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Quality Check of Saving Water in Irrigation

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Contents

Abbreviations

BWF = Blue Water Footprint

CA = Circular Agriculture

CAP = Common Agricultural Policy

CSA = Climate-Smart Agriculture

DIM = Deficit Irrigation – Mulching

EAFRD = European Agricultural Fund for Rural Development

EEA = European Environmental Agency

EU = European Union

GAEC = Good Agricultural and Environmental Conditions

GHG = Greenhouse Gases

GWF = Green Water Footprint

GrWF = Grey Water Footprint

ILUC = Indirect Land Use Change

MAGIC = Moving Towards Adaptive Governance in Complexity: Informing Nexus Security

QST = Quantitative Story Telling

UAA = Utilised Agricultural Area

WF = Water Footprint

WFD = Water Framework Directive

WFN = Water Footprint Network

List of tables

List of figures

Summary for Policymakers

Irrigation is one of the main drivers behind a number of environmental challenges related to water. While there are many benefits associated with irrigated agriculture (most notably increased food security), across the EU irrigation is also negatively contributing to over-exploitation and degradation of precious but limited local water resources. Rates of water use for irrigation are particularly high in the dryer South, where agriculture can account for up to 90% of local water abstractions.

In the EU, irrigation practice is mainly governed by the Water Framework Directive (WFD) and the Common Agricultural Policy (CAP). Where the WFD provides a basis to ensure the long-term sustainable use of water bodies across Europe, the CAP decidedly shapes the course of agricultural practices in Europe. The CAP seeks to integrate objectives of the WFD, and both policy documents have a clear bearing on water use in agriculture. However, a comprehensive integration of the two policies has not been fully achieved and the water challenges prove persistent. The major question that still stands, therefore, is how the EU can effectively save water in irrigated agriculture?

There are many innovations that have been developed with the potential to achieve water savings in agriculture. In the first place, agricultural management practices can significantly influence both crop water use and water productivity. In the second place, smart irrigation strategies can promote reductions in the application of water in the field - without significantly lowering yields. Moreover, there are efficient irrigation techniques and technologies that facilitate crop water uptake and reduce water use. Lastly, particular socio-economic responses can support water savings in irrigation as well, by steering changes in behaviour among producers and consumers.

Effective adoption of particular water-saving innovations depends on more than their water-savings potential alone. Uptake and acceptance varies as a function of the narrative or perspective one holds on the way crops should be produced and which role irrigation ought to play therein. Given the inherent complexity of interlinked water systems and the wide spectrum of narratives that exist, a careful understanding of both is crucial or order to make informed policy choices.

Our analysis identified five overarching narratives that govern crop production in the EU. Each narrative assigns a specific role to water and irrigation, and hence promotes uptake of different water-saving innovations. Assessing the consistency between these different narratives and a number of selected innovations confirmed that the main goals and assumptions behind each narrative exert a significant influence on the uptake of a given water-saving innovation. Moreover, there are trade-offs in selection of particular innovations between the different narratives and socio-economic innovations form an important part of any innovation mix. The five narratives and their preferred broad innovation categories to save water in EU agriculture are:

1. Food Security – Irrigation is a means to meet EU food demand. Innovations that increase yield and water productivity of food crops are the focus.
2. Market Competitiveness – Irrigation is a means to increase the global competitiveness of the European agricultural market and improve the EU economy. Innovations that enhance market opportunities and maximize profit are the focus.
3. Environmental Protection – Irrigation is a primary cause of the degradation of natural resources. Innovations to reduce the use of water are preferred.
4. Circular Economy – Irrigation is a means to support a low carbon economy based on the production of biofuels. Innovations that support reduced greenhouse gas emissions and increase yield and water productivity of energy crops are the focus.
5. Technological Optimism – Irrigation is a technological challenge that may boost crop production. Innovations based on the use of technology that maximizes irrigation efficiency and crop water productivity are the focus.

Our results show that the path towards effectively saving water in EU agriculture requires both clarity on the goals sought (here framed through the lens of dominant narratives) and coherence between these goals and the innovations that support them. The broad spectrum of goals currently portrayed by the CAP and the incomplete integration with WFD objectives illustrate such clarity and coherence is still lacking in EU policy. The increased understanding through this work on viable narratives and their preferred innovations contributes towards drafting more effective EU policies that help solve the persistent environmental challenges related to water.

Technical Summary

Irrigation is one of the main drivers behind water scarcity, depletion of resources and degradation of water-dependent ecosystem. In the EU, irrigation practice is mainly governed by the Water Framework Directive (WFD) and the Common Agricultural Policy (CAP). Where the WFD provides a basis to ensure the long-term sustainable use of water bodies across Europe, the CAP decidedly shapes the course of agricultural practices in Europe. Both policy documents thus have a clear bearing on water use in agriculture, they are not operationally prescriptive. The question on how to effectively save water in irrigated agriculture in Europe is therefore still open.

Several studies have proposed a wide spectrum of innovations that can potentially serve the purpose of achieving water savings in irrigation. While individual innovations may prove effective in reducing water consumption to a certain degree, it will take a set of innovations to solve the entire problem of overuse of water. The composition of this mix of innovations, however, does not merely depend on the sum of reduction potential of its constituent parts. It also depends on the preconceived notion that the composer (either scientists or policy makers) has about the way in which crops ought to be produced and what role irrigation should play therein. The complexity of interlinked water systems and the wide array of stakeholders naturally leads to a diverging set of (normative) narratives on saving water in agriculture.

The first aim of this report is to identify the main narratives present in the actor landscape. Hereto, we first demarcated main stakeholder communities that are related to crop production. Next, we derived stakeholder's preferred views from both a literature analysis and a stakeholder engagement exercise. Our analysis identified five main narratives that govern crop production in the EU, which are labelled Food Security, Market Competitiveness, Environmental Protection, Circular Economy and Technological Optimism.

Since each narrative assigns a specific role to water and irrigation, it promotes uptake of different (sets of) water-saving innovations. The second aim, therefore, is to assess the consistency within the different narratives of the selected innovations and their feasibility, viability and desirability. Hereto, we inventoried a large number of innovations and described their potential to achieve water savings in irrigation using Quantitative Story-Telling as a method. We used various case studies and scenarios from literature and the results of a second stakeholder engagement to support the assessment. The results confirmed that the main goals and assumptions behind each narrative exert a significant influence on the uptake of a given water-saving innovation. Moreover, it was found that there are trade-offs in selection of particular innovations between the different narratives and that socio-economic innovations form an important part of any innovation mix. The preferred broad innovation categories to save water in EU agriculture for each of the five narratives are:

1. Food Security – Irrigation is a means to meet EU food demand. Innovations that increase yield and water productivity of food crops are the focus.
2. Market Competitiveness – Irrigation is a means to increase the global competitiveness of the European agricultural market and improve the EU economy. Innovations that enhance market opportunities and maximize profit are the focus.
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1 Introduction

Freshwater scarcity is a major global concern and irrigation is a key piece of the puzzle. Irrigation is crucial in dry climates where precipitation is regularly insufficient for plant growth, and it is typically required to maintain crop productivity during dry periods elsewhere. Irrigated agriculture plays a fundamental role in the provision of food worldwide, generation of renewable energy, and economic development (FAO, 2017; Mekonnen & Hoekstra, 2011b; Morison et al., 2008). Simultaneously, irrigation is also one of the key drivers behind the depletion of freshwater resources, contributing to water scarcity (Eurostat, 2019d).

The European Commission defines water scarcity as a “recurrent imbalance that arises from overusing water resources, led by consumption being significantly higher than the natural renewable availability” (Eurostat, 2019d). Agriculture is the largest consumer of freshwater resources globally, most of which is used to produce crops (Hoekstra & Mekonnen, 2012). The sector accounts for approximately 70% of total freshwater withdrawals and 92% of water consumption (FAO, 2017; Hoekstra et al., 2012; Morison et al., 2008). This fact is of particular interest given the current contexts of climate change, rising population and increased economic development, all of which intensify the competition over limited water resources (FAO, 2003a).

In the European Union (EU) context, the challenges posed by water scarcity and the role that irrigated agriculture plays therein, underscore the urgent need to save water in irrigation. High rates of water use for irrigation in the south, where agriculture can account for up to 90% of total water abstractions, contribute to an on-going over-exploitation of the local water resources (Eurostat, 2019d). The need for a more sustainable approach towards the use of water for agriculture in the EU presents itself with the following simple question: How can water be saved in irrigation? While the question may be simple, the answer is certainly ambiguous at best. This is due in part because the answer depends on the narrative one holds on to about the way in which crops ought to be produced and what role irrigation should play therein (Section 1.1). Also, there are many complex interlinkages between water and other domains that need to be unearthed - the so-called nexus thinking (Section 1.2).

1.1 Innovations and Narratives on Water-Saving Agriculture

There is a large variety of innovations that have a bearing on saving water in agriculture. One category of innovations that hold great potential is that of more efficient irrigation strategies, techniques and technologies (Berman et al., 2012; Chukalla et al., 2015; European Parliament Research Service, 2016; Nouri et al., 2019). Moreover, other innovations can complement the use of technological innovations, or even make these redundant. Examples include agricultural management practices such as mulching or tillage, which can reduce the use of water and boost crop yield hence resulting in water savings if properly regulated (Chukalla et al., 2015; Hoekstra, 2020; Mekonnen & Hoekstra, 2011b; Zane, 2015). Socio-economic responses and policy instruments may also exert a positive influence on the use of water (Berman et al., 2012; Hoekstra, 2020).

In many cases, the different innovations have the most substantial water-saving potential if they are deployed in combination rather than stand-alone (Chukalla et al., 2015; Nouri et al., 2019). The particular perspective one holds on crop production (and the role of irrigation therein) prescribes to a large extent which (sets of) innovations are preferred to achieve water savings. It is therefore essential to identify the main or dominant narratives on crop production that exist, and draft consistent sets of water-saving innovations that are congruent with these respective narratives.

Discussions in both science and policy regarding crop production are diverse and divergent. There are many different stories to tell, and each one approaches water savings in different ways. Crop production is perceived as a channel to achieve food security (FAO, 2003a), competitiveness in the global market (FAO, 2003b), and renewable energy generation (European Commission, 2019b), among others. Furthermore, crop production can both impact and be impacted by the environment (FAO, 2017; Mann, 2018; Mekonnen & Hoekstra, 2011b). The perspective taken dictates the role of water and hence how to save water in irrigation. For example, from a food security perspective, the use of resources (e.g., water) and measures to boost yield are the focus. Following this narrative, water savings are approached through increased water productivity. Conversely, from an environmental standpoint, water is a resource that should be protected. This perspective implies that water savings should ideally be approached through reduced water consumption in agricultural areas (Mann, 2018). Different narratives hence foster certain innovations over others, which they substantiate by their own goals and assumptions. Each perspective or narrative offers different prospects for water savings in irrigation and moreover has different implications for water and its interconnected domains.

1.2 Towards Nexus Thinking

Water is inextricably linked to other domains, including biodiversity and conservation, food, and energy. Actions regarding the use of water are often related to different impacts in other areas, both negatively and positively. Innovations that target water savings in irrigation are no different, as they may trigger a spillover or cascade effect in other domains.

