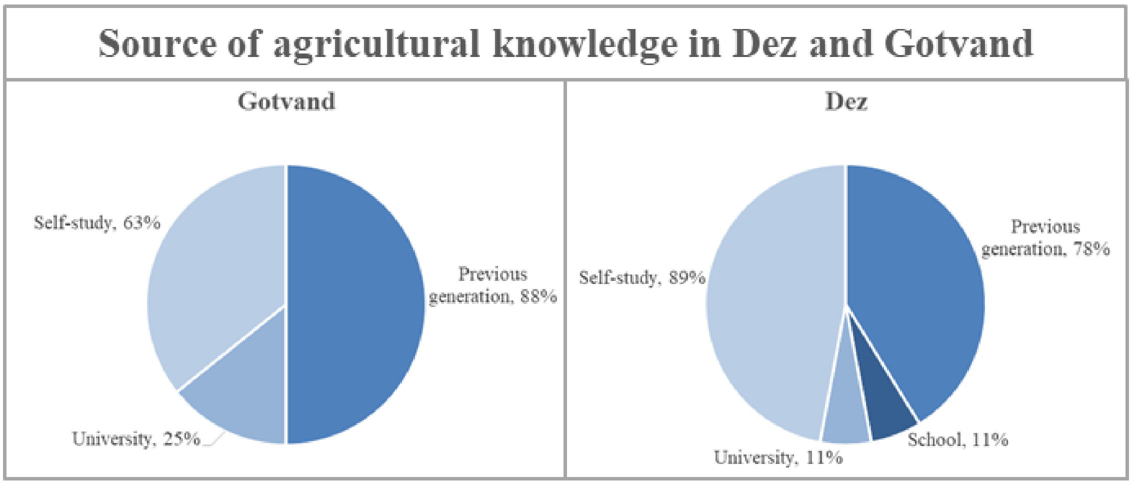



**Figure 20: Source of agricultural knowledge in Dez and Gotvand**

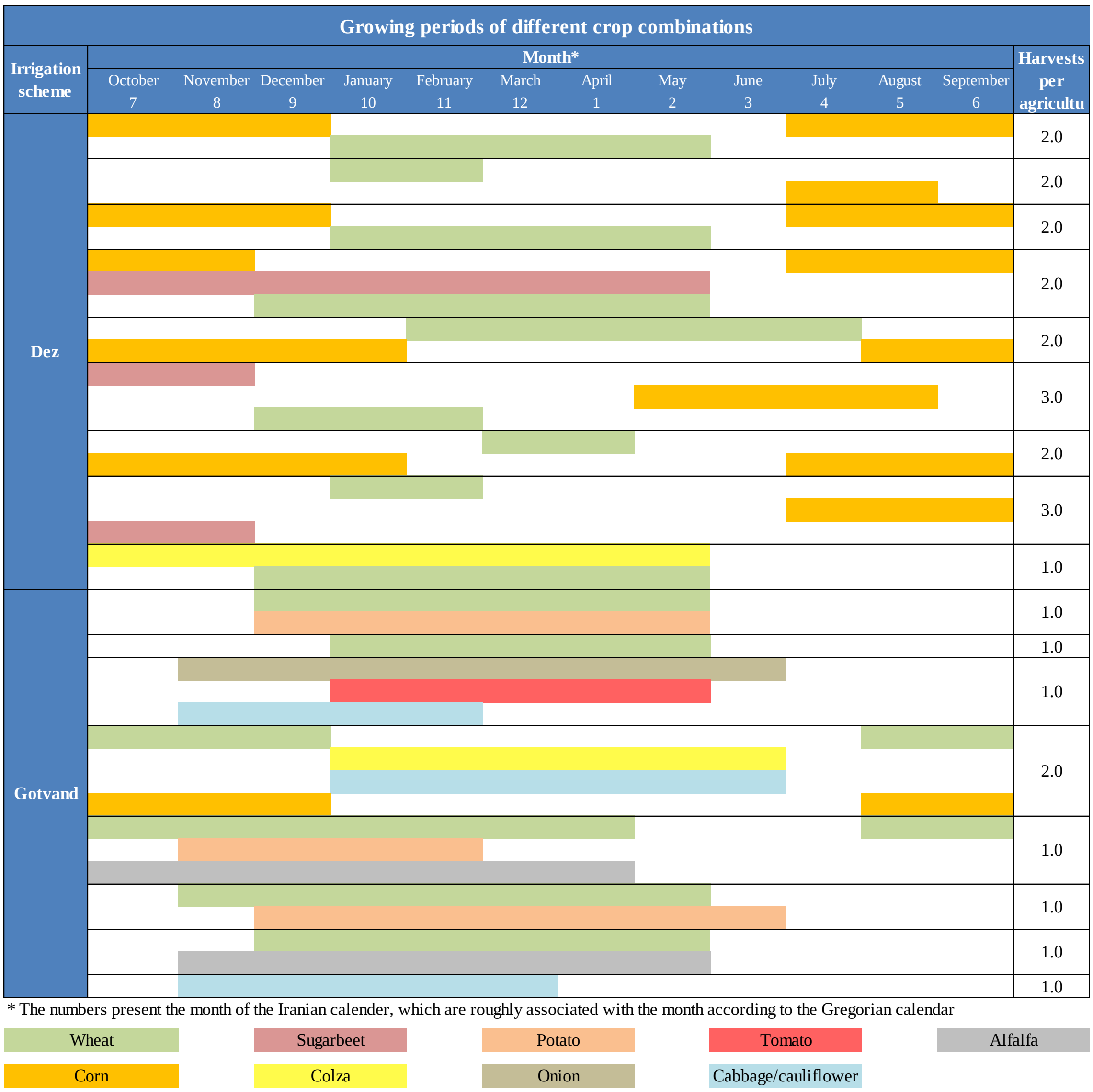
Another factor influencing farmers' overall performance is agricultural land properties, notably size and geographical location. The farm size of the participating farmers shows differences in Dez and Gotvand, which does not necessarily need to be representative for both irrigation schemes, but can be due to the random selection of farmers. Additionally, the issue of land ownership means that land sizes can change from year to year. Eight out of nine farmers in Dez lease land for time periods ranging from one to twenty years. In Gotvand, only three out of eight farmers leased land for one to five years. Consequently, in Gotvand, all farmers live close to their land with a commute distance of less than 5km. In Dez, farmers have a longer commute to their land, with an average of 15 km, which can be due to the high amount of leased land.

**Table 13: Physical and cumulative farm size of farmers in Dez and Gotvand**

| Farm sizes | Physical size | | Cumulative size | |
|---|---|---|---|---|
| | Dez | Gotvand | Dez | Gotvand |
| Minimum size | 5.5 | 0.6 | 10.5 | 0.6 |
| Average | 12.6 | 5.6 | 21.5 | 6.4 |
| Maximum | 52.0 | 12.0 | 72.0 | 14.6 |

Out of the nine participating farmers in Dez, the smallest one cultivated the physical size of 5.5 ha and the largest one 52 ha. In comparison, Gotvand farmers had much smaller farms, as the maximum land size of Gotvand farmers is still smaller than the average land size of farmers in Dez. The cumulative size, which takes into account multiple harvests per year, shows that all farmers in Dez harvest at least twice a year, whereas only one farmer in Gotvand cultivates the full area twice a year (compare Table 14). This is mainly due to the cropping pattern, as corn and wheat growing periods complement each other. This planting choice also means that farmers in Dez cultivate their land during the extremely hot summer months, whereas the majority of farmers in Gotvand leaves their land bare during the hottest period of the year.

**Table 14: Growing periods for different crops in Dez and Gotvand irrigation scheme**



### 4.2.2 Environmental factors

Environmental factors to investigate farmers' performance include crop diversity, soil fertility, water consumption, and fertilizer and pesticide use. While Gotvand has more crop diversity and lower pesticide use, farmers in Dez use comparatively less water and fertilizer less frequently, and have higher soil quality.

Similarly to the mentioned environmental issues as a consequence of the construction of the Gotvand reservoir dam, farmers in Gotvand estimated the fertility of their soil to be lower than the ones in Dez. In Dez, 44% of the farmers responded that their land is very fertile, and the rest of the farmers still classified their land as fertile. In Gotvand, only 25% referred to their land as fertile, while the majority of farmers (75%) selected neither fertile nor poor. These results remain subjective, as this research did not measure the soil parameters.

In regards to crop diversity, Gotvand farmers have a wider portfolio of crop types covered, whereas in Dez, wheat and corn cultivation dominates. In Gotvand, farmers do also cultivate vegetables, such as potatoes, onions and tomatoes, and animal fodder, such as alfalfa. This is not only a result of the farmer selection, but also the crop variety per farmer in Gotvand is higher than in Dez.

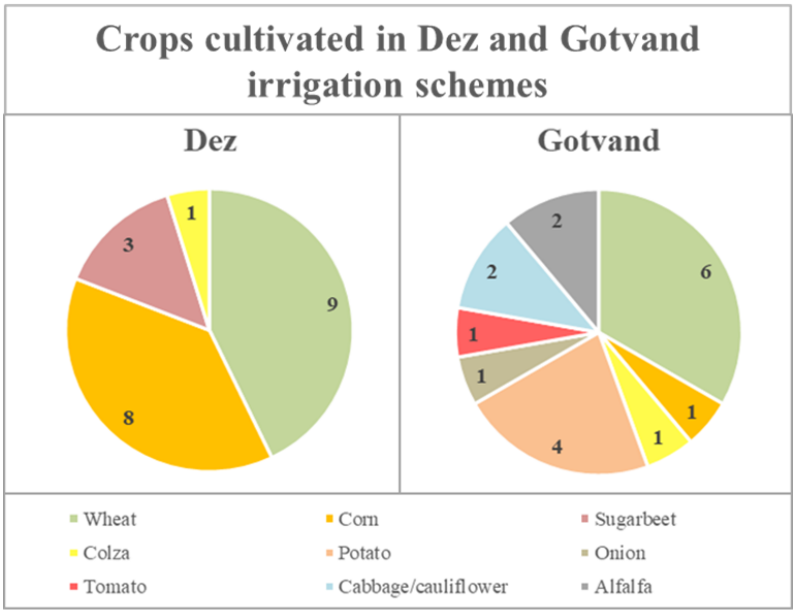



**Figure 21: Crop diversity in Dez and Gotvand**

Even though farmers do not know the amount of water consumed and the KWPA does not measure water consumption on farm level, the uniform calculation method for water allowance contrasts the high variety of the frequency of water consumption per crop type (compare

Table 15). An example for the deviation is especially the crop alfalfa, which has the highest water allowance of 36,878 $m^3$/ha in Gotvand. In the questionnaire, alfalfa had the lowest frequency of irrigation of all crops, with an average irrigation interval of every 85 days. Even though the frequency of irrigation is only comparable to the water allowance to a limited extend as the frequency does not allow a calculation of the water amount consumed, the comparison on farm level reflects how different farmers irrigate under the same framework conditions and similar cropping patterns.