Willaarts et al. (2020), for example, showed for Spain how the modernization of the irrigation systems in Spain prompted a reduction not only in the water footprint but also in the energy and carbon footprints, creating a positive impact across different dimensions similar to the results obtained by Krol (2019) for the Segura Basin in Spain. Even so, improvements in the irrigation efficiency were found to result in increased production, commonly known as the Jevons' paradox, offsetting the initial environmental benefits (Sears et al., 2018). Another example corresponds to the use of fertilizers, which can increase crop yield and therewith crop productivity. If the potential production growth is handled wisely, the use of fertilizer may result not only in water savings, but also in increased land productivity. It can thus help achieve lower water and land footprints simultaneously (Eurostat, 2019c). However, an increase in the use of fertilizers is also often associated with soil and water pollution as it can lead to higher concentration levels of nitrogen and phosphorus on the soil and water bodies (Eurostat, 2019e). Furthermore, the production of fertilisers accounts for 1.2% of the total use of energy worldwide (International Fertilizer Association, 2014) and thus represents a significant source of GHG emissions. It goes to show negative trade-offs between domains can be expected as well.

The complex interactions related to water for irrigation call for an integrated approach where different aspects of the relevant domains are brought together (Hoff, 2011). In the context of policymaking, adopting nexus thinking is imperative too. The positioning of certain innovations to save water in irrigation may not be plausible in a broader context. In the face of climate change and growing populations, the use of water for irrigation is one among many environmental challenges. Neglecting possible trade-offs among different areas may reduce or reverse the success of the implemented strategies and will be reflected in the form of significant environmental and socio-economic issues. On the other hand, overlooking possible synergies is a wasted of opportunity. Given both the inherent complexity behind the interlinked domains relevant to achieving water savings in irrigation and the variety of narratives that shape how to approach them, an in-depth understanding of both bordering domains and narratives is crucial.

1.3 The Focus of the Report

The main goal of this study is to assess the consistency of a number of innovations that influence water savings in irrigation with various narrative in which they are embedded, withing the context of the EU agricultural sector. Hereto, we first identify the dominant narratives influencing crop production in the EU and describe what each one entails for water savings in irrigation (Phase 1, Section 2), Second, in phase 2 (Section 3), we perform a quality check on the narratives by assessing the coherence between the the goals that they pursue and the way in which they operationalise these goals in terms of employing (sets of) water saving innovations.

The following research questions guide our efforts:

- What are the most prominent innovations to achieve water savings in irrigation, and what do they entail considering a nexus approach?
- What different narratives, with their related assumptions, drivers and goals predominantly govern crop production in the EU?
- What are the potential implications of the different narratives for water savings?
- Are the water savings in irrigation for the different narratives consistent in terms of feasibility, viability and desirability considering a nexus approach?

1.4 Quantitative Story-Telling

We employ Quantitative Story-Telling (QST) as on of the methodological underpinnings for this study. QST is used to improve the understanding of the operation of a complex system and its current and future constraints. In this report, it is used to inquire into the quality and the robustness of the narratives and innovations that govern the system at hand. QST here is employed to provide a quality check on different innovations that influence water savings in irrigation in the EU regarding the narrative in which they are embedded in terms of feasibility, viability, and desirability. To do so, we describe the metabolic patterns of the system in terms of funds and flows. One the one hand, funds are elements that remain fixed across the analysis (e.g. land, capital, water bodies, humans, etc.). On the other hand, flow elements change over time (e.g. food, water, energy, etc.) (Giampietro et al., 2013). For more information about the methodology of this report in genral and QST in particular, please consult Section 5.

2 Phase 1

In Phase 1, we identify five dominant narratives that shape the course of crop production in the EU and describe what each one entails for water savings. First, we provide some background information on irrigation, crop production and water savings, followed by an inventory of a large number of innovations that have the potential to achieve water savings in irrigation. We then proceed to identify and develop five main overarching narratives that govern crop production in the EU, with a clear link to the water savings innovations that each narrative fosters and which is supported by the narrative's goals and assumptions. To do so, we demarcated the main stakeholder communities that are related to crop production, as derived from an exercise on stakeholder engagement. Subsequently, we performed a literature analysis of the documents that best represent the different views. For more information regarding the methods and materials of Phase 1, please refer to Section 5.1.

2.1 A Glimpse into Irrigation and Crop Production

Crop production, rather than agriculture as a whole, accounts for most of the freshwater consumption (FAO, 2011; Hoekstra & Mekonnen, 2012; Morison et al., 2008) since most of the water consumption attributed to livestock originates from the production of feed for the cattle (Gerbens-Leenes et al., 2013; Hoekstra, 2020; Morison et al., 2008).

Irrigation has as objective to secure optimum yields by supplying plants with sufficient water. In dry climates it, where precipitation is rather scarce, it is essential to foster plant growth as it is the only source of water for crops (e.g. some Mediterranean areas). In semi-arid and sub-humid climates, its is supplementary to rain-fed agriculture as it is necessary to maintain high productivities due to its capacity to bridge the water gap in dry season periods and drought spells (Eurostat, 2019d). However, the use of water for irrigation is often unsustainable as, in some places, the demand for water exceeds the amount available during a defined period (Eurostat, 2019d; Krol, 2019). In the EU, the Joint Research Centre (JRC) and the European Environmental Agency (EEA), measure water use trough the water extraction index WEI+, where a value of 40% of extractions indicate unsustainability in the use of water (Krol, 2019).

The demand for water in irrigation varies in function of the crop water requirement. The CWR, which can be fulfilled by rainfall and/or irrigation, refers to the total amount of water required for evapotranspiration (i.e. evaporation from the soil surface and the transpiration from plants) under optimum growth conditions (Wriedt et al., 2008); and, to a relative small percentage, to the water embedded in the plant (Mekonnen & Hoekstra, 2011b). The CWR varies widely from crop to crop and is sensitive to factors such as climate, soil characteristics, and different agricultural management practices (Berman et al., 2012; Chukalla et al., 2015; FAO, 2003a; Hoekstra, 2020; Nouri et al., 2019). The water in the field is stored in the soil where water stocks to satisfy the CWR that originates from rainfall are labelled as 'green water' whereas water stocks that do it from natural water bodies (i.e. groundwater and surface water) and are applied through irrigation, as 'blue water' (Hoekstra, 2019).

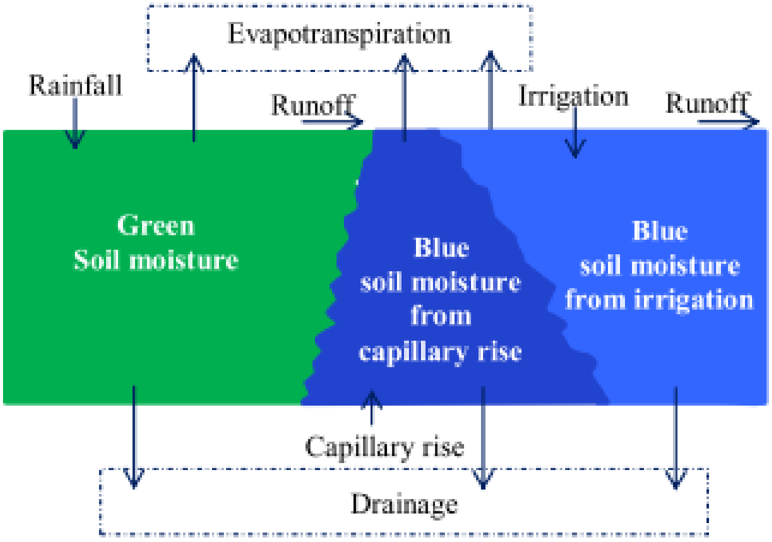

Figure 1. Incoming and outgoing fluxes of the green and blue soil water stocks. Source: Chukalla et al. (2015).

The irrigation water demand thus corresponds to the amount of blue water applied to serve the CWR, or, in other words, the amount of water required that is not provided by rainfall (Wriedt et al., 2008). Figure 1 explicitly illustrates the blue and green water fluxes for crop production. Note that for the purpose of this report, the blue water that originates from capillary rise is not explicitly addressed, although it reduces irrigation water demand in places where the crop can benefit from the presence of shallow groundwater through capillary uptake.

When we think about water savings in irrigation, a noteworthy remark lies in the fact that irrigation water demand refers to water required for crop consumption and not to water abstracted. Water abstracted indicates the total volumes taken from natural water bodies which may in part be returned through surface run-off and groundwater recharge (Hoekstra, 2020). In agriculture, it is estimated that around 40% of the water extracted returns to local water bodies (Hoekstra et al., 2012; Morison et al., 2008). Excesses on water applications on the field along with non-recoverable losses at the system level through water storage and conveyance thus may explain the difference between water abstractions and the actual irrigation water use (Berman et al., 2012; Chukalla et al., 2015; Morison et al., 2008). Figure 2 schematizes the process of irrigation from extraction to water application on the field. Innovations to reduce the use of water in irrigation should then focus on reducing non-recoverable system losses or on the consumption of water in the field.

System losses, before application of water in the field, occur due to evaporation and leakages on storage reservoirs and distribution canals (Berman et al., 2012; Chukalla et al., 2015; Eurostat, 2018a; Hogeboom et al., 2018; Morison et al., 2008). Globally, these losses are estimated at 30% (Morison et al., 2008). Water savings in irrigation hence can be achieved, for example, by improving the efficiency and maintenance of the storage and the conveyance. Table 1 presents different innovations to save water through irrigation storage and conveyance. Even though the potential to save water off-field at the system level cannot be neglected, the focus of this document revolves around innovations that target the consumption of water at the field. Such innovations will be addressed in Section 2.3.

Table 1. Innovations to reduce system losses. Based on Berman, Jana, et al. (2012).

Water losses	Innovations
Storage	Covers
	Monolayers
	Wind breaks
Conveyance	Canal lining
	Low pressure piping systems
	Water measure
	System maintenance

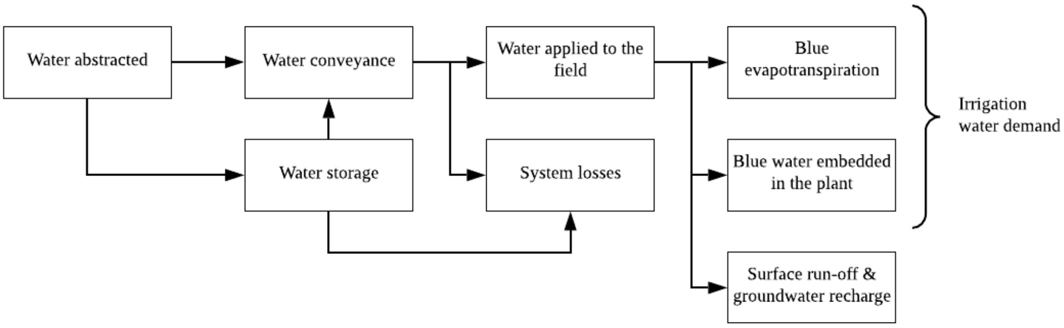

Figure 2. A schematic representation of the use of water for irrigation.