**Table 15: Comparison of water allowances and irrigation frequencies of farmers in Dez and Gotvand**

| Comparison of water allowances and irrigation frequency | Cumulative water allowance per farmer | Evaluation of irrigation frequency per farmer |
|---|---|---|
| | in m3/ha*a | 5= longest interval<br>1= shortest interval |
| Dez | 9,345 | 3.5 |
| | 9,345 | 2.0 |
| | 9,345 | 3.0 |
| | 9,240 | 4.7 |
| | 9,345 | 2.5 |
| | 9,464 | 1.6 |
| | 9,345 | 2.5 |
| | 9,263 | 3.2 |
| | 9,429 | 4.7 |
| **Average** | **9,347** | **3.1** |
| Gotvand | 7,385 | 2.6 |
| | 6,780 | 3.0 |
| | 10,756 | 3.3 |
| | 9,799 | 1.4 |
| | 17,630 | 2.6 |
| | 7,083 | 2.0 |
| | 18,067 | 3.0 |
| | 6,488 | 2.0 |
| **Average** | **10,499** | **2.5** |

The water allowance is the cumulative amount of water calculated after the KWPA method per hectare and year weighted after crop types and their retrospective area under cultivation - and thus, is purely dependent upon the structure and given water calculation method. The frequency is the time interval in which farmers irrigate their land and evaluated as described in the methodology in relation to the average per crop type weighted per area and crop types of the respondent.

Farmers in Dez have similar average water allowances as they cultivate mostly the same crops, whereas the Gotvand water allowance variation reflects the crop diversity. Compared to Gotvand, Dez farmers overall have comparatively lower cumulative water allowances and comparatively lower frequencies of water consumption. But this evaluation represents the average of farmers that perform differently. As visible in the following figure, the irrigation frequency of wheat and corn varies between farmers and also in Dez and Gotvand, despite all farmers using the same traditional furrow irrigation system.

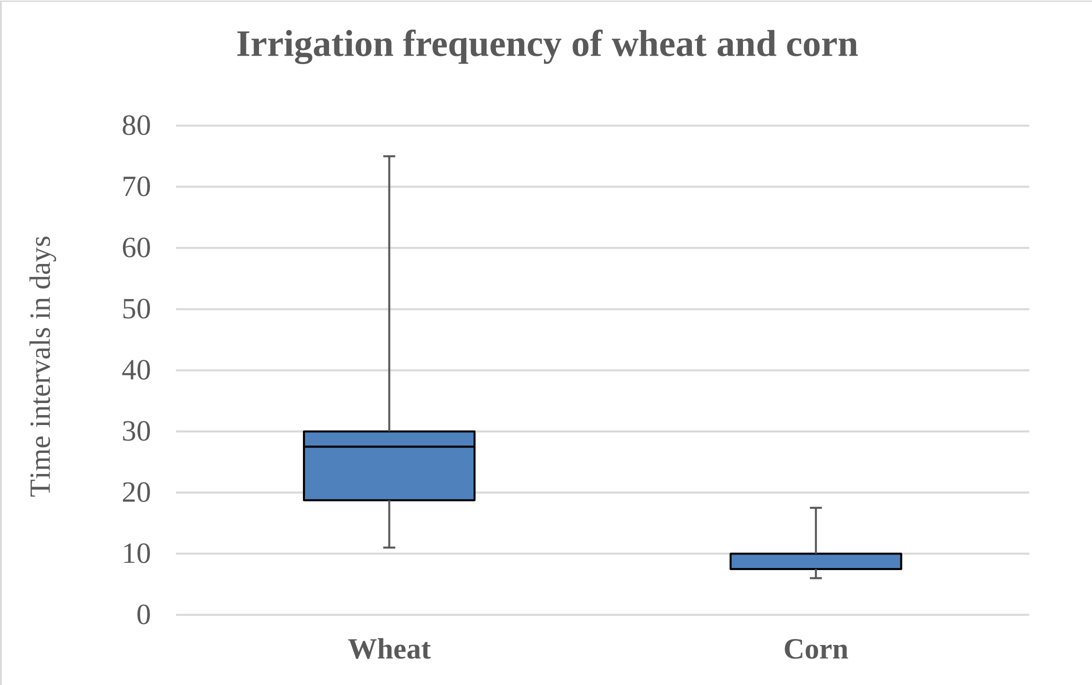



**Figure 22: Irrigation frequency variation in Dez and Gotvand**

The time intervals of irrigation for wheat vary from every 75 days to 11 days, and for corn from every 18 to every 6 days, even though the long intervals are the expectation. Also, reflecting the general evaluation of irrigation frequency for wheat, Gotvand farmers irrigated in shorter time intervals, on average every 24 days, and in Dez wheat is only irrigated every 32 days. These differences do not state whether farmers in Gotvand actually use a higher amount of water and might be due to different precipitation and planting periods, especially since farmers in Gotvand stated that they plant wheat during the summer months.

Similarly to water use frequency, the usage of fertilizer and pesticides shows high variation and is highly individualistic. Overall, farmers in Dez compared to the ones in Gotvand use less fertilizer but more pesticides. The evaluation of the amount used is again following the methodology comparing farmers' fertilizer and pesticide use with each other.

**Table 16: Evaluation of fertilizer and pesticide use of farmers in Dez and Gotvand**

| Comparison of fertilizer and pesticide use | Fertilizer<br>5= lowest amount<br>1= highest amount | Pesticides<br>5= lowest amount<br>1= highest amount |
|---|---|---|
| Dez | 5.0 | 4.0 |
| | 2.5 | 2.8 |
| | 4.7 | 3.0 |
| | 3.5 | 3.5 |
| | 4.0 | 2.8 |
| | 4.0 | 3.5 |
| | 4.0 | 2.5 |
| | 3.0 | 2.8 |
| | 3.7 | 3.4 |
| **Average** | **3.8** | **3.1** |
| Gotvand | 2.8 | 4.4 |
| | 1.0 | 3.0 |
| | 3.9 | 3.0 |
| | 3.4 | 3.0 |
| | 2.9 | 2.2 |
| | 4.0 | 3.2 |
| | 4.0 | 3.6 |
| | 2.0 | 3.0 |
| **Average** | **3.0** | **3.2** |

The comparative evaluation of fertilizer and pesticide use shows discrepancies between Dez and Gotvand, but also on the individual farm level. The results of fertilization show that the amount of applied fertilizer for the two main crops in both irrigation schemes, wheat and corn, varies by up to 600%.

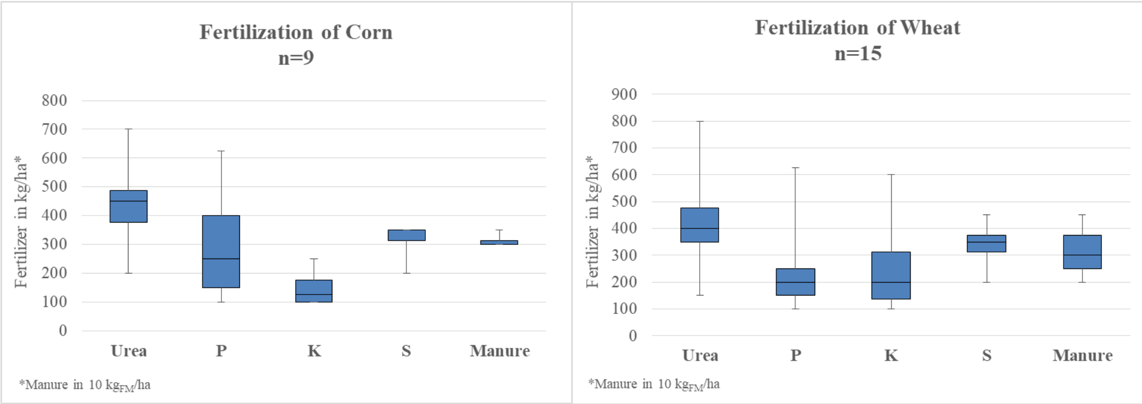



**Figure 23: Variation of wheat and corn fertilization**

In regards to corn fertilization, Urea and Phosphorus show high variation especially in regards to upper values, and for wheat the three main fertilizer components NPK show high variation. The different fertilization behavior of farmers' is a result of different approaches. When asked how to decide the amount of fertilizer, farmer #4 (personal communication, February 25, 2018) explained: "I put as much fertilizer as I think is good". In contrast, farmer #6 (personal communication, February 25, 2018) conducts soil analysis regularly and adjusts the fertilizer application accordingly.

### 4.2.3 Economic factors

In regards to economic performance of the evaluated farmers in Dez and Gotvand, the ones in Dez show on average advantages in all measured parameters. Regardless of whether farmers are in Dez or in Gotvand, the water costs have only a small influence on the profit, accounting for 12-13% of the variable cost and making up 2-3% of the calculated revenue. Also regardless of the location, the majority of farmers think that an additional income despite the revenues from crop production would influence their farming activities positively, with only few farmers having one. Similarly, only a few farmers receive governmental support, even though the definition has issues, as some farmers mention subsidized prices for agricultural support.

The revenue and water cost are calculated as the weighted average of all revenues (or water cost) from crop cultivation per farmer and expressed in the functional unit of Toman/ha. On average, in Dez, the revenue per hectare is higher, while all variable costs measured (fertilizer, pesticide and water cost) are lower than the average in Gotvand. The best performing farmer per category is marked green in the following table, whereas the worst is marked in red.

**Table 17: Evaluation of economic factors of farmers in Dez and Gotvand**

| Comparison of economic factors | Revenue | *Fertilizer Cost* | *Pesticide Cost* | *Water Cost* | Variable Cost | Profit |
|---|---|---|---|---|---|---|
| | in Toman/ha | | | | | |
| Dez | 68,890 | *11,310* | *1,035* | *1,674* | 14,019 | 54,871 |
| | 81,354 | *18,340* | *2,013* | *1,674* | 22,027 | 59,327 |
| | 93,551 | *11,378* | *1,490* | *1,674* | 14,542 | 79,009 |
| | 115,115 | *4,650* | *2,589* | *2,246* | 9,485 | 105,630 |
| | 61,800 | *10,775* | *2,835* | *1,674* | 15,284 | 46,516 |
| | 138,011 | *7,511* | *4,402* | *2,817* | 14,730 | 123,281 |
| | 77,732 | *6,600* | *1,840* | *1,674* | 10,114 | 67,618 |
| | 114,493 | *11,590* | *2,279* | *2,119* | 15,988 | 98,505 |
| | 62,523 | *7,214* | *1,873* | *1,285* | 10,372 | 52,151 |
| **Average** | **90,385** | ***9,930*** | ***2,262*** | ***1,871*** | **14,062** | **76,323** |
| Gotvand | 74,785 | *7,580* | *2,280* | *1,613* | 11,473 | 63,312 |
| | 76,230 | *14,500* | *1,500* | *1,334* | 17,334 | 58,896 |
| | 151,775 | *13,000* | *5,400* | *2,805* | 21,205 | 130,570 |
| | 83,183 | *12,316* | *1,597* | *1,683* | 15,596 | 67,587 |
| | 50,581 | *13,923* | *2,562* | *2,722* | 19,207 | 31,374 |
| | 41,118 | *10,594* | *5,260* | *1,473* | 17,327 | 23,791 |
| | 85,183 | *10,594* | *1,316* | *2,640* | 14,550 | 70,634 |
| | 35,613 | *16,400* | *1,450* | *2,610* | 20,460 | 15,153 |
| **Average** | **74,808** | ***12,363*** | ***2,670*** | ***2,110*** | **17,144** | **57,665** |

Nevertheless, there exist again great differences between the different individuals of the sample. For example, the best and worst performing farmers in terms of revenue and profit are in Gotvand. The great variance of different farmers is illustrated further in Figure 24.