2.2 The Water Footprint Concept

The water footprint (WF) measures the water that is consumed for a particular purpose, and it is, therefore, a suitable concept in discussions on saving water and reducing water scarcity. The WF concept indicates the direct and indirect appropriation of water resources and is expressed as a water flow – flow/fund ratio. For example, it can measure the volume of water needed per unit of good (e.g. kg or kcal) produced (flow), or per hectare of land used (fund). The WF composed of three parts: the blue (BWF), green (GWF) and grey (GrWF) water footprints (Mekonnen & Hoekstra, 2011b).

The BWF (surface- and groundwater) and GWF (rainwater) credit the consumption of water required for production while the GrWF accounts for the volume of water required to assimilate the pollution derived from the production process. The inclusion of water pollution as a driver for water scarcity is justified since it increases the competition for freshwater (Mekonnen & Hoekstra, 2011b). For irrigation, the focus lies in the BWF; nevertheless, changes in the GWF can also exert an influence in the BWF (Chukalla et al., 2015; Mekonnen & Hoekstra, 2011b).

2.3 Dimensions of Water Savings

To better understand water savings and how to achieve them, we highlight three different dimensions of water savings, following Hoekstra (2020), namely, production, trade and consumption. The nexus originated by irrigated agriculture in Europe requires solutions from all dimensions as it is expected that irrigation will continue to fulfil all of its functions while still sustainably managing Europe's freshwater resources (see Section 2.7 for more information about the different narratives assigned to irrigated crop production). The different water-savings dimensions will be described in the following sub-sections.

2.3.1 Production

The production dimension focuses on the supply side. For crop production, it considers the intensity of application of inputs. Water-wise, it encompasses how water is applied to crops and its consequent impact on production. Three main pathways govern crop production and have shaped it across the years (Mann, 2018): intensification, sustainable intensification, and extensification (Eurostat, 2019c; Garnett et al., 2012).

Intensification refers to an increase in agricultural inputs (e.g. water, fertilisers, pesticides, and similar) to increase production. This vision prioritizes higher productions above all and assumes that there are no limits in the provision of inputs to reach higher crop yields. In Europe, intensification has been driven in the past by factors such as the decline of agricultural labour after the WWII, which stimulated technological development; and the need for economic gains achieved through improved productivity (Eurostat, 2019c). However, the increased crop productivity generated by the indiscriminate use of agricultural inputs comes at the cost of the environment and sparks serious sustainability concerns (Eurostat, 2019c; Garnett et al., 2012; Mahon et al., 2017; Schiefer et al., 2016). Intensification can be expressed as increased input flows per hectare to produce a higher crop output flow per hectare. For example, for <water, m^3 / ha = <tons/ ha. In WF terms it can be expressed as higher WF to produce higher yields (kg).

Sustainable intensification, albeit located on the same spectrum as intensification, undertakes limits and addresses sustainability concerns. High production levels are still pursued, but the main difference lies in the acknowledgement that the application of inputs must be selective, which demands the careful analysis of trade-offs and their unavoidable consequences. Sustainable intensification seeks an increase in production per unit of input to reduce environmental impacts. For water, it follows a 'more crop per drop' vision (Vos et al., 2019), or, in other words, increased water productivity. Environmental performance is a relatively new concern, which developed to become a critical driver behind this path. Sustainable intensification recognizes that agriculture is reliant on the natural resources on which it depends (Eurostat, 2019c). However, it has been subjected to scrutiny because of its lack of a more holistic approach; it favours productivity over other dimensions (Garnett et al., 2012; Mahon et al., 2017). Furthermore, sustainable intensification may fall victim of the Jevons' paradox, also known as the rebound effect. The Jevons' paradox states that efficiency improvements tend to increase production, which counteracts the initial environmental gains (Dumont et al., 2013; Hoekstra, 2020; Sears et al., 2018). It is important to keep in mind that, increased production is not per se a problem as long as it stays within the sustainable limits. For water, we commonly look at environmental flow ratios to define such limits (Krol et al., 2018). Sustainable intensification can be expressed as a minimised flow of agricultural inputs per maximized flow of crop output per hectare. For example, in the case of water, > m^3 / <tons / ha. In terms of WF, it can be expressed as the inverse of the WF, or high-water productivity, increasing yield to reduce water consumption per unit of area.

Extensification embraces a retrofitted way to address production which prioritizes the environment above production. It targets a reduction in the application of inputs to reduce environmental impacts, which, similarly to sustainable intensification, calls for the proper handling of trade-offs and their potential outcomes. For water, this revolves around a 'less drop per crop' vision (Vos et al., 2019). However, such focus often comes at the cost of production, which may bring undesirable consequences. Examples of such correspond to, for example, decreased competitiveness and reduced food security. Else, an expansion of production areas into zones currently used otherwise, and that may include forests or high-value ecosystems, may take place (Eurostat, 2019c; Hoekstra, 2020; Van Grinsven et al., 2015). Extensification can be described as a reduced flow of inputs per hectare. For example, in the case of water, > m^3 / ha. In terms of WF, it can be expressed as low WF per unit of area.

2.3.2 Trade (Geographic)

The trade dimension focuses on the international traffic of crop products, where water is traded in virtual form. The danger of focusing solely on the production dimension is that we may end up producing the wrong crops in the most efficient manner. Several local and global studies have shown that significant water savings can be achieved, maintaining current production levels if crops would be produced in different places than they are at the moment (Davis et al., 2017). This dimension suggests a re-distribution of crop products from a water point of view as an opportunity to release the pressures imposed on the water bodies (Hoekstra, 2020; Vos et al., 2019).

The water footprint of different products varies across different regions (Mekonnen & Hoekstra, 2014). These differences may be explained by natural variables such as climate and by human variables such as crop efficiency (productivity). Hence, the import of water-intensive crops from places with higher water efficiency may result in water savings. Trade offers water-scarce regions the opportunity to acquire water in the form of crop products from elsewhere. Ironically, highly water productive crops are often exported from water-scarce regions to other regions, often more water abundant (Hoekstra, 2020; Mekonnen & Hoekstra, 2011b; Vos et al., 2019). Virtual water transfers externalise the indirect impacts of consumption on other countries. In other words, the externalization of crops, and the resources utilised for their production, inflicts pressures on the freshwater resources on other regions (Chapagain, Hoekstra, & Savenije, 2006; Hoekstra, 2020; Vos et al., 2019).

Water-saving trade calls for the correct allocation of crop production based on geographic convenience and their water productivity. On one hand, trade may reduce water consumption when seasonality is considered, and when it endorses crop products specialisation in those regions where they are the most water productive (European Commission, 2019d). In the other hand, Hoekstra & Mekonnen (2016) propose a trend opposite to specialisation, diversifying the import of water-intensive commodities. In such way, the environmental impacts attributed to the production of a certain crop will be distributed on a larger spatial area instead of concentrated in a specific region. Sustainability comes when trade reconsiders water-intensive crop imports that originate in severely water-scarce regions (Hoekstra & Mekonnen, 2016).

Trade focused on water savings requires international collaboration on sustainable water use (Hoekstra & Mekonnen, 2016) in line with the fourth target of the Sustainable Development Goals (SDGs) on water, which is: to ‘substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity´ (Hoekstra & Mekonnen, 2016). Even so, it remains a fundamental challenge which ought to consider aspects such as the spatial scale of the potential water savings, the production efficiency, and the potential trade-offs that may exist (Hoekstra, 2020).

2.3.3 Consumption

A consumption dimension looks at the demand side, focusing on consumption patterns. It leaves the food supply behind and targets the consumers with the aim to reduce water consumption. There are two main strategies employed to reduce the water footprint considering a consumption dimension: dietary changes and reductions on food waste.

Dietary changes refer to changes towards less water-intensive diets (i.e. vegan and vegetarian diets). Diets with low or no-meat intake decrease the water footprint attributed to food consumption because the production of animal products is associated with significant water footprints (Hoekstra, 2020; D. Vanham, Hoekstra, et al., 2013; D. Vanham, Mekonnen, et al., 2013).

Reducing food waste can decrease the water footprint of consumption which is justified by a drop in the food demand. It is estimated that 40% of the world’s food ends up as waste (FAO, 2003a, 2009). This percentage accounts for 24% of the freshwater resources consumed in crop production (Hoekstra, 2020). Furthermore, reducing losses may also have other environmental benefits such as a reduction in GHGs emissions, energy conservation, soil conservation, and reduced agricultural land expansion (Kummu et al., 2012). Table 2 categorizes and defines the different types of losses along the food supply chain and proposes interventions to minimise them according to Kummu et al. (2012). Food supply-chain losses are higher in regions governed by intensification and large per capita food supply (Kummu et al., 2012). Acting upon them may drastically reduce demand and, therefore, water consumption.

Table 2. Definitions of food losses/waste and potential interventions. Adapted from Kummu et al. (2012).

Type of loss	Definition	Possible interventions in industrialized countries
Agricultural	Losses due to mechanical damage and/or spillage during harvest operation, crop sorting etc.	Cooperation among farmers could reduce risk of overproduction that often leads to these losses.
Postharvest	Losses due to storage and transportation between farm and distribution, and spillage and degradation during handling.	Improved on-farm facilities.
Processing	Losses during industrial or domestic processing.	Develop a market for 'sub-standard' products that are eatable; enhanced production lines.
Distribution	Losses and waste in the market system, including wholesale markets, supermarkets, retailers, and wet markets.	Lower standards for size, weight, etc.
Consumption	Includes all the losses and waste at the household level.	Public awareness, smaller packages, better planning in restaurants and households

The main strategies hereby defined specifically look at food crops. However, the consumption of non-food agricultural crops such as cotton for textiles, or energy crops for biofuels is also important. For example, cotton is responsible for 2.6% of the global water consumption and approximately 84% of the EU water footprint of cotton consumption is externalized (Chapagain, Hoekstra, Savenije, et al., 2006). Given that the production of cotton is minimal in the EU, it would make sense to look at it from the consumption dimension. Socio-economic responses such as consumer product policies, product transparency and water pricing are examples of innovations targeted to influence consumption that may exert an influence in the consumption of both non-food and food crop products (Chapagain, Hoekstra, Savenije, et al., 2006; Ercin et al., 2013; Hoekstra, 2020). More information about such type of innovations can be found in Section 2.4. For the case of biofuels, more information can be found later in the document in Section 2.7.4.

2.4 How to Achieve Water Savings: Water Footprint Reduction Measures

If current blue WFs worldwide are reduced to benchmark levels associated with the best-25th percentile of production, global average blue water savings are 31% compared to the reference consumption, of which 89% can be achieved in water-scarce areas. Policy measures encouraging producers to meet WF benchmarks would thus boost the transition towards sustainable use of freshwater globally (Hogeboom et al., forthcoming).

Many studies have calculated the BWF of crop production and have proposed reduction measures (Chukalla et al., 2015; Gerbens-Leenes et al., 2009a; Hoekstra, 2019, 2020; Hoekstra et al., 2011; Mekonnen & Hoekstra, 2011a, 2014). WF in this context is defined as the crop water use divided by the yield (Hoekstra, 2020). Water savings can be accomplished by either or both increasing the yield or reducing crop water use (Chukalla et al., 2015; Hoekstra, 2020).

Decreasing the crop water use can be done via a reduction in the non-productive water uses at the field level. These can be diminished by reducing the field evapotranspiration (m^3 of water) per unit of crop (kg), which ratio is the WF (Hoekstra et al., 2011). In other words, it targets a reduction of the evaporation from the soil surface that is wetted during irrigation and the transpiration from the plants that does not benefit plant growth. Savings can also be achieved by increasing yield (kg) per evapotranspiration (m^3 of water), which ratio is known as water productivity (Chukalla et al., 2015).

Water savings in irrigation have been accomplished when the BWF associated with crop products has been reduced; or the water productivity, increased. There is a large variety of innovations out there that can reduce the WF or increase water productivity. Here, we group them in four categories: (1) agricultural management practices, (2) irrigation strategies, (3) irrigation techniques and technology, and (4) socio-economic responses.

Certain agricultural management innovations can reduce soil evaporation losses (e.g. mulching) and limit non-productive transpiration (e.g. tillage). The implementation of such innovations alters evapotranspiration, which can be beneficial for the WF. Water-saving irrigation strategies innovations target a reduction in the productive transpiration (Berman et al., 2012) focusing on the timing and quantity of the irrigation (Chukalla et al., 2015). These strategies comprise the application of slightly lower quantities of water to the crops, under the CWR (Berman et al., 2012; Chukalla et al., 2015; Karandish, 2016; Morison et al., 2008). Irrigation techniques and technologies encompass the way in which water is applied to the crops in terms of the location of the water application and the wetted area (Chukalla et al., 2015). The implementation of such innovations can reduce soil evaporation and wind losses, and facilitate crop water uptake (Berman et al., 2012). Within this category, precision irrigation technology is also comprised as it allows farmers to monitor the state and needs of the crop in live time (Smith et al., 2010). Lastly, socio-economic responses innovations aim to change practices through the utilisation of soft measures (Arcadis, 2012; Berman et al., 2012; European Commission, 2012). These innovations indirectly target water-savings through the producers and consumers behaviours (Berman et al., 2012). For example, supporting the growth of water productive crops may result in water-savings because their CWR is lower. Crop type plays a significant role in the BWF since the water requirements vary from plant to plant (FAO, 2014)[1].

Different types of water-savings innovations are employed simultaneously in practice and the characteristics of the different locations largely influence the selection of different innovations. Actions to increase productivity, for example, are frequently employed in water-scarce countries in response to the limited water resources (Hoekstra, 2020). In the water-scarce Mediterranean, yield increases had been attained through crop enhancements (drought-resistant crops) and better agricultural management practices (Morison et al., 2008). Arid and semi-arid climates are associated with larger BWFs than humid and sub-humid climates (Chukalla et al., 2015) which appears to be a key driving force behind improved agricultural productivity (Hoekstra, 2020).

Table 3 presents different innovations, their potential for water savings, and what may constrain them. A more detailed description of each innovation, how they support water savings, and important nexus considerations can be found in ANNEX I. It is worthy to keep in mind that while these innovations can achieve water savings, the potential to do so varies greatly, both in particular and combined. For example, on average, drip sub-surface irrigation and deficit irrigation are associated with the most considerable reductions on the BWF (Chukalla et al., 2015). However, a combination of the innovations thereof along with the practice of mulching is associated with even larger reductions, especially if the mulches are of synthetic origin (Chukalla et al., 2015). Figure 3 displays the potential reduction on the water footprint that Chukalla et al. (2015) calculated for different combinations of innovations.

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[1] *For detailed information regarding the blue water requirements per different types of crops see Hoekstra (2013) and Mekonnen & Hoekstra (2011) or visit the Water Footprint Network Website https://waterfootprint.org/en/*

Table 3. Innovations to achieve water savings

Innovation category	Innovations	Water savings potential	Influence to BWF or WP (direct or indirect)	Constraints	Source
Agricultural management practices	Mulching	Mulches reduce non-productive evaporation. Also, they can improve yield when they contain high nitrogen levels.	Lower ET per of yield	Plastic mulches may pollute the soil as they do not degrade.	(Berman et al., 2012; Chukalla et al., 2015; Liu et al., 2014; Morison et al., 2008; Zane, 2015)
	Tillage	Soil tillage reduces the coverage of weeds and thus reduces non-productive transpiration. Low tillage improves water retention and reduces non-productive evaporations.	Lower ET per unit of yield	Tillage is also associated with an increase in evaporation because it brings wet soil to the surface.	(Berman et al., 2012; FAO, 2011; Morison et al., 2008; Nouri et al., 2019)
	Zero tillage	Reduces non-productive evaporation by maintaining soil moisture.	Lower ET per unit of yield	No-tillage may increase non-productive transpiration if weeds are not eliminated.	(Berman et al., 2012)
	Application of fertiliser	The use of fertilisers significantly increases yield; therefore, water productivity.	Higher yield per unit of ET	Residual nitrogen and phosphorus contribute to water and soil pollution. Also, the application and production of mineral nitrogen fertilisers is associated with GHG emissions and accounts for 1.2% of the total energy consumed.	(Eurostat, 2019e; Fertilizers Europe, 2019; International Fertilizer Association, 2014; Mekonnen & Hoekstra, 2011a)
	Application of pesticides	The use of pesticides prevents losses reductions and thus increases yield. Herbicides reduce the competition for water from weeds and thus non-productive transpiration.	Higher yield per unit of ET and lower ET per unit of yield	Pesticides can impact soil and water quality and biodiversity.	(Berman et al., 2012; Eurostat, 2019b; Morison et al., 2008)
	Intercropping	It supports higher yields and so water productivity.	Higher yield per unit of ET	-	(Lithourgidis et al., 2011)
	Crop diversification	Crop diversification enhances soil properties which increase yield and reduces evapotranspiration.	Higher yield per unit of ET and lower ET per unit of yield	Its use requires a careful analysis of the crops to grow since some may degrade the state of the soil.	(European Commission, 2019h)

	Crop rotation	It may improve soil fertility and so water productivity.	Higher yield per unit of ET	Its use requires a careful analysis of the crops to grow since some may degrade the state of the soil.	(Eurostat, 2019b; Nouri et al., 2019)
Irrigation strategies	Partial root-zone drying	It reduces water use without significant reductions in the crop yield.	Lower ET per unit of yield	Unpredictable rain can interrupt drying cycles. Also, localised irrigation such as the one provided by trickle systems is more suited for the implementation of this measure.	(Berman et al., 2012; Karandish, 2016; Morison et al., 2008)
	Deficit irrigation	Reduces water use by applying slightly less water than the water requirement.	Lower ET per unit of yield	Requires careful water management, otherwise, it can result in dramatic yield reduction.	(Berman et al., 2012; Chukalla et al., 2015; Morison et al., 2008)
Irrigation techniques and technology [2]	Surface drip irrigation	Reduces evaporation by allocating water next to the plant.	Lower ET per unit of yield	Requires high levels of management. Also, it is associated with a higher cost of installation and management.	(Berman et al., 2012; Chukalla et al., 2015; Nouri et al., 2019)
	Sub-surface drip irrigation	Eliminates surface water evaporation.	Lower ET per unit of yield	Requires high levels of management. Also, it is associated with a higher cost of installation and management.	(Berman et al., 2012; Chukalla et al., 2015; Nouri et al., 2019)
	Micro-sprinklers	They reduce non-productive evaporation by delivering water very near the plant.	Lower ET per unit of yield	Requires high levels of management. Also, it is associated with a higher cost of installation and management.	(Berman et al., 2012)
	Precision irrigation	Tools that provide real-time information on the input requirements of the crops.	Higher yield per unit of ET and lower ET per unit of yield	Requires high levels of management. Also, it is associated with a higher cost of installation and management.	(European Parliament Research Service, 2016; Smith et al., 2010; University of Wageningen, 2019)
Socio-economic responses	Water pricing	It incentivises the efficient use of water resources	Higher yield per unit of ET and lower ET per unit of yield	Setting the right price, and equity and monitoring issues.	(Arcadis, 2015; Berbel et al., 2004; Berman et al., 2012;

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[2] *For alternative sources of water, which can also achieved blue water savings in irrigation, refer to (Cabello Villarejo et al., 2020).*

					Hoekstra, 2020)
	Trade	Sustainable allocation/redistribution of crops	Higher yield per unit of ET and lower ET per unit of yield	Import tariffs, market disruptions and threatens local production. Also, it implies transportation and so GHG emissions.	(European Commission, 2019i; Hoekstra, 2020)
	Water regulation and allocation	Organises water use and abstractions among users.	Higher yield per unit of ET and lower ET per unit of yield	Setting the right regulations to restrict the use of water. Organising the use of water among the different users. Also, it requires adjacent measures like a change of cropping patterns or improved crop varieties.	(Berman et al., 2012; Hoekstra, 2020)
	Water auditing and benchmarking	Measurement of water use.	Higher yield per unit of ET and lower ET per unit of yield	High costs for auditing and ambiguous benchmarks.	(Berman et al., 2012; Hoekstra, 2020)
	Market pressure	Traceability and labelling of products.	Higher yield per unit of ET and lower ET per unit of yield	It implies changes in human behaviour, which are not easily nor rapidly attained.	(Berman et al., 2012; Hoekstra, 2020)
	Raise awareness	Raising awareness of the amount of water used and the related impacts.	Higher yield per unit of ET and lower ET per unit of yield	Learning time.	(Berman et al., 2012; Hoekstra, 2020)
	High water productivity crops selection	Certain crop types have lower water footprints than others, and some crops have shorter growing seasons. Also, GMO's provide crops with high yield characteristics and resistance to extreme climates.	Higher yield per unit of ET and lower ET per unit of yield	Active support of agricultural policies required. Increased research to facilitate crop selection. Financial support and market regulation.	(Berman et al., 2012; Mann, 2018; Morison et al., 2008)

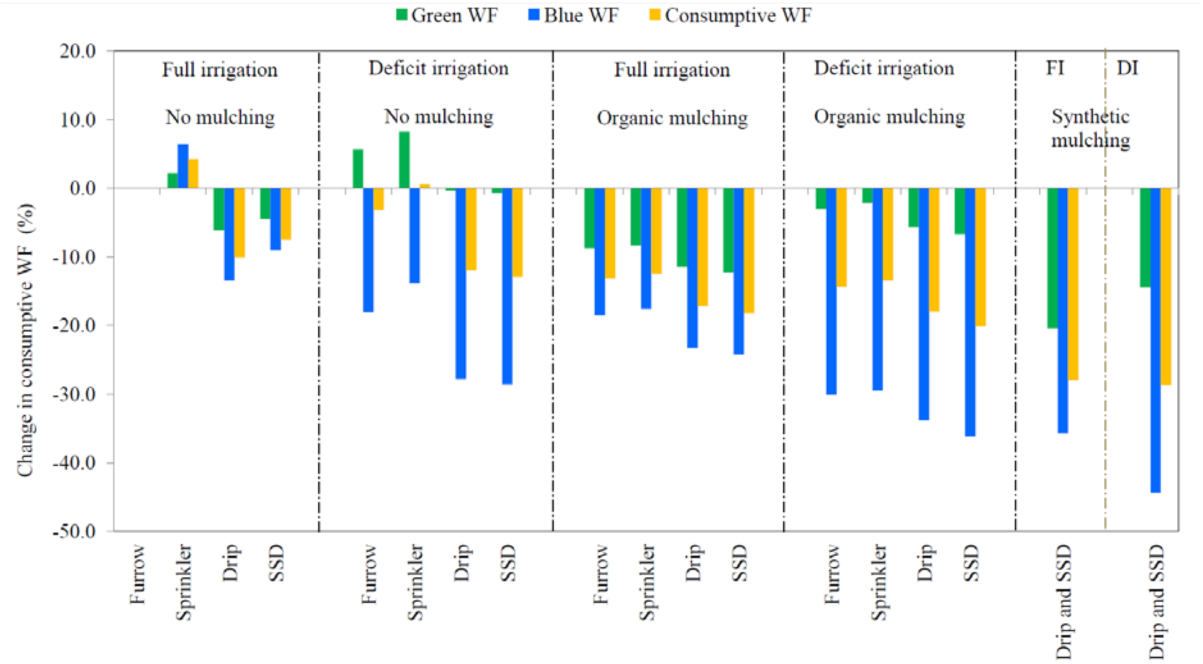

Figure 3. Simulated changes in water footprints in different management practices, and irrigation techniques and practices. SSD stands for sub-surface drip, FI for full irrigation, DI for deficit irrigation, NoML for mulching practice, OML for organic mulching and SML for synthetic mulching. Source: Chukalla et al. (2015).