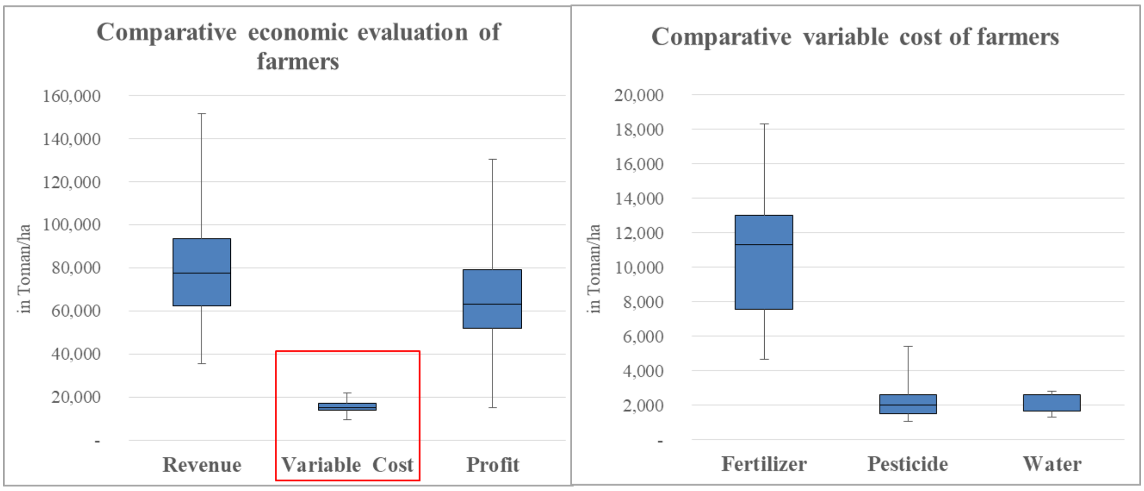



**Figure 24: Variance of economic performance and variable cost**

The profit as the result of the economic evaluation is only partially significant, as other cost positions, such as labor costs, costs for seeds and other agricultural supplies, machinery and fuel costs, and tenure costs, are not taken into account. Water costs are overall in Dez and Gotvand a minor cost. The overall water cost per hectare shows little variance and is similar for all farmers, despite the different farm sizes and cultivated crops, and the resulting different amounts of water allowances and the different comparative prices per $m^3$. The majority of considered costs are due to fertilizer use, with especially extreme values on the upper value. This reflects not only the amount of fertilizer and pesticides applied, but also different prices indicated by farmers. For example the price for Urea varies from 7.5 to 9 Toman/kg, which might depend on the place of purchase. While the government usually subsidizes price for fertilizer, pesticides and seeds for example, most farmers do not receive additional help from the government. Only three farmers in Dez receive governmental support in the form of educational classes on cultivation methods.

Next to the economic evaluation of the farming activities themselves, the effect of an additional income on the farming activities is another subject of this study. Most farmers view the effect of an additional income on the farming activities positively, except farmer #7 (personal communication, February 25, 2017) who states, that "it will distract you from your responsibilities as a farmer".

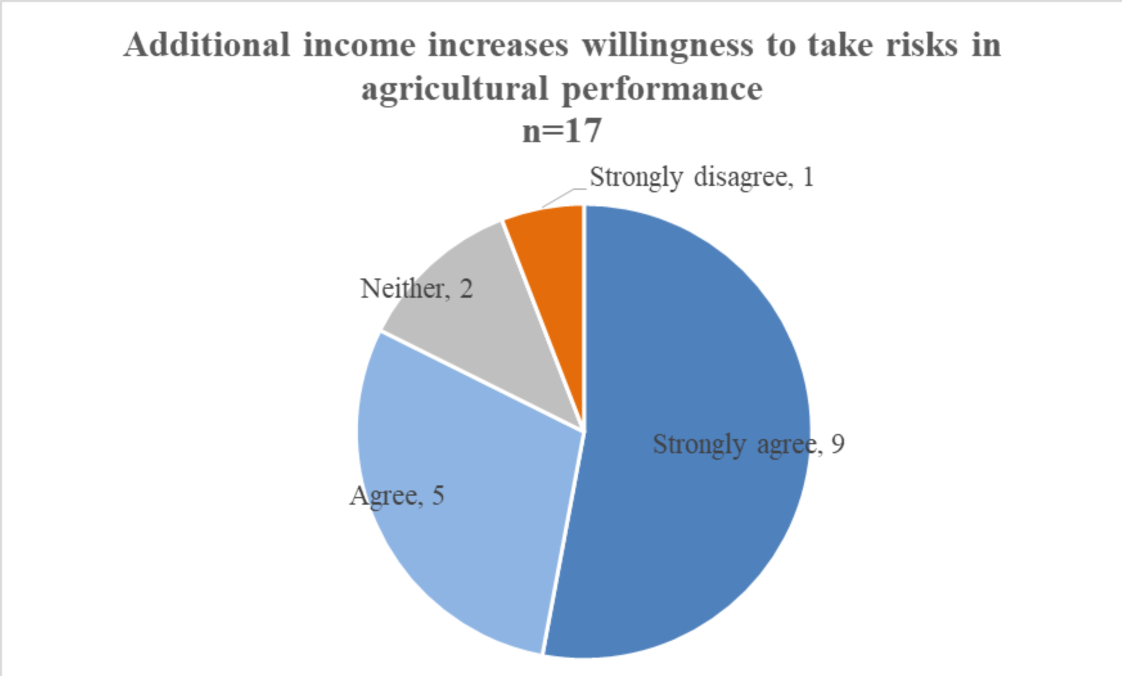



**Figure 25: Farmers attitude towards the effect of an additional income on their farming activities**

Out of the 94% of farmers who perceive an additional income positively, 29% have another source of income. The additional income derives from activities directly related to farming, such as machinery rental or being a retailer for agricultural supplies. Farmer # 13 also generates a higher revenue of his products and an additional income from sharing his agricultural facilities to dry fodder. Out of all farmers, he is the only one to produce a crop of higher value and not sell the raw product.

### 4.2.4 Social factors

The most decisive units of social interaction and influences on agricultural decision-making for farmers remain the family and the gate community. Additionally, community and religious activities, and the mosque serve as a platform for farmers to discuss and exchange with others or get information on agricultural activities, but are viewed more controversially. Similarly, the attitude towards farmer cooperatives varies, even though the majority of farmers are part of a farmer cooperative.

At most of the farms, the family contributes directly to the farming activities, expect for three farmers, where the family is not in the situation to support the farming activities. The forms of family involvement include temporary workforce, advice, sale of agricultural products, support during harvesting, and bureaucratic support, e.g. to pay for water allowances. The occurrence of these different forms of support for farming in Dez and Gotvand is displayed in the following figure.

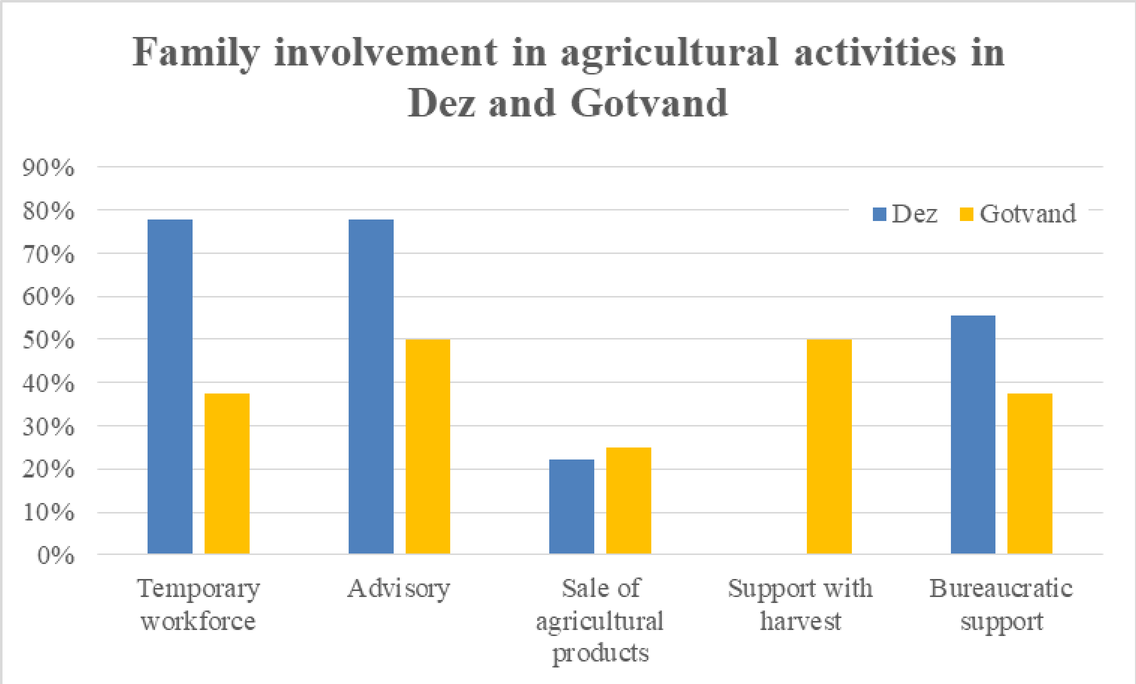



**Figure 26: Family involvement in agricultural activities in Dez and Gotvand**

The dominant contributions of the family in Dez are temporary workforce, advisory and bureaucratic support, whereas in Gotvand the family is especially involved during the harvest, giving advice,as acting as a temporary workforce, and for bureaucratic support. Farmer #4 (personal communication, February 25, 2017) explained furthermore, that "[his] daughter studies agricultural science at the university and helps him a lot to improve his farming”. Despite contributing actively to the agricultural performance on the farm or in direct communication with the farmer, the family is only a little involved in selling the agricultural products, which reflects the division of production and sale in general as farmers sell directly after harvest to buyers.