2.5 European Union Context

Agriculture is a key driver of water scarcity in Europe (Eurostat, 2018a). In the European context, water scarcity affects 11% of the population and 17% of the territory (European Commission, 2007). The proportion of water withdrawals due to agriculture within the EU territory is around 45%, most thereof used for irrigation, where the southern European countries claim approximately two-thirds of the total (European Commission, 2019a; Eurostat, 2019d). There, crops often rely on full irrigation, whereas in the northern and water-richer countries, supplementary irrigation might suffice. (Eurostat, 2019d). Some countries, like Spain and Belgium, are currently extracting 20% or more of their long-term water supplies every year. This situation is expected to keep aggravating in the face of climate change and a rising population and water demand (European Commission, 2010b).

Central and Southern Europe are and will continue experiencing the most significant water-related pressures in the EU. Forecasts indicate that crop water deficit and irrigation requirements will increase as a response to extreme climate events (EEA, 2016; Irrigants d'Europe, 2018). On one hand, some studies suggest that this will be reflected as an expansion in the irrigated agricultural area (Berman et al., 2012; Nouri et al., 2019), which is expected to be supported by policy measures to provide farmers with adequate irrigation infrastructure and equipment (Irrigants d'Europe, 2018). However, such expansion will be constrained by a reduced and increasingly competed water availability (EEA, 2016). On the other hand, Krol (2019) demonstrated that water scarcity does not necessarily correlate with the trend of expansion of the irrigated area using Spain as an example; from 2005 to 2013, Spain showed a fixed reduction of 14% in its irrigated area. This result is aligned with those published by Eurostat (2019d), which show that the irrigated areas in the EU-28 have decreased by 6.1% between

2005 and 2016. In any case, the highest concentrations of irrigated areas, expressed as percentage of irrigated area in relation to the total utilised agricultural area, are located in Southern Europe as displayed in Figure 4. Although this indicator is not enough to estimate the sustainability of the irrigation systems, it does provide a general picture on where the larger risks for irrigated agriculture are located and where the biggest pressures to the local freshwater resources may be imposed. The government is expected to react accordingly and reduce the risks for irrigated agriculture and the pressures that irrigation imposes on the water resources, especially in the areas at larger risk.

2.6 European Policies

At the governmental level, two main policies influence irrigation in the EU: The Water Framework Directive (WFD) and the Common Agricultural Policy (CAP). The WFD plays a vital role in protecting water quality and quantity through the establishment of river basin management plans and water pricing policies. Its main goal is the sustainable use of water through the long-term protection of resources (Berbel et al., 2004). The CAP chiefly shapes the course of agriculture in the EU (European Commission, 2019h). Although both policies oversee water management related matters, the WFD can be considered an environmental norm rather than a regulatory instrument (Berbel et al., 2004) while the CAP plays a more important role concerning water saving due to its direct relation with agriculture. Given the role that agriculture plays on water scarcity, full integration between the WFD objectives and the CAP is crucial for achieving the European water vision (Krol, 2019). However, this integration as been catalogued as partial (European Court of Auditors, 2014) and there is still a lot of room for improvement. Next, the WFD and the CAP will be briefly introduced and discussed.

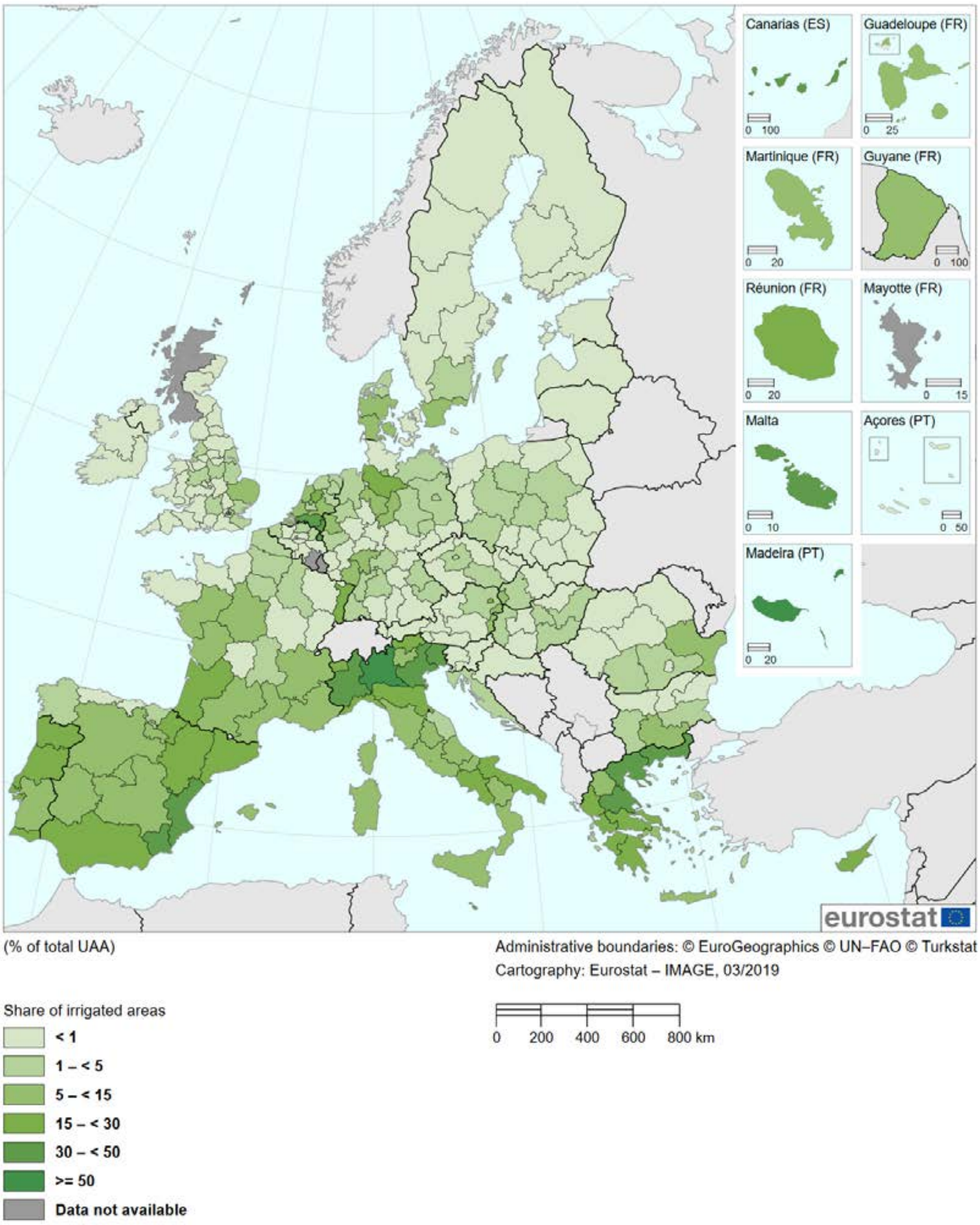

Figure 4. Share of irrigated areas in utilised agricultural area by EU regions, EU-28, 2016. Source: Eurostat (2019d).

2.6.1 Water Framework Directive (WFD)

The origins of the WFD can be traced back to 1975 when the first water legislations took effect. However, it was not until the year 2000 when the directive entered into full force. The WFD plays a fundamental role in the area of water policy. The main overall objective of EU water policy is to ensure access to good quality water in sufficient quantity for all Europeans, and to ensure the good status of all water bodies across Europe" primary objective: to achieve a good qualitative and quantitative status of the European water bodies (European Parliament, 2000). The directive requires member states to reach specific goals but without mandating them how to do it. Particular strategies to do it depend on the local situation and can vary accordingly. The member states of the EU address the WFD standards through the Common Implementation Strategy (CIS) (European Commission, 2003; European Court of Auditors, 2014).

The WFD requires member states to draft river basin management plans with concrete measures to be taken in relation to water use. Also, the WFD sets essential recommendations for water management. The following four are specifically important for irrigated agriculture due to the implications they have for the use and allocation of water resources (Berbel et al., 2004):

- River basin management;
- Cost recovery for water services, where the overall cost includes environmental protection costs;
- Participatory decision-making;
- Protection of groundwater and wetlands.

Irrigation, however, is captured relatively loosely by the WFD in comparison to other areas linked to agricultural water management. For example, the WFD, along with the Nitrate Directive, has established regulations and measures to limit nutrient losses to water bodies, both which are captured by the cross-compliance scheme of the CAP (see section 2.6.2). These provisions may explain a 19% reduction in the use of nitrogen mineral fertilisers in the EU during the period of 1990 – 2010 (Eurostat, 2019e). Nevertheless, no specific regulations are comprising the use of water for irrigation at such level.

2.6.2 Common Agricultural Policy (CAP)

The CAP was launched in 1962 after WWII. To this day it remains as a critical binding agent for the EU. The CAP owes its existence to the desire of Europe to become self-sufficient in its provision of food, while at the same time guaranteeing farmers a fair price for their products. Consequently, the CAP was built upon two pillars: food security for the EU and the provision of a reasonable living standard for its farmers. Before its implementation, successful integrations of agriculture-related matters within Europe were non-existent (European Commission, 2019h).

Over time, the CAP has undergone several reforms all, of which progressively widened its scope. The objectives sought by the CAP have evolved according to the changing needs of the environmental and socio-economic context. In addition to food security and reasonable standards for the farmers, the latest additions to the objectives of the CAP include climate change mitigation and sustainable management of natural resources, preservation of rural areas and landscapes, and keeping the rural economy alive (European Commission, 2019h). However, given its broad coverage, the current objectives of the CAP have been catalogued as potentially opposing. Furthermore, the means by which it addresses sustainability are often questioned (European Court of Auditors, 2014; Matthews et al., 2018). Future reforms of the CAP, yet, will likely make it an even more integrative and thus more complex policy[3]. Addressing the CAP challenges derived from its rising complexity hence is imperative.

2.6.2.1 CAP Instruments

The CAP traditionally rewarded farmers for their crop productivity. However, in 2003 the CAP cut ties between subsidies and production. Nowadays, the financial reward to the farmers is positively related, in principle, to their farm's size in hectares, albeit it is constraint by the fulfilment of some requirements (European Commission, 2019h).

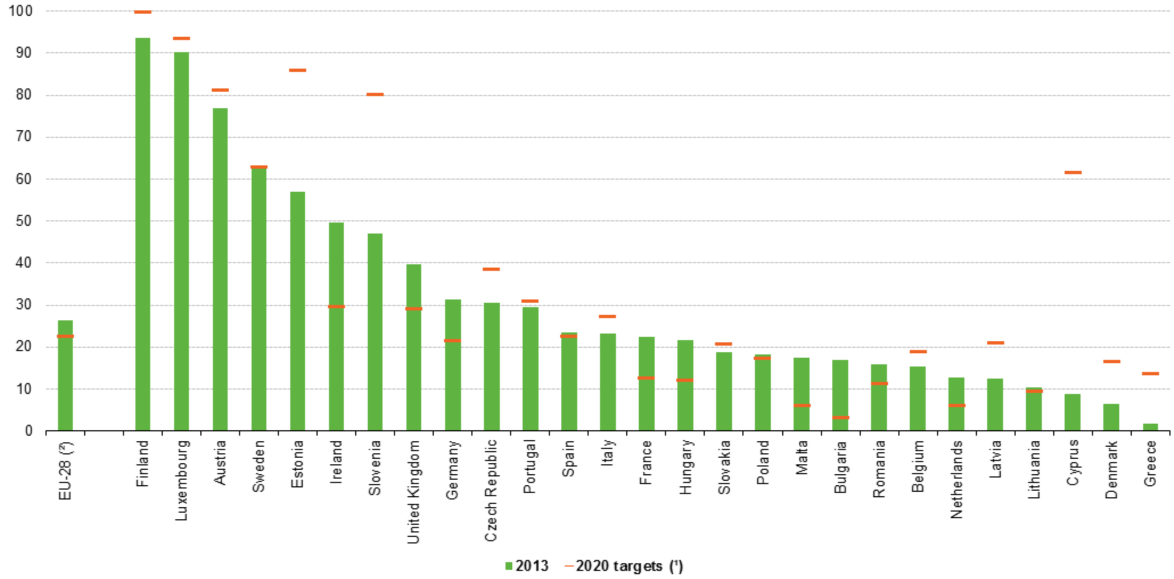

Figure 5. Percentage of agricultural land under agri-environmental commitment measured as a share of the country's utilised agricultural area. The green bars denote the area under agri-environmental commitments in 2013, and the orange lines represent the targets for 2020. Source: Eurostat (2019a).

The latest reforms of the CAP encourage sustainable practices as long as they are cost-effective. Such change has been driven since 1992 when the CAP acknowledged the need to include sustainable development in its composition. For example, the subsidy payments to the farmers are positively related to the extent of compliance with different standards, which include environmental issues. Maintaining environmental conditions considers, for example, the protection and proper management of water through the establishment of buffer strips alongside watercourses, the authorisation of water used for irrigation, and the protection of groundwater from pollution. Such requirements have their origin on the good agricultural and environmental conditions (GAEC) described in Annex III of Council Regulation (EC) No 73/2009 and are defined either at the national or regional level. However, there are no specific requirements set for authorisation procedures

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[3] *It is expected that it will contemplate the following nine different objectives: ensure a fair income to farmers, increased competitiveness, rebalance power in the food chain, climate change action, environmental care, preserve landscapes and biodiversity, support generational renewal, vibrant rural areas and protect food and health quality (European Commission, 2019e).*

(European Court of Auditors, 2014). For instance, in Scotland, farms abstracting more than 10 m^3 of water per day are required to acquire a water abstraction license; and, those abstracting more than 2,000 m^3, a complex license (Scottish Government, 2019). Another instrument employed on the CAP to promote sustainability corresponds to the 'greening' payments. Such rewards are dependent on the fulfilment of three key functions, none of them directly related to the use of water. Such functions correspond to crop diversification to improve resilience, the maintenance of permanent grassland to support carbon sequestration and protect biodiversity, and the allocation of 5% of the arable land to areas beneficial for biodiversities such as trees, hedges or land left fallow functions (European Commission, 2018). The EU promotes the adoption of these practices through the destination of 30% of the CAP budget assigned to the different EU nations to the greening payments.

Still, sustainability is a topic that remains a grey area for the policy, especially for water consumption., For example, small farms constitute more than three-quarters of the farming holdings in the EU, yet these are exempted from the cross-compliance sanctions and the 'greening' obligations. Figure 5 shows that the share of the utilised agricultural area under agri-environmental commitments in 2013 and the projection for 2020, which is less than 30% of the agricultural land (European Commission, 2018, 2019h). However, the extent to which smaller holdings add to the negative environmental impacts (e.g. water withdrawals and consumption) is unknown. In any case, the instruments that the policy uses to promote environmental practices have many exceptions which can affect their success. Furthermore, if the focus is set on water, as mentioned before, there are no specific instruments that target water consumption, which is why the CAP is considered as only partially adhered to the WFD objectives (European Court of Auditors, 2014)

2.7 Narratives on Crop Production

There are many visions and ideas on how to save water in irrigation. These visions may address one or more aspects of the broader issue of saving water in irrigation and may be more or less coherent with starting assumptions, values and objectives. Regardless of their scope or internal consistency, they vary significantly across the actors' landscape. Here, we strive to explore existing visions and ideas, which we try to converge into five overarching narratives regarding crop production.

The different narratives represent the vision of different stakeholder communities. To ascertain such narratives, first, the main stakeholders were identified (see Sections 4 and 5 for more information regarding stakeholders). Proceeding with the analysis of the different perspectives, we were able to define the following five overarching narratives that, we consider, define the course of crop production:

- Food security
- Global competitiveness
- Environmental protection
- Climate mitigation
- Technological optimism

The identified narratives portray leading views for crop production and are considered, to different extents, in the major policies within the EU. Next, descriptions of the different narratives are presented. Each description included assumptions and objectives that may be behind each narrative. Also, we present past and present examples of formulations and applications within the EU that are linked to each narrative.

2.7.1 Food Security: Increased Domestic Production to Meet Demand

As a result of the many food shortages experienced during WWII that threatened the European population with starvation, Europe has made food security a top priority across time, and irrigation has been an integral part of their strategy to make it so. Irrigated agriculture produces some of the largest flows of food worldwide, which makes it a fundamental tool for food security. Irrigated agriculture accounts for around 20% of the total global utilised cropland, yet it produces roughly 40% of the total food supply (FAO, 2017; Morison et al., 2008).

For more than 50 years, the EU has consistently nourished its population through the production of domestically grown crops (Zahrnt, 2011, 2017). However, comparable to crop production, food security is sensitive to the repercussions of factors such as population growth, climate change, and the state of the natural resources in which it depends (European Commission, 2010a; Hoekstra & Mekonnen, 2012). Forecasts estimate that the global food demand will increase exponentially reaching increments of 50 to 70% by 2050 (European Commission, 2010a; FAO, 2017). Simultaneously, climate change and anthropogenic activities will continue aggravating water scarcity (Hoekstra et al., 2012), which therefore will increase competition over water resources and further limit water availability for irrigation. Granted that irrigation has a critical role in guaranteeing food security, it is imperative that suitable innovations are rapid and effectively implemented to overcome the pressing socio-economic and environmental challenges associated with it.

Food security is a multidimensional concept comprising aspects of food availability, access, utilization and stability (FAO, 2006). It can be achieved by a singular or combined choice of self-sufficiency in the food production and externalization of the food supply. This narrative supports a self-sufficiency approach where the focus revolves around food availability. While the externalization of supplies shifts the environmental burden associated with crop production elsewhere (de Olde et al., 2019; Hoekstra, 2020), it also creates import dependency. Despite the potential environmental gains at the local level, externalisation comes with underlined risks; for example, imports may come from places where water use is not sustainable, resulting in compromise of the future availability thereof (de Olde et al., 2019; Hoekstra & Mekonnen, 2016). Improving self-sufficiency, instead, mitigates the risks associated with import dependency (Hoekstra & Mekonnen, 2016).

A self-sufficiency approach requires domestic production flows to meet internal demand. Meeting food demands has historically been done through intensification. However, in the face of the rising environmental concerns, a shift towards sustainable intensification has progressively taken place. Still, it is important to keep in mind that self-sufficiency, aligned with sustainable intensification principles, targets a reduction in environmental impacts – but only as long as it does not jeopardize production.

For this narrative, water flows applied via irrigation are a critical input necessary for the metabolic process of food production, where the limited renewal rate of funds may limit the flow supply necessary to meet rising food demands. The role of water here is of particular concern, due to the fact that water shortages are already increasing the burden on crop production in some regions within the EU (Eurostat, 2019d). Prioritizing food security thus requires a focus that favours high crop production flows and fosters innovations that target higher yields. Consequently, water savings are mainly accomplished through high water productivities.

Examples within the EU

In its very beginning, the CAP supported food self-sufficiency through price support to keep stable prices above world market levels and import restrictions (Eurostat, 2019c). However, these measures led to overproduction. Surpluses of crop products progressively increased budget costs and caused problems with importing nations, which, eventually, led to several reforms on the CAP (Commission, 2016; European Commission, 2019h). Nowadays the CAP rewards farmers through direct decoupled payments. In other words, crop production is still rewarded but the ties with production have been severed.

The EU also addresses food security through a policy framework to assist developing countries in addressing food security challenges. However, as it can be inferred from its name, it focuses on the provision of food outside the EU territory (European Commission, 2010a), which, for the purpose of food self-sufficiency, is out of the scope of this narrative, albeit it may exert an influence on self-sufficiency.

2.7.2 Market Competitiveness: Liberalisation of Agricultural Trade

Trade is an essential component of the EU economy. The EU is considered a critical player in the agricultural global markets. It is the largest importer and exporter of agricultural products in the world (European Commission, 2011a). Since 2010, the EU agricultural trade balance has remained positive, making the EU a net agricultural exporter (DG Agriculture and Rural Development, 2017). The most exported crop products are cereals and vegetable fats, and the most imported products are edible fruits and nuts (Eurostat, 2019g). Exports to external nations exhibited an increase of 104% in the period of 2007-2016, which denotes the increasing importance for the EU economy of extra-EU exports (DG Agriculture and Rural Development, 2017).

Worldwide, trade is regulated by the World Trade Organization, which was established in 1995. It sets the basis for a multilateral system for trade. WTO stands for the liberalisation of agricultural trade on the grounds of a contribution to economic growth and increased benefits for the consumers via specialization and increased crop flows (Moon, 2011). Agricultural trade in the EU must exploit open market opportunities and create and strengthen bilateral relations due to the fact that bilateral trade agreements have contributed to the increased EU trade, which in turn improves market competitiveness (DG Agriculture and Rural Development, 2017).