After the family as the most direct unit, also the gate community, the local farmers’ community and the religious community as well as the farmer cooperative play an important role and influence farming performance. While 89% of the interviewed farmers in Dez and 63% in Gotvand are members of a farmer cooperative, the attitudes towards farmer cooperatives as a positively influencing factor are mixed. Some cooperatives are exclusively for medium and big-size farmers and most of the farmers participate in only one annual meeting with the whole cooperative.

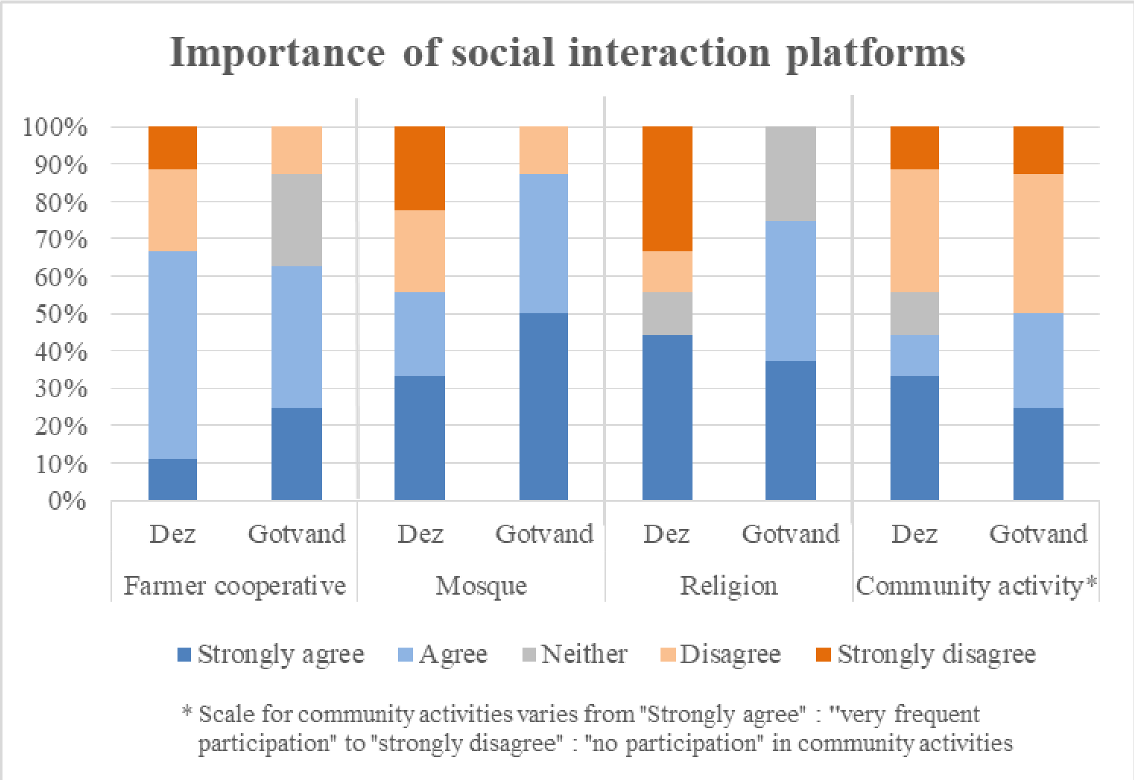



**Figure 27: Social factors evaluation of farmers in Dez and Gotvand**

Thus, the dominant level for knowledge transfer and agricultural influences is the village (community) level. Approximately half of the farmers participating in this study in Dez and Gotvand participated in discussions with other farmers and community activities, such as maintaining irrigation channels and roads, and discussing with other farmers on best times for fertilizer and pesticide application, at least once a month. Helping farmers directly with their farming activities is subject to the reciprocity principle: In Dez, 44% of the farmers stated that they don't receive help from other farmers and also don't help, whereas 56% help other farmers and also receive help in return. In Gotvand, the mutual support between farmers is slightly higher, with 63% of the respondents receiving help and helping others, and only 37% doing neither.

Additionally, the gate community is a well-established platform on the community level for farmers to cooperate in Dez, where all farmers pay their water fee through the gate community. In Gotvand, the gate community is less dominant as five farmers out of eight pay their water fee directly to the KWPA.

Contrariwise, the connection between religious and professional life is stronger in Gotvand, as farming aspects are also discussed at the mosque and are part of religious activities. Meetings at the mosque are focal points for farmers to exchange knowledge, but are also very controversial among farmers. While farmer #12 (personal communication, 2017) states, "the mosque looks like a school before the prayer"; farmer #1 (personal communication, February 25, 2018) explains, that "the mosque and prayers should exclude agricultural topics and focus solely on religious ones." In contrast to the mosque as physical place for farmers' to exchange, the evaluation of "religion" in Figure 27 is the spiritual connection to their farming activities, e.g. they might reflect on their agricultural performance also in prayers or retreive information from the Koran, that influences their agricultural choices. This connection is also stronger in Gotvand than in

Dez.

## 4.3 Factor Interaction

Most factors within the same category correlate strongly with each other, such as age and education. The educational level shows in the given sample only high correlation on fertilizer and pesticide use, but influences water use, economic and social factors little. As expected, bigger farmers show a comparative advantage in economic factors, but economic and environmental factors correlate only moderately.

On average, farmers in Dez show higher performance in all environmental and economic factors than the ones in Gotvand, but are more skeptical about farmer cooperatives and have less years of formal education. Comparing the best and the lowest environmentally and economic performing farmer from both schemes with each other, it is visible, that the ones in Dez score relatively high (or low) in all factors, whereas the ones from Gotvand show extreme values, especially in regards to cumulative size and profit.

The correlation analysis per category shows that age and education, size and harvests, and farmer cooperative attitude and participation in community activities have a large effect. Soil fertility and fertilizer use correlate only moderately, whereas the existence of an additional income influences the profit from agricultural activities only to a little extent.

**Table 18: Correlation coefficients for factor interaction within the same category**

| Correlation coefficients (r) of factors from the same category | | | | |
|---|---|---|---|---|
| Age & education | Size & harvests | Soil fertility & fertilizer use | Additional income & profit | Farmer cooperative attitude & community activities |
| -0.5734 | 0.5311 | 0.4581 | 0.1886 | 0.5061 |

The negative correlation for age and education signifies that for the sample of this study, the younger the farmer, the higher educational level. The same can be said for farmers with bigger land sizes and the tendency to plant multiple crops per year. In regards to social factors, farmers who think more positively about farmer cooperatives and their effects on farming performance are more actively involved in community activities. In opposition, the effect of soil fertility estimation and fertilizer use has only medium effects, which means that even though farmers' might think their soil is fertile, they do only partly adapt their fertilization accordingly. Even though the majority of farmers stated that an additional income would have positive effects on their agricultural performance, this sample shows only a small positive effect.

In contrast to the interaction of factors from the same category, the influence of factors from two different categories on each other is limited. While education level and fertilizer and pesticide use, and size and profit show medium correlation, the other factors measured just show low effects on each other.

**Table 19: Correlation coefficients for factor interaction of factors from different categories**

| Correlation coefficients (r) of factors from different categories | | | | |
|---|---|---|---|---|
| Education & fertilizer + pesticide use | Education & irrigation frequency | Education & profit | Size & profit | Size & irrigation frequency |
| 0.3768 | 0.0430 | 0.1759 | 0.4346 | -0.2785 |
| Revenue & fertilizer + pesticide use | Revenue & irrigation frequency | Profit & community activities | Farmer cooperative attitude & education | Farmer cooperative membership & profit |
| 0.2272 | 0.1627 | -0.1572 | 0.1857 | -0.0046 |

These results show that farmers with a higher level of education use comparatively less fertilizer and pesticides than those with less years of formal education. On the irrigation frequency or the profit as the overall economic result, education has only little impact, though. The correlation coefficient for size and profit confirms the principle of economies of scale, that bigger farmers also have a comparatively higher profit. Even though the effect of the size on the irrigation frequency is only medium, the negative value indicates that smaller farmers by trend have lower irrigation frequencies, which translates into less water usage. Although the use of fertilizer and pesticides and irrigation frequency influences the profit due to the costs of application, it effects the yield (and thus the revenue) only moderately. The positive values are an indicator that some farmers might use more fertilizer and pesticide and irrigate more often than required, as the higher the evaluation value, the less fertilizer and pesticides as well as water are consumed.

The influence of social factors on environmental and economic parameters is medium, while being member of a farmer cooperative has no effect on the economic performance. Farmers that are socially more active on the community level tend to irrigate a little bit less often (r=0.258), but their frequent participation in community activities has a medium negative impact on their economic performance. The effect of education on the perception of farmer cooperatives is only medium. Thus, farmers with higher formal education only think to a limited extend, that being a member of a farmer cooperative can help to enhance agricultural performance.

Next to analyzing the correlation between several factors, the factor interaction of average performance in Dez and Gotvand can be compared. As visible in following figure, Dez farmers perform on average better environmentally and economically, as they also have bigger farm sizes, harvest multiple times per year and have high soil fertility. Gotvand farmers, in opposition, have a higher education on average and showed a more positive attitude towards farmer cooperatives.

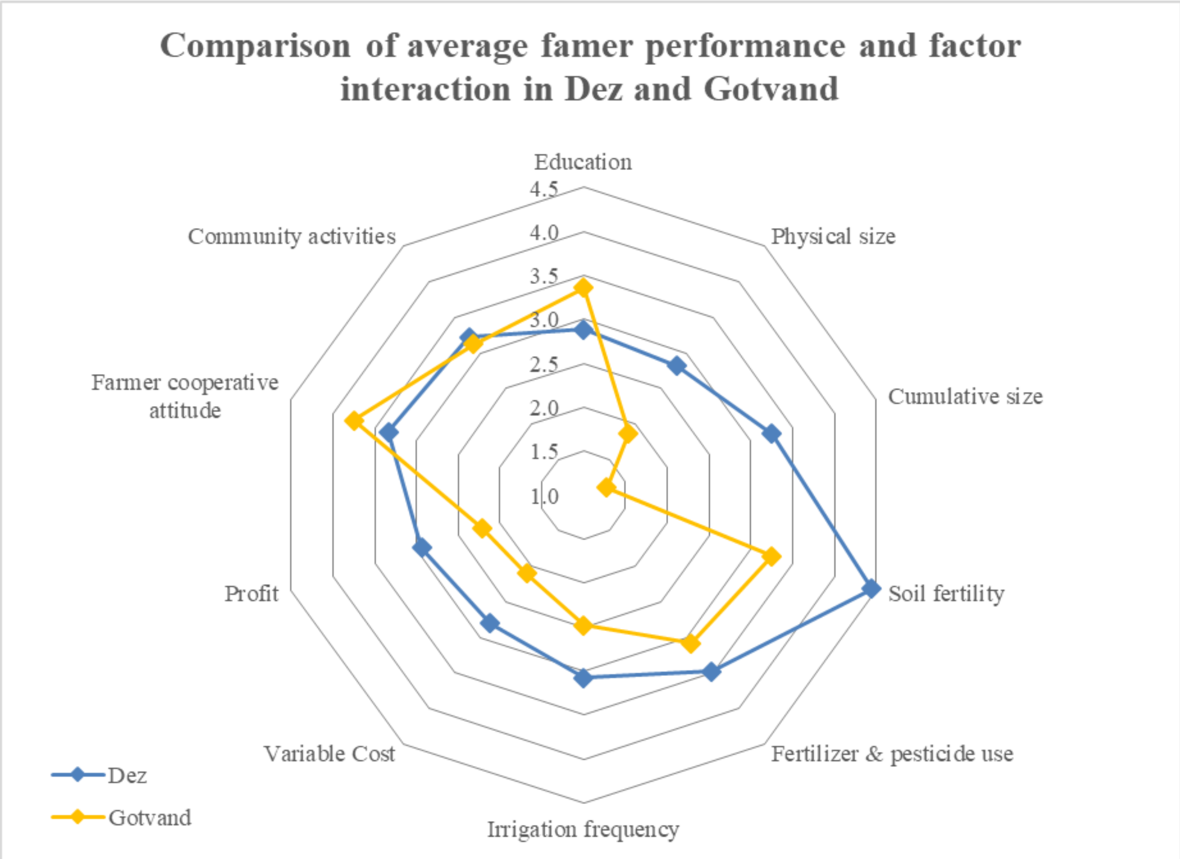



**Figure 28: Comparison of average farmer performance in Dez and Gotvand**

Figure 27 displays the average results of farmers' in Dez and Gotvand, which diminishes the accuracy of the individual farmer performances. As there exist significant differences between farmers' of the same irrigation scheme, also the best environmentally and economic performing and the worst performing farmer from both schemes are compared with each other. The results are visible in Figure 29.

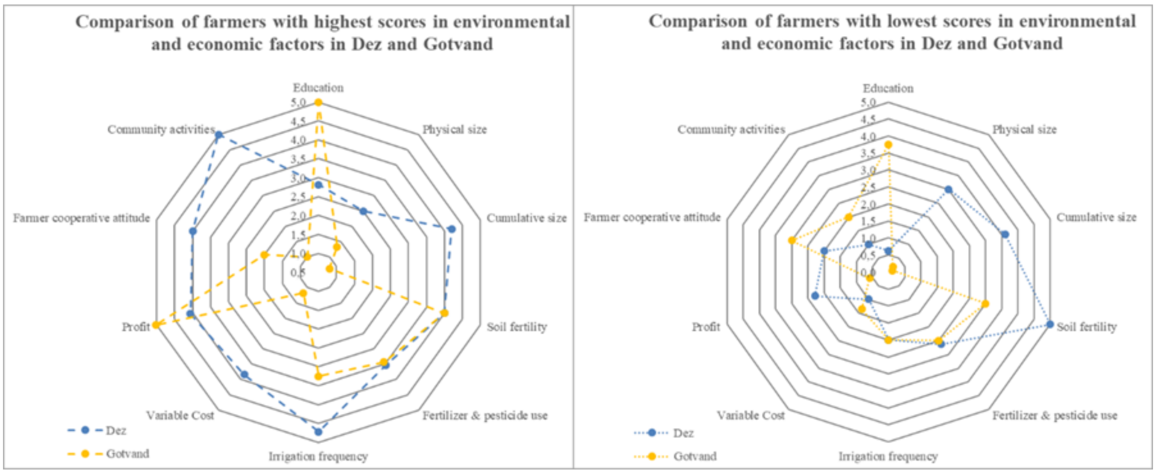



**Figure 29: Comparison of the highest (a) and lowest (b) environmentally and economical performing farmers in Dez and Gotvand**

The factors that both of the most environmentally and economically successful farmers in Dez and Gotvand have in common are the relatively high soil fertility and the relatively little amount of fertilizer and pesticide used. While the farmers in Dez scored on all parameters relatively high, especially in irrigation frequency, variable cost, profit and participation in community activities; the farmer in Gotvand has more extreme values, with high scores on profit, education and irrigation frequency, but very low scores on variable cost, farm size and cumulative farm size. In Gotvand, the farmer with the lowest environmental and economic score is also the farmer with the smallest land size, the counterpart in Dez has a bigger farm and mentioned a higher soil fertility than the best performing one. Again, the farmer with the lowest environmental and economic score in Dez shows relatively similar scores on all factors despite soil fertility, while the Gotvand one is more diverse. The specific performance of all farmers in Dez and Gotvand is available in the Appendices two and three.

# 5. Discussion

The discussion consists of three main parts, namely the discussion of the chosen method, the discussion of the factors influencing farming performance including recommendations for involved stakeholders, and a general discussion on sustainability of irrigation-based agricultural systems.

## 5.1 Methodological discussion

Strengths of the method are the comparability of farmers with each other, which is a result of the intensive analysis of the framework conditions and development of the questionnaire. Therefore, it is recommended for future research to invest in the analysis of framework conditions, as many farmers in developing countries are similar to those in Khuzestan embedded in a strong given structure. Even though this research can provide insights on factors influencing farmers' performance in the irrigation schemes of Dez and Gotvand, the methodology shows some deficiencies, namely the incompletion of the questionnaire, the static nature of modelling, the small sample size, and the strong dependence on interpretation. In order to improve the quality of results using the developed method, a larger sample size and data collection throughout a time series are needed.

In order to paint a preferably complete picture of factors influencing farmers' performance, the chosen factors in the questionnaire were retrieved from several expert interviews and farmer interviews. Nevertheless, the group of these factors is not complete, which is especially obvious in regards to economic assessment. Important cost factors that influence farming performance, such as machinery and workforce costs, do not enter the economic assessment. These data are difficult to retrieve, as e.g. farmers list the workforce on the field, but rather than an organized factor which can be quantified, the workforce is rather unspecified. All workforces are only temporary to support farming activities with high labor requirements, such as fertilizer or pesticide spraying. Also, the qualification and relation of the workers with the farmer complicates the economic assessment, as in some cases these workers are family members or friends, that are not necessarily professional farmers nor do they receive monetary reimbursement for their work. The farmers that pump water use mostly submersible and centrifugal pumps with diesel engines. These are responsible for high energy consumption and lead to low energy-production ratios and negative net energy in farming (Hormozi et al., 2016).

Additionally, correlation as a statistical indicator is not causality; therefore, correlations of factors can be random and unrelated. This means as a consequence that recommendations on the improvement of the system might not cause the desired effect. This is also the reason why the author did not apply results from this study on the DPSIR model. Similarly problematic is the static nature of the modeling. Changes in the environment and in pricing structure can transform not only components of the system, but also change the links between them, as these drivers and changes effect farmers' decision-making (Marques, Lund, & Howitt, 2005).

Several points need to be verified by a bigger sample, as with the sample size used, differences in Dez and Gotvand are not representative. This deficiency is especially conspicuous in the environmental evaluation of farmers whom are the only respondents to plant the one crop, as in this case no comparison is possible. For example, does only one farmer cultivate tomatoes. Therefore, his amount of fertilizer and pesticide use, as well as irrigation frequency is the average (equaling the evaluation value of 3), even though he might be well above the average. The environmental evaluation comes to the conclusion that farmers in Dez perform comparatively better than the ones in Gotvand in irrigation frequency and fertilizer use, which may not be true. Actually, the crops wheat and corn have an overall high fertilizer use when compared to German standards. The German standard for total N-fertilization per year is 200 kg/ha. Urea (which is used as N-fertilizer by all wheat- and corn-farmers) has an N-content of 46%. The N-fertilization for corn has an average of 200 kg N/ha, varying from 90 to 320 kg N/ha. The average for corn is similar, with even greater variance of 70 to 370 kg N/ha. Thus, the application of total N per year for farmers that plant wheat and corn within one year is approximately 400 kg N/ha, which is still high compared to the maximum German value. Also, in regards to water consumption farmers' in Dez plant corn, which has a comparatively high crop water demand, during the summer months, where water losses due to evapotranspiration are especially high. Farmers' in Gotvand in opposition do not cultivate their fields during the two hottest month, so generally their overall water consumption should be lower than the one of farmers' in Dez.

## 5.2 Recommendations and discussions factors influencing farmers' performance and factor interaction

Major issues that limit farmers' environmental, economic and social performance comprise inefficiencies due to small scale farming, unused regional potentials, excessive water use, and communication issues; especially of governmental institutions with farmers. These factors are correlated. Other than just an irrigation technology change, as emphasized by various researchers, this research suggests, that a system change is needed. This change can also build upon the existing system by empowering social structures and cooperation among farmers, and developing and using a common vocabulary. The recommendations on each level of the hierarchy are visible in the figure below.

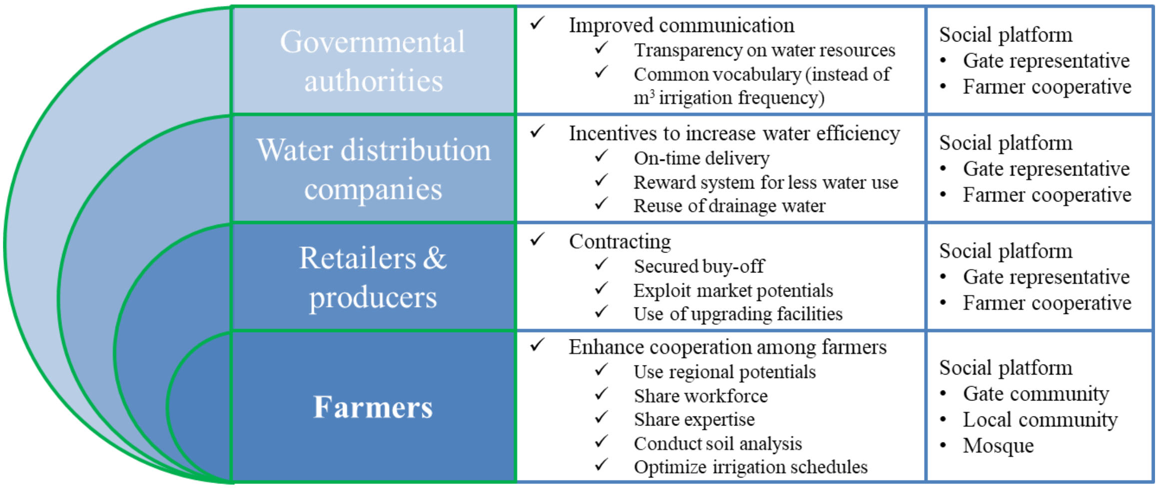



**Figure 30: Recommendations to enhance farmers' performance on different hierarchic levels**

At the basis of the system change is the increased knowledge of farmers of their own farming activities to support long-term planning by building upon existing potentials within the communities. Especially problems of small scale farming and illiteracy can be deviated at the community level, when small parcels of different farmers are managed together using the gate community as the platform and administrative operator. These are based upon democratic principles and farmers can share their farming machinery, their workforce, as well as harmonize their irrigation schedules. The gate community as well as farmer cooperatives can also serve as platforms to enhance the circulation of regional resources when livestock farmers receive fodder and supply manure as fertilizer. At the moment, the majority of fertilizer demand is covered by mineral fertilizers, which causes GHG emissions during their production.