Despite the economic benefits that this narrative suggests, liberalised trade has been continuously criticised as it is accused of exacerbating the degradation of the natural funds (Moon, 2011). Although this fact is acknowledged by the EU and the government promotes environmentally-friendly innovations, the EU is much more strict on quality and the demand for specific products from specific regions (European Commission, 2019j). The EU asserts trade as a way to improve the variety of crop-related products and meet particular food demands (European Commission, 2019j). The trade of agricultural products plays a key role in the global provision of food and the delivery of a superior choice in consumer goods.

This narrative supports agricultural trade as a way to enhance the EU's economic development (Vos et al., 2019). Saliently the GDP from agriculture is increasingly insignificant in the whole of the EU economy, contributing to only 1.1% of the EU's GDP in 2018 (Eurostat, 2020). Nevertheless, in this narrative market dynamics play a central role. The demand of the consumers, as particular as they can be, are seen as a market opportunity. Since crops with higher returns are preferred, such as those assorted as high-value crops like cereals and horticulture (Eurostat, 2020), trade responds to what the market dictates as more profitable. Whether the export or imports of crop products have large water footprints is not a major concern. Consequently, water for this narrative is a flow necessary to maintain steady crop production flows that meet the market's needs, so as to maintain and improve the competitive role that the EU has in the global market. Water savings may be achieved through trade as long as they do not work against the market. They may also be accomplished through sustainable intensification, favouring production over the environment through increased water productivity. This fact is justified because increases in the value of exports can be achieved either by increases in production flows or by increases in the price, as illustrated in Figure 6. Extensification is only possible if the market's demand for organic or sustainably produced crop product exists.

Examples within the EU

The EU took part in the Uruguay Round Agreement on Agriculture in 1994, and also in the latest round of WTO negotiation in 2001 at Doha, both of which support a market-oriented perspective in agricultural trade. The WTO members committed to a gradual withdrawal of trade-distorting domestic subsidies (European Parliament, 2019). Such an agreement requires a reduction in the support provided in domestic agricultural policies and discourage agricultural export subsidies, domestic support to farmers, and high tariffs for agricultural imports.

In the EU, three pillars set the foundation for agricultural trade: non-distorting domestic support, market access, and export competition. The CAP, in response, underwent several reforms to comply with the current vision of agricultural trade aligned with the WTO standards (European Commission, 2011a). Although a market-oriented perspective considers domestic supports for agriculture as fundamentally opposing, the CAP complies with WTO´s standards for domestic support. The WTO categorizes agricultural policies according to the ´traffic lightbox system´.

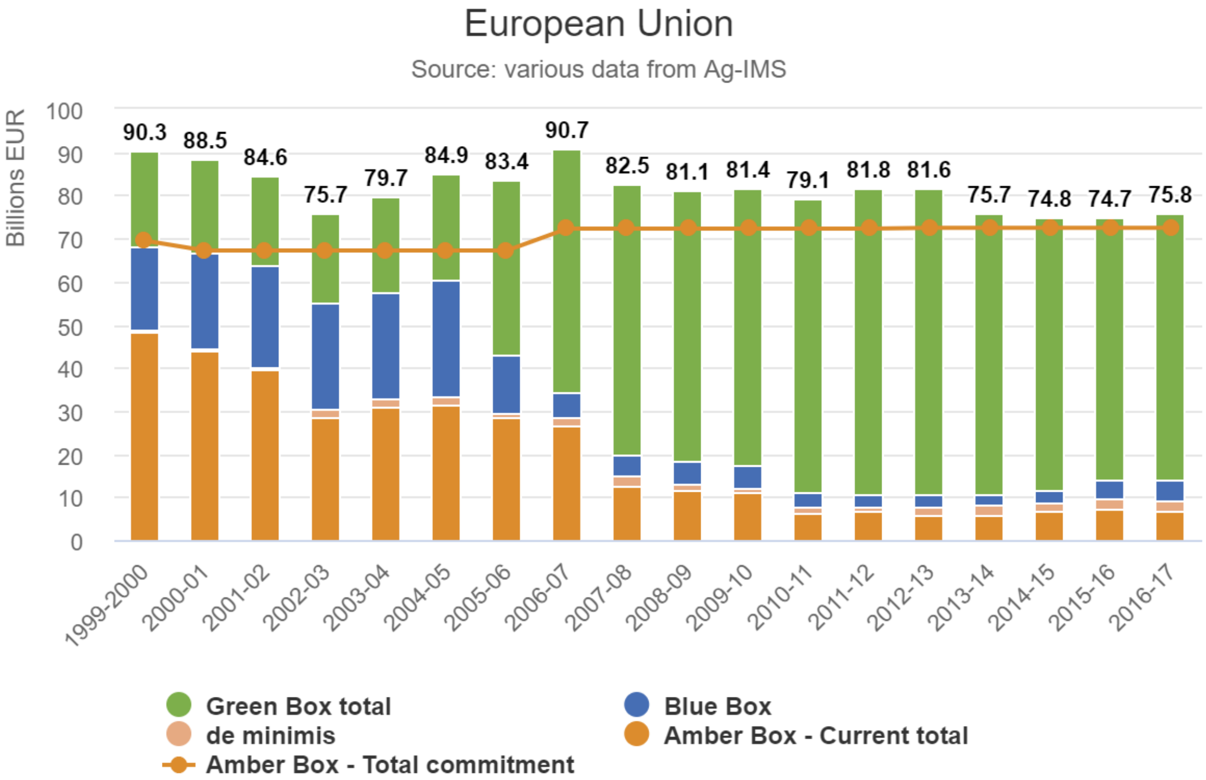


Figure 6. Development in EU Domestic Support. Retrieved from European Commission (2019h).

The system comprises three boxes distinguished in base on distort trade patterns. Currently, the CAP instruments fall into the "green box" support classification of the WTO (European Commission, 2010b, 2019j). Green box support comprises policy instruments that do not distort trade (or cause minimal distortion), are government-funded and leave price and production supports out (WTO, 2019). Adhering to the lightbox guidelines, the support from the CAP to its farmers is now given disregarding the production via decoupled direct payments. Figure 7 displays the developments on the domestic support granted by the CAP in terms of distortion to the global market. However, despite the non-distorting status of the CAP, the EU is considered as a weakening agent to the global small-scale agriculture because it exports subsidized crop products elsewhere (Ajena, 2017) as the CAP helps bridge the gap between the EU and the world prices (DG Agriculture and Rural Development, 2017). Figure 7 displays the developments on the domestic support granted by the CAP in terms of distortion to the global market.

Nowadays, the EU adopted a globalised and liberalised agricultural trade perspective. The EU´s position regarding trade seeks a market-oriented multilateral trading system that is also considering societal, economic, and environmental sustainability of that system (European Parliament, 2019) by maintaining open markets and increasing new ones, strengthening multilateral rules, and promoting sustainable development (European Commission, 2011a, 2019j; Eurostat, 2020). However, sustainability concerns are not explicitly addressed, as there are no regulations in place regarding environmental (including water) considerations for trade. The regulations for trade within the EU revolve mainly around the quality of the imported products (European Commission, 2011a). Also, increases in the GDP in agriculture obtained through agribusiness are coupled to a continuous decrease in the number of farmers in the EU, which is essentially conflicting with the vision to increase the farmers' force through programs such as the Young Farmers Scheme (European Commission, 2019h).

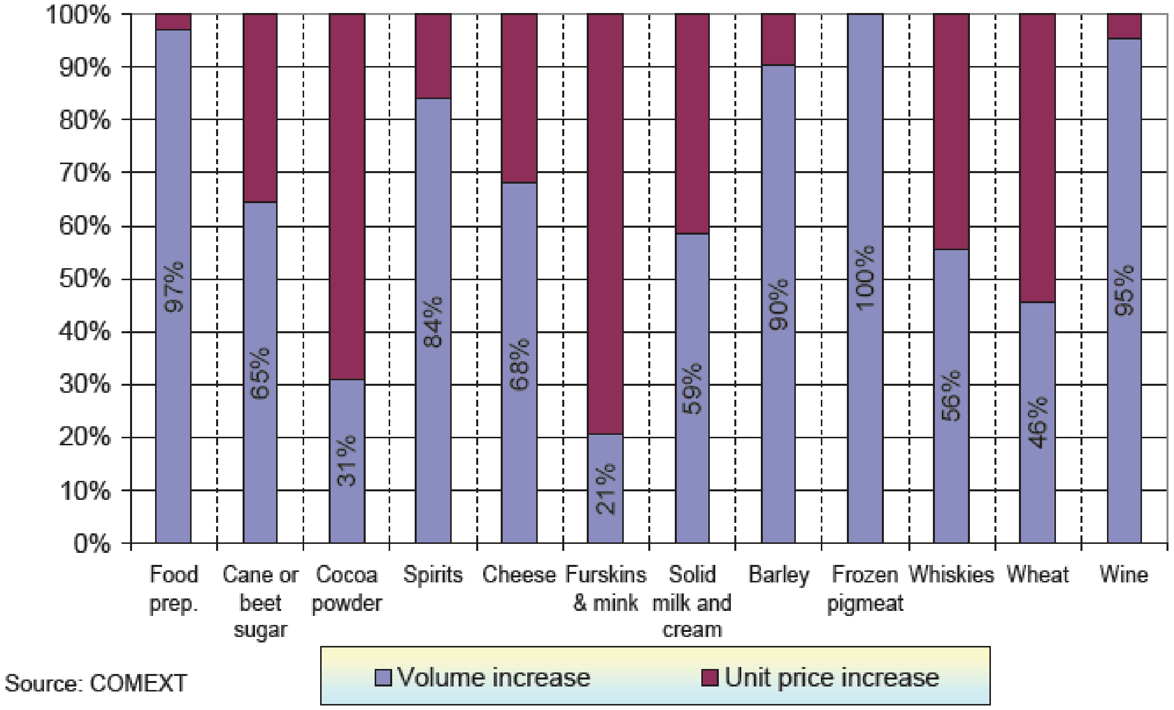


Figure 7. Contribution of volumes and unit prices to the increase in value of 2010 exports. Source: European Commission (2011b).

2.7.3 Environmental Protection: Sustainable Consumption and Production

The EU has made sustainability and environmental protection one of its main policy themes during the last years. The degradation of the natural resources has been an increasing concern for the modern EU society, and the role that irrigation plays on it puts it under high scrutiny. Natural funds such as land and water bodies are agents necessary for the metabolic process of crop production, but they are also sinking harm due to current EU crop production practices which increasingly detriments the state of the natural funds. Staying within the sustainable limits associated with crop production is a key priority for the EU.

Carrying capacity is a term that was first introduced by William Vogt (Mann, 2018). Later, it evolved into the concept of planetary boundaries (Rockström et al., 2009; Steffen et al., 2015). Planetary boundaries acknowledge the earth's natural funds limits, limits that should not be surpassed. According to this idea, crop production must comply with such limits and restrict the flows of crop production to stay within sustainable thresholds. Increased crop production and liberalised trade are seen as threats to the environment which must be avoided. Taking more than what natural funds require to be conserved would result in degraded ecosystems and global upheaval (Mann, 2018; Moon, 2011).