Most famers show short-term oriented, risk adverse behavior, visible in the usage of loans for immediate needs, such as buying seeds or other supplies. Also, farmers cultivate governmentally subsidized corn and wheat, even though some express concerns about these crops' water demand, because they are vulnerable and not very resilient to market changes. The annual land leasing system contributes to short-term planning and hinders the sustainable progress of farmers to upgrade their performance and improve steadily.

Due to the potential lease of land for a short amount of time, farmers barely plan for more than the next year as the actual cultivated area might change. Positive effects of this leasing system might be a possibility for farmers to reduce their cultivated land in years of drought without losing money, but possible problems arising from the leasing system are the tragedy of the commons: Farmers tend to care less about restoring soil fertility, as they are not sure whether they will obtain the same land the year after again. Another negative effect lies within the high competition among farmers over leasing land, which might negatively affect social capital on the village level. These issues as well as long distances from the farm can be alleviated by farmers changing their land or having long-term contracts, building on the trust within the local (gate) community. In this regard and to raise awareness on the limitation of resources, the mosque, which is an important element of everyday-life and moral orientation for many respondents, can also play a crucial role.

Next, to being a platform for internal exchange and cooperation of farmers within a community, the gate community also represents the farmers to the outside and can undertake steps to decrease every farmer's administrative effort and even business risk. The existence of gate communities reflects an administrative necessity, as it is easier for water distribution companies and off-takers to deal with the gate representative than with each small farmer individually. These external competencies of the gate community or farmer cooperative can be extended by being the responsible party for contracting. In this system, the farmers can already establish a contract with an off-taker at the beginning of the agricultural year which guarantees them a certain price and off-take for a part of their harvest. This avoids market uncertainties and provides, to some extent, income security.

Even though cooperation among farmers helps to overcome some issues farmers are facing in the current system, cooperation on the level of the farmer cooperative is controversially discussed. The questionnaire results showed that farmers are sceptical about the usefulness of farmers cooperatives. This lack of trust is related to the little personal contact and involvment farmers have with farmer cooperatives, as there are several hundred farmer members and they mostly meet only once per year to elect the cooperative's representative. As Scholar #1 (personal communication, July 26, 2017) puts it; "the farmers that profit most from cooperation are the ones that do not cooperate".

In contrast, none of the interviewed farmers articulated concern about the gate community or its successful functioning. Farmers are more personally involved in gate community activities and proceedings due to the direct effect it has on their agricultural activities, the informal character, the small size, and the proximity of the farmers to each other. In order to enhance this successful form of cooperation, the gate representative could have more responsibilites or represent the farmers forming the gate community at a higher level, such as the farmer cooperative and to other stakeholders mentioned above.

Another factor that diminished farmers' performance is the "lack of water user's participation in operation and management of the system" (Ahmadizadeh, Ehsani, & Wahaj, 2011). These authors' recommendations to improve water delivery services, to increase efficiencies and water productivity, to cultivate of high value crops, to involve water users in the decision making, and to cover full O&M costs of the irrigation system by service fee can be transferred. An example for a method to increase water efficiency is the on-time delivery pilot-project implemented in Dez, which is based upon the frequent communication with the farmers as well as the incentive given by the reward for less water use. The increase of water productivity by financial means, namely the increase of the water price, is not an option for the KWPA as it collides with the political agenda and Islamic principles. Additionally, water consumption can still not be verified (KWPA, personal communication, July 23, 2017). In order to integrate farmers into the decision-making process, a common vocabulary needs to be developed. While the KWPA and water distribution companies use $m^3$ for the water, farmers use irrigation frequencies.

Furthermore, a more transparent and clear communication between authorities and farmers is needed. It could be observed that among farmers, there is very little understanding of water as a limited resource, but there existed rather an impression of authorities' lack of will to distribute water to the farmers in the face of water shortage. All interviewed farmers were unable to even give a rough estimation of their water consumption and mostly responded to water crisis and droughts with extracting more water from the irrigation channels or rivers directly. Also, in regards to the evaluation of soil fertility, several farmers in Gotvand mentioned a subjective feeling of decline in their soil fertility since the construction of Gotvand dam. Results of water quality measurements can be disseminated on the farmer cooperative level, as well as discussing possible countermeasures. Similarly, the KWPA strategies on how to meet challenges of environmental pollution from drainage water require active participation from agricultural stakeholders to be successful. Among these strategies are (Shamsaee, 2017):

- Transferring main drainage flows to low environmentally impacted areas (e.g. the Persian gulf)
- Modification of irrigation methods to increase efficiency,

- Modification of drainage methods to increase the quality of drainage water, and
- Reuse of drainage water (e.g. to irrigate salt-tolerant plants).

The expansion of irrigated areas and increase of irrigation methods is widely recommended by various scholars (Ahmadizadeh, Ehsani, & Wahaj, 2011). As Albaji (2010 and 2012) recommended, the area is rather suitable in regards to irrigation technology improvement for sprinkle irrigation instead of drip irrigation due to the relatively low calcium carbonate concentration in most soils. A change from surface irrigation to sprinkle irrigation would improve the land suitability by 66-% (thus nearly 36,000 ha) of the land around Karoun River (Albaji, Naseri, & Nasab, 2010), and achieve an arability of 94% of the land in the Gotvand plain (Albaji, Golabi, Nasab, & Jahanshahi, 2014). The biggest challenge to improve the irrigation technology is the limited access to capital by farmers, especially in regards to the administrative framework, where land cannot serve as a mortgage.

Nevertheless, not solely the shift to another irrigation method is required to improve irrigation performance, but also the existing traditional way of furrow irrigation can be modified to reach higher efficiencies. The advantages of surface irrigation comprise low costs, no initial investment needed, little maintenance required, and it is feasible with unskilled labor. The surface irrigation system can be improved by adapting design, implementation and management, e.g. (Golabi, Sikakinezhad, Shir Afrous, & Albaji, 2017) calculated the optimal length of furrows to be 100 m. Some farmers also adapted their growing periods, by leaving the land bare during the hot summer month, and thus cutting their irrigation water demand. In regards to drainage, the low discharge leads to increased infiltration depths, which results in very poor quality drainage water, because the drains lay deeply and over-drain the land, as they work longer and they also wash out the salt from deeper strata (Akram et al., 2013).

## 5.3 Achieving sustainability?

Although comparing farmers' performance on a local level helps to identify BMP and therefore allows one to define short-term measures, this comparative degree of sustainability is not a definite one. Considering Khuzestan Province's natural framework conditions under the light of climate change, a fundamental question is whether agriculture should take place in such an environment; or, whether agriculture can even be sustainable in this environment. This research discusses this question briefly, but cannot answer this question ultimately. To do so, future research, e.g. comparing agricultural key indicators from Dez and Gotvand farmers with those of other farmers under similar natural conditions, is needed.

Achieving sustainability is the ultimate goal of a system, with a human socio-economic system simulating the natural system, with its endogenously closed metabolism, and not producing unwanted emissions, such as pollution and wastes, or exhausting the stock of a resource. The agricultural system of Dez and Gotvand is an imperfect simulation of the natural system, by destroying the resources it depends upon (e.g. over-extracting water) while trying to maximize output. Thus, the evaluation of environmental, economic and social indicators shows that agriculture in Dez and Gotvand as practiced by the participants of this study can hardly serve as a role model for sustainability or zero-emissions agriculture. The shift to modern agriculture, and especially the shift to modern irrigation technology, caused the negative system change from the historically successful and sustainable agricultural system to the water-intensive agricultural system of present days. One example illustrating this system quality degradation is the abandonment of sustainable local water extraction methods, such as the mentioned qanat. Due to lower groundwater levels, these channels ran dry and can no longer be used to extract and transport irrigation water.

In the face of the current climate aggravations due to climate change and the damage done on the system, it is questionable whether Khuzestan Province is a place where agriculture should happen. Mesgaran et al. (2016) found out in their research on Iran's land suitability for cropping that the majority of land in Khuzestan Province is classified as unsuitable, poor or very poor, with only a small part of the area being classified as medium suitable for agriculture. This low suitability for agricultural activities is mainly due to unfavorable soil properties, topography and climate. During the field trip, these extreme climate conditions could be observed as well, with temperatures reaching up to 52 Degrees C, and severe drought and sand storms. Nevertheless, some farmers' especially in Dez evaluated their land as very fertile, but this was their opinion as only one farmer actually conducted a soil analysis.

Implementing an agricultural system that adopts to these harsh natural conditions rather than imposing an artificial system needs long-term political and economic guidance. Comparing farmers on the local level can improve their performances, but not transform the system as a whole. Also, the farmers are already embedded in a strong structure, so they have a limited scope of action. Nevertheless, a common articulated goal of MoE and MoJA is the future empowerment of farmers, which could contribute to widening their possibility to influence their own and Khuzestan's agricultural system's fate (KWPA, personal communication, July 23, 2017; Ommani, 2011).

In order to do so, the political premise to supply farmers with necessary goods to "keep the people on the land" and ensure food security (Scholar #2, personal communication, July 25, 2017) has to change to the premise to ensure a good and sustainable rural livelihood and principles of good governance. But also bottom-up initiatives, with high initial investment and individual dedication, such as SEKEM initiative in Egypt, can establish a circular agriculture, which is economically advantageous and socially equitable. Key stone of this initiative is the cooperation of farmers under a knowledgeable foundation to produce high value crops, such as pharmaceutical production or organic products, and access a high-priced, qualitatively advanced target market (Hatem, 2007; Zsolnai, 2015). Evaluating these approaches and applying further methods to transform the system towards more sustainability would expand the scope of this research and can be subject to future investigations focusing of the social structure and development theory.

# 6. Conclusion

Coming back to the initial research outline, the goal of this research was to determine factors that influence farmers' performance and their correlation, and deriving from this system understanding formulated recommendations for irrigation-based agricultural system transformation towards more sustainability. Dez and Gotvand irrigation schemes in Khuzestan Province in Iran were chosen as models for the system analysis for two main reasons. First, Khuzestan Province is among the most important agricultural regions in Iran and faces already severe issues of water management (like droughts and environmental pollution), which are expected to worsen in the future due to climate change. Second, previous research stated that Dez and Gotvand have very different water productivities, despite their geographical proximity.

The system modeling consists of a framework condition analysis, which determines the structure that farmers are embedded in, and a comparison of individual farmers' performances within the structures of Dez and Gotvand irrigation schemes. The evaluation of environmental and economic factors is based on the comparison to the average per factor and category. The data used derives mainly from 17 questionnaires and interviews collected during two field trips in July 2017 and February 2018 to Khuzestan. The methodology applied to evaluate farmers' performance in regards to demographic, agricultural, environmental, economic and social factors includes quantitative statistical analysis and qualitative interpretation of data. The qualitative interpretation is based on results of the literature review on system modeling and sustainable agriculture and water management practices.

Farmers in Dez and Gotvand are both acting under a strong given structure, which is comparatively more favorable in Dez in regards to cropping pattern and water delivery system. Farmers in Dez plant mostly wheat and corn, for which prices are fixed by the government, whereas farmers in Gotvand cultivate a variety of different crops without secured buy-off. Also, while Dez has a pilot system to supply water on-demand, in Gotvand the irrigation channels are filled every 48 hours disregarding the actual demand. Even though the semi-arid climate naturally limits water resources in Dez and Gotvand, the water quality in Gotvand is potentially worse due to a constructional mistake of Gotvand dam being built on a salt layer. Nevertheless, farmers in Dez and Gotvand use the same traditional method of furrow irrigation, and have difficulties to access capital due to restrictions from the land serving as mortgage. The water prices are fixed by the governmental authorities and do not reflect water consumption, but are calculated as a fixed percentage of the revenue of different crops. In both irrigation schemes and for all farmers despite their irrigation scheme the water cost influences the farmers' economic performance only marginal.

The comparison of factors influencing farmers' performance showed even though farmers in Dez are on average more successful in terms of economic performance and environmental impact from water and fertilizer use, there exists a great variance between individual farmers in most factors analyzed especially in Gotvand. The farmer with the highest profit per hectare as well as with the lowest profit per hectare are respondents from Gotvand. The economic performance in Dez is high on average compared to those of Gotvand due to economies of scale, as farmers in Dez have bigger farm sizes and cultivate their land twice a year. The on average better educated farmers in Gotvand, though, have a comparatively lower environmental impact in regards to pesticide use. Furthermore, their cropping diversity and leaving the land bare during the hot summer months should reduce their water consumption, but the evaluation of irrigation frequencies results in on average higher scores in Dez. This result reveals a deficiency of the application of the chosen method to an insufficient big sample size. As farmers' environmental factor performance is evaluated by the deviation from the average per crop type, the crop diversity of the eight farmers interviewed in Gotvand becomes disadvantageous because irrigation frequency, fertilizer and pesticide use cannot be compared. In order to achieve a higher quality of results a bigger sample size is needed.

In regards to social performance, more farmers in Dez are part of a gate community, which is the local semi-formal organization of farmers whose lands are situated closely to each other using the same irrigation channel, dealing with the distribution of their shared water resources. The gate community is a successful and well-respected local organization, visible in the positive attitudes of farmers. Other than the farmer cooperative, whose functioning and importance is reviewed controversially by farmers, the gate community builds upon existing relations of trust in the local community.

Therefore, the main recommendation of this research to enhance farmers' performance is to use the gate community as a platform and instrument to facilitate a system transition. Not only can farmers exchange knowledge, help each other, use regional potentials (such as organic fertilizer from livestock farming) and optimize their irrigation schedules within this structure, but they can also overcome problems of small-scale farming by taking external action together. The gate representative can diminish risk of non-guaranteed purchase by contracting with local retailers, and thus by producing crops on demand. It can also serve to improve communication with external stakeholders, such as water distribution companies and governmental bodies. These, on the other hand, need to create a more enabling environment for farmers to improve their performance, especially in regards to improving water use efficiencies, and need to improve their communication with farmers. The KWPA stated that water price increase is not a political option, but the reward system of Dez can give good incentives. Also, more transparency of the limited nature of water and soil resources is needed and the development of a common vocabulary, as for example farmers have no estimation of the unit "$m^3$" and therefore what their water allowance actually is. Improving these influences on farmers' performance would simultaneously also contribute to the goal articulated by MoJA and MoE to empower farmers.

While all of these measures, derived from the gained understanding of the irrigation-based agricultural systems in Dez and Gotvand, can help to comparatively enhance the system performance, a holistic system change towards more sustainability and zero-emission agriculture requires a bigger disruption. There exist socio-economically successful examples, such as the SEKEM initiative in Egypt, and development theory offers a wide range of approaches to elaborate on mechanisms for how to transform anthropogenic systems. The exact definition of zero-emission agriculture and possible ways to achieve it expand the possibilities of this research and can be subject to future investigations.

# Appendices

## Appendix 1: Farmer questionnaire

### Farmer Questionnaire

This questionnaire is designed to support my master thesis research on "Understanding Irrigation-based Agricultural Systems: Factors Influencing Agricultural Performance in Khuzestan Province, Iran" in sustainability science at Ritsumeikan Asia Pacific University in Beppu, Japan, supervised by Prof. Faezeh MAHICHI. If you have any questions in regards to the survey or my research, please do not hesitate to contact me or Prof. MAHICHI via: ulriki16@apu.ac.jp or fmahichi@apu.ac.jp.

All data are confidential and will be analyzed anonymously. The collected data serve only for research purposes and have no commercial use. Also, your participation in this survey is voluntary and please skip questions, you cannot or do not want to answer. Please indicate the unit you used to answer the questions, as the given units in brackets are tentative. Furthermore, if you need additional space, please use the backside of the retrospective page and indicate the question number you are referring to.

Thank you very much for your help.
Ulrike KIRSCHNICK and Faezeh MAHICHI

## Personal discloser

1. **How old are you and what is your gender?**
   Age: ________________________[years] Gender: ________________________________

2. **In which city/village do you live?**

   ________________________________________________________________________________

3. **What is your highest educational diploma?**
   Highest educational diploma: ______________________Total schooling years:________

4. **Where did you obtain your agricultural knowledge (multiple answers possible)?**
   □ From previous generation

   □ At school

   □ At a higher education institution (e.g. university)

   □ Through self-study

   □ Other: ___________________________________________________________________

## Agricultural land and properties

1. **What is your farm size (in terms of own land and leased land)?**
Own land: _______________[ha] Leased land: ________________[ha] for ________ year(s)

**What was your farm size last year (in terms of own land and leased land) [ha]?**

Own land: _______________[ha] Leased land: ________________[ha] for ________ year(s)

2. **In which irrigation scheme is your farm located?**
□ Gotvand □ Dez □ Other:______________________________

3. **What are the closest cities and/or villages to your farm?**
____________________________________________________________________________

4. **How many people from where work on your farm generally and in what time period (including yourself)?**
**Employee 1**: _________________[position] Period:_____________ [starting month – ending month] Commuting distance to work: __________________ [km]

**Employee 2**: _________________[position] Period:_____________ [starting month – ending month] Commuting distance to work: __________________ [km]

Others: _____________________________________________________________________

5. **How do you describe the soil fertility of your agricultural land (own property as well as leased land)?**
□ Very fertile □ Fertile □ Neither □ Poor □ Very poor

6. **How far do you travel from your place of residence (home) in average to reach your agricultural land?**
□ 0-5 km □ 5-10 km □ 10-15 km □ 15-20 km □ > 20 km

## Cropping pattern and livestock

1. **What crops do you plant on what area, when do you plant them and what are annual yields?**

| **Crop Name** | **Area** | **Planting period** | | **Yield** |
|---|---|---|---|---|
| | ha | Planting month | Harvesting month | t/ha |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

2. **What kind of fertilizer (or fertilizer mix) and how much do you use annually and where does it come from? Please specify the unit. The options for the origin are:**
   1. Own production from farm (e.g. intertillage, manure from livestock, organic residues)
   2. From neighboring farm or within community (e.g. organic residues, soil improver)
   3. From within the province (e.g. organic residues, soil improver)
   4. From within the country (e.g. organic or mineral fertilizer produced in Iran)
   5. From outside the country (e.g. mineral fertilizer from other countries than Iran)

| **Crop Name** | **Name of Fertilizer** | **Amount** | **Price** | **Origin** |
|---|---|---|---|---|
| | | kg or l/ha | Toman/l or kg | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

3. **What kind of pesticides and herbicides and how much do you use annually and where does it come from? Please specify the unit. The options for the origin are:**
   1. On farm (e.g. manual removal of weed and pest, local techniques)
   2. Within community (e.g. manual removal, biological pest control, local techniques)
   3. From within the province (e.g. biological pest control, local techniques)
   4. From within the country (e.g. synthetic pesticide or herbicide produced in Iran)
   5. From outside the country (e.g. synthetic pesticide or herbicide from other countries than Iran)

| **Crop Name** | **Name of Herbicide or Pesticide** | **Amount** | **Price** | **Origin** |
|---|---|---|---|---|
| | | kg or l/ha | Toman/l or kg | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**4. What animals do you have, how many and how to you accommodate them?**

**Animal 1:** ________________________________________ **Number**: _____________________

**Accomodation**: □ All year round in the stable

□ Stable and fenced pasture regulated

□ Fenced pasture, shelter unregulated (free movement all year round)

□ Fenced pasture all year round unregulated

□ Free movement in rangeland around the farm

□ Other:______________________________________________________

**Animal 2:** ________________________________________ **Number**: _____________________

**Accomodation**: □ All year round in the stable

□ Stable and fenced pasture regulated

□ Fenced pasture, shelter unregulated (free movement all year round)

□ Fenced pasture all year round unregulated

□ Free movement in rangeland around the farm

□ Other:______________________________________________________

**Other:** ________________________________________________________________________

**5. Do you have some upgrading facilities(e.g. to dry the cereals, to make milk products, …) to sell a product of higher value?**

□ No, I don't have any facilities, I just sell the raw material.

□ Yes, I do have: _________________________________________________________________

## Water and irrigation system

**1. What is your personal annual water allowance for irrigation (within the organization of the gate community) per crop type, how much do you pay for it, and where do you extract it from? Please specify the unit. The options for the origin are:**

1. Own pumping from river/lake/well directly
2. From irrigation channel, that is shared as a gate community
3. From irrigation channel, that is not shared by a gate community
4. From main irrigation channel (channels operated by KWPA directly)
5. Other

| Crop Name | Amount | Price | Origin |
|---|---|---|---|
| | $m^3/a$ | Toman/$m^3$ or a | |

| | | | |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

**2. Despite the water allowance, do you have a rough estimation on how much water you actually use?**

□ No
□ Yes:________________________________________[$m^3$/a; % of the allocated water; …]

**3. How do you pay for your water fees?**

□ Individually to KWPA
□ Individually to Water Distribution Company
□ Indirectly, as part of a gate community
□ Indirectly, as part of a farmer cooperative
□ Other:________________________________________________________________

**4. What irrigation methods for each crop type, what technology is involved, and how often do you irrigate the retrospective crop? Please be as detailed as possible.**

**Irrigation method 1**: □ Drip irrigation
□ Sprinkler irrigation
□ Furrow irrigation (traditional trenches)
□ Flooding

**Description:**____________________________________________________[time period]

**Crops irrigated with**: ______________________________________________

**Irrigation method 2**: □ Drip irrigation
□ Sprinkler irrigation
□ Furrow irrigation (traditional trenches)
□ Flooding

**Description:**____________________________________________________[time period]

**Crops irrigated with**: ______________________________________________

**Other:**__________________________________________________________________

**5. How much electricity do you use annually, where does it originate from and how much of the total electricity consumption is approximately used for irrigation purposes?**

Amount:___________[kWh/a] Source: □ Grid □ Fossil fuel motor □ Own production

Electricity used for irrigation purposes:_______________________________________[%]

**6. Do you have a drainage system in place? If yes, please specify.**

□ No, I don't have a drainage system. Excess water just runs off.

□ Yes, I have: ___________________________________________________________________

## Cooperation and formal organization

1. **Are you part of a farmers' cooperative?**
   □ No, I am not interested
   □ No, but I would like to join one
   □ Yes
2. **If you are part of a cooperative, what is your position?**
   ___________________________________________________________________________
3. **If you are part of a cooperative, how often do you meet annually?**
   ___________________________________________________________________________
4. **Being member of a farmer cooperative does/would influence my agricultural performance positively.**
   □ Strongly agree □ Agree □ Neither □ Disagree □ Strongly disagree

## Informal knowledge transfer within the community

1. **In what way is your family involved in the farming activity? Multiple responses possible.**
   □ Workforce on the field □ Advice for decision-making
   □ Selling of agricultural goods □ Support during harvesting
   □ Support for bureaucratic processes (e.g. water allowances)
   □ Other: ________________________________________________________________
2. **Do you participate in community activities? If yes, please specify in what kind of activities.**
   □ No
   □ Yes: __________________________________________________________________
   ___________________________________________________________________________
3. **How often do you participate in these activities?**
   □ Every week □ Once a month □ Once in 2 months □ Once a year
   □ Other: ________________________________________________________________
4. **Do you discuss with other farmers about your farming activities (e.g. about what crops to plant, where to buy seeds, …)? If yes, please specify what information you exchange with farmers.**
   □ No
   □ Yes: __________________________________________________________________
   ___________________________________________________________________________
5. **How often do you exchange information about your farming activities with the other farmers of your community?**
   □ Every week □ Once a month □ Once in 2 months □ Once a year

□ Other: ______________________________________________________________

6. **Do you help other farmers or receive help from other farmers in your community?**
□ I receive help and I help other farmers.

□ I receive help from other farmers, but I don't help other farmers.

□ I help other farmers, but I don't receive help from other farmers.

□ I neither receive help from other farmers, nor do I help other farmers.

7. **Activities related to the mosque (after the prayer, on the way to the mosque, …) are important for me to communicate with other farmers.**

□ Strongly agree □ Agree □ Neither □ Disagree □ Strongly disagree

8. **Information I get at the mosque or my prayers involve agriculture.**

□ Strongly agree □ Agree □ Neither □ Disagree □ Strongly disagree

## Income diversity

1. **Having an additional source of income means I am willing to take more risks to try out new farming methods.**

□ Strongly agree □ Agree □ Neither □ Disagree □ Strongly disagree

2. **Do you have an additional source of income despite your farming activities? If yes, please specify.**
□ No

□ Yes: ______________________________________________________________

________________________________________________________________________

3. **If you have an additional source of income, do you use your income from the additional source to invest in your farming (e.g. to buy new equipment, …)? If yes, please specify what you use it for.**
□ No
□ Yes: ______________________________________________________________
________________________________________________________________________

4. **Do you receive help from governmental or non-governmental or other public authorities? If yes, please specify.**
□ No
□ Yes: □ Financial aid
□ Free material (seeds, fertilizer, pesticides, …)
□ Free water
□ Free education (e.g. advice on crop choices, fertilizer/pesticide use)
□ Other: ______________________________________________________________

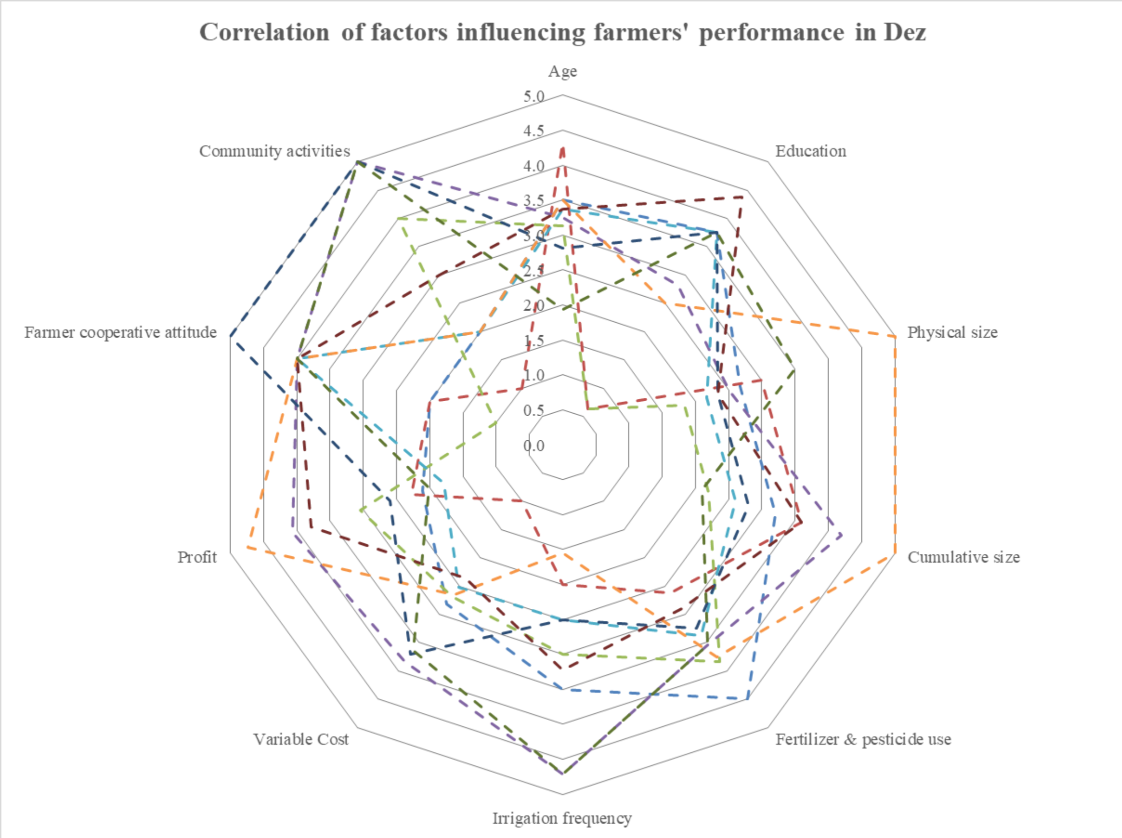
5. **Do you have a loan from a bank at the moment to invest in your agricultural activities? If yes, please specify, what you are using it for.**

□ I don't have a loan.
□ I have a loan and I am using it for:_____________________________________________

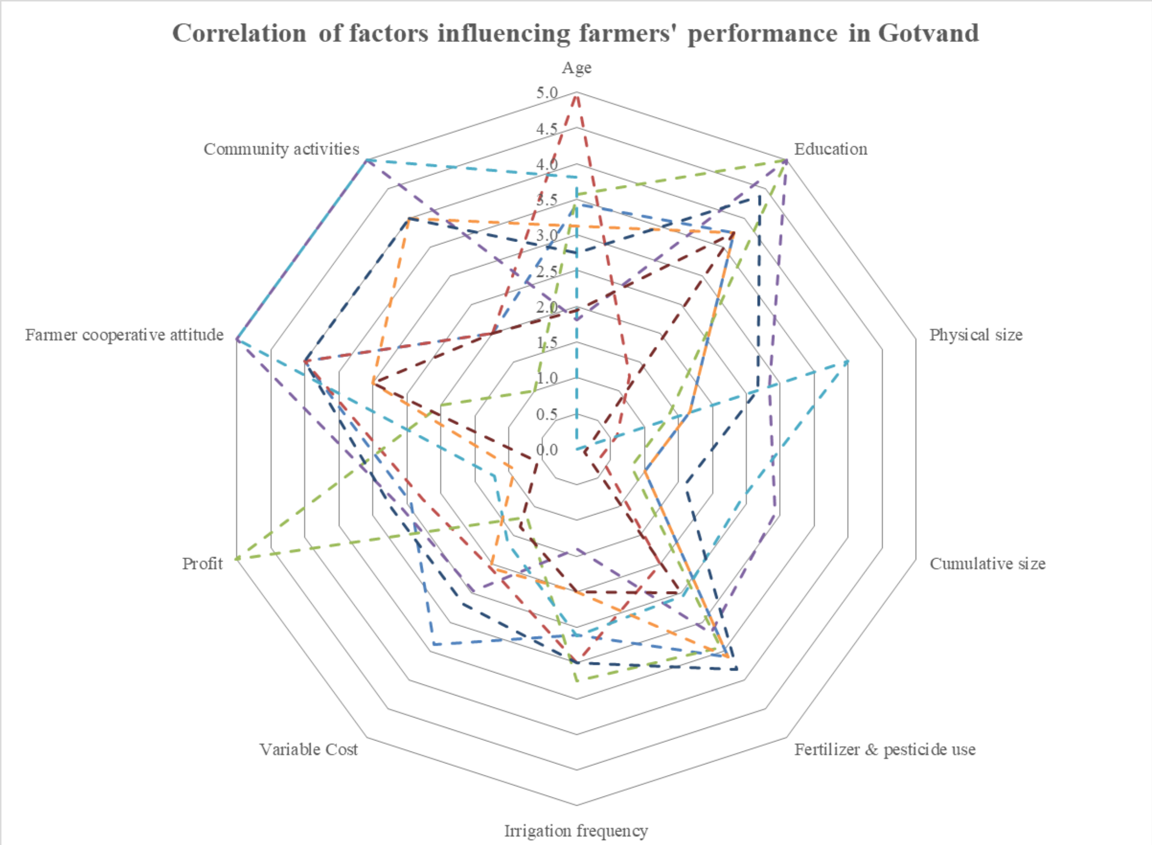
6. **If you don't have a loan from a bank at the moment are you interested in having one to invest in your agricultural activities? If yes, please specify, what you would use it for.**
□ I am not interested in having a loan.
□ I am interested in having one to use it for:_____________________________________

Thank you very much for your participation!

## Appendix 2: Spider graph evaluation of all farmers in Dez



## Appendix 3: Spider graph evaluation of all farmers in Gotvand



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