Restricting crop production implies a change in the related consumption. This narrative hence revolves around targets the consumption flow. Rather than implementing strategies focused on the production flow, this narrative argues for an approach that targets the consumption dimension. A reduction in food waste and a change on diets are appointed as strategies to reduce the consumption flow. The reduction of waste could potentially cut back the crop demand by one third. Furthermore, healthy and sustainable diets is a concept that promotes the provision of nutritional food with low environmental impacts (De Boer & Aiking, 2019; FAO, 2019; Springmann et al., 2018; Willett et al., 2019). It is based on local and equitable consumption. This narrative hence argues for a change in the crop demand flows rather than an increase in the production to increase the supply flow.

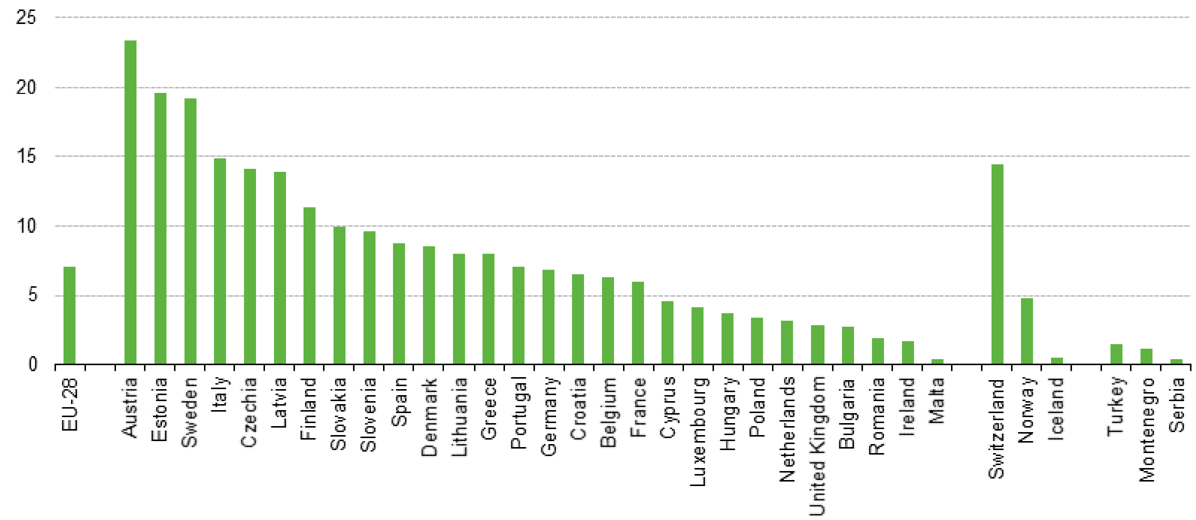
This narrative promotes alternative approaches to agriculture that ameliorate the many environmental issues raised by conventional intensive agriculture. Sustainable diets thus follow an extensification vision for agriculture. Organic farming, agroecology and conservation agriculture, for example, are groups that fit this narrative given their ´environment first´ focus (FAO, 2017). For the water sector, this narrative revolves around the local value of water resources, their uses and related risks (Vos et al., 2019): and, innovations that reduce the water flows required for crop production are the main focus. Water savings thus are approached by reduced water flows per crop production flows.

Examples within the EU

The CAP comprises environmental protection and sustainable development through the cross-compliance scheme and the greening payments (see Section 1.4.1). The CAP considers the practices of certified organic farmers as sustainable as it is aligned with the cross-compliance and greening schemes. Therefore, certified organic farmers are automatically entitled to greening payments. Certified organic products in the EU have fulfilled strict conditions on how they are produced, transported and stored. The EU has strict control and enforcement over organic farming methods to guarantee the compliance of the regulations (European Commission, 2019f).

Organic farming is a fast-growing area in European agriculture, which is a direct result of increased consumer interest in organic products (European Commission, 2019f). 7% of the total utilised agricultural area corresponds to organic farming according to 2017 statistics. Figure 8 portrays the share of the organic farming area by country.

Now, regarding food waste, the European Parliament (2012) set out the target to halve the food losses and waste of the EU by 2025. In the EU, households are responsible for 42% of the food waste; manufacturers, for 39%; retailers, for 5%; and the catering sector, for 14% (European Parliament, 2012).



Share of total organic area (fully converted and under conversion) in total utilised agricultural area (UAA), by country, 2017

Note: No data available for the Former Yugoslav Republic of Macedonia

Note: Estimated data for EU-28, Italy, United Kingdom, Norway and Turkey

Note: Preliminary data for Montenegro

Source: Eurostat (online data code: org_cropar)

eurostat

Figure 8. Share of the total organic area in the total utilised agricultural area, by country, 2017. Source: Eurostat (2019h).

2.7.4 Climate Mitigation: Agriculture as a Low Carbon and Circular Economy Agent

Agriculture plays a noteworthy role in climate change and mitigation. On the one hand, agricultural activities in the EU-28 were behind 10% of the total EU's GHG emissions for 2012, where agricultural soils (nitrification and denitrification) account for more than half of that number (Eurostat, 2018b). Reducing agricultural GHC emissions contributes to climate mitigation. On the other hand, climate mitigation often implies a transition from fossil fuels to clean and renewable energies, and crop production has been endorsed as a potential tool for renewable energy generation in the EU (European Commission, 2019c). Crop production thus can contribute to climate change mitigation in two ways; through the adoption of circular thinking and the production of biofuels.

The potential of agriculture to reduce its GHG emissions can be exemplified via two trending concepts, namely ´Circular Agriculture´ (CA) and ´Climate Smart-Agriculture´ (CSA). CA is a term originated in the Netherlands, which is gaining increased recognition. Circular agriculture aims to make optimal use of waste streams and produce resources locally. Its states that since 30% of the crops are suitable for human consumption, the residual flows could be utilised as animal feed (University of Wagningen, 2018). Feed opportunities must be seized by farmers who often opt for intensive production systems (Gerbens-Leenes et al., 2013) through enhanced cooperation. The optimum use of waste flows to which circular agriculture aspires implies less natural degradation of unused biomass and its respective

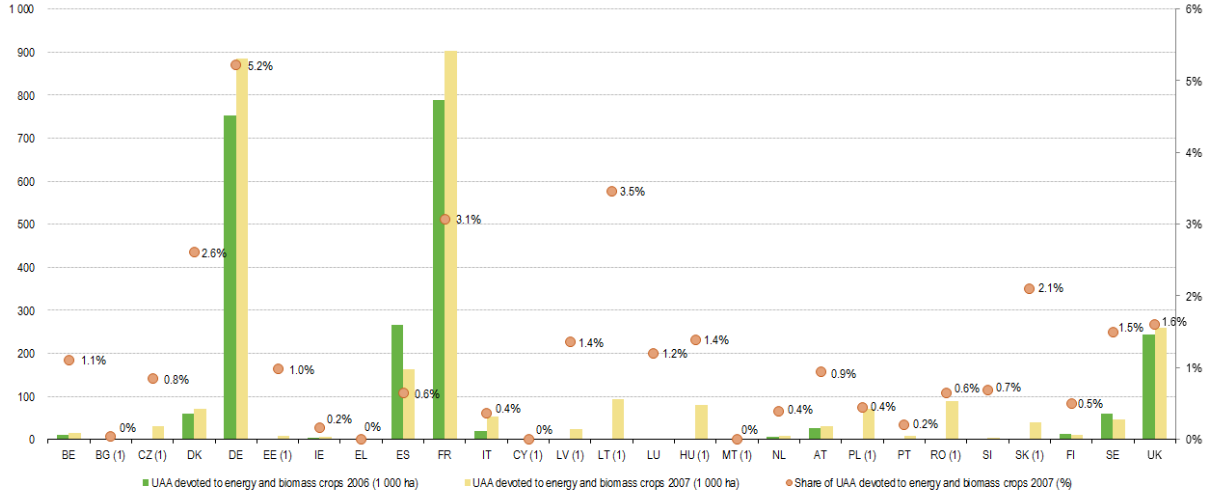
GHC emissions. Furthermore, circular agriculture promotes the use of manure as fertiliser which can improve carbon sequestration in the soil, and also suggests that the production of artificial fertiliser could be reduced diminishing the GHG emissions associated to its production. (University of Wageningen, 2018). CSA also targets reduced emissions and increasing carbon sinks as a way to mitigate climate change. CSA is a concept defined by FAO (FAO, 2013) built on three pillars: (1) sustainable increases of agricultural productivity and incomes, (2) adaptation and building of resilience to climate change, and (3) reductions of GHG emissions. CSA not only targets a reduction of emissions in agricultural activities but also considers reductions in the use of energy for farming and deforestation due to expansions in the agricultural area. Therefore, the main two strategies that seek a reduction in the GHC emissions related to crop production are to reduce the flow of emissions in the crop production flows and to enhance soil carbon sinks.

Addressing the renewable energy side, crop production plays a crucial role in the production of biofuels. Biofuels are the result of the conversion of biomass resources into fuel for energy; and, since biomass can regrow, it is considered as renewable energy. Biofuels are divided into two categories, conventional and second-generation. Conventional biofuels, such as biodiesel and bioethanol, originate from specifically grown energy crops, (e.g. rapeseed, soy, palm, maize, wheat, sugar cane and sugar beet), whereas second-generation biofuels come from (agricultural) waste and residues. Biofuels are associated with decreased GHG emissions, reduced energy import dependency, and greater revenues from agricultural by-products for the case of second-generation biofuels (Eurostat, 2019f). However, the dark side of bioenergy revolves around conventional biofuels and emphasizes the intensive agricultural practices and the expansion of the agricultural land required for their production, both of which negatively the environment (Eurostat, 2019f; Gerbens-Leenes et al., 2009b). For a detailed analysis focused explicitly in Biofuels, please consult the MAGIC Deliverable 6.3 on biofuels Ripoll-Bosch & Giampietro (2020)

This narrative assigns to crop production the role of climate mitigation agent, either by reducing their GHG emissions or by supporting the production of renewable energy. For this narrative, water is a flow necessary to support a low carbon economy through increased biofuel production flows. The water flows here must be directed to the growth of energy crops, employing innovations on the intensification side that target higher yield flows to confront the environmental constraints. Water-savings may be achieved through improved crop productivity.

Examples within the EU

The EU has committed to obtaining 20% of its primary energy consumption from renewable resources by 2020. In this narrative, biofuels are one of the ways in which the EU could meet its greenhouse gas reductions targets. Furthermore, biofuels serve as a renewable alternative to fossil fuels in the EU's transport sector, helping to reduce greenhouse gas emissions and improve the EU's security of supply. By 2020, the EU aims to have 10% of the transport fuel of every EU country come from renewable sources (European Commission, 2019c).



(1) No data available for 2006

Figure 9. Percentage of utilized agricultural area (UAA) devoted to grow energy crops per EU country. Retrieved from Eurostat (2019e).

In 2010, around 59% of the renewable sources of energy came from biomass (agriculture and forestry), which represented 11.9% of the total primary energy produced (Eurostat, 2019f). Out of the former, 10.6% came from crop production. Germany and France have the most significant share of the production of renewable energy from crop production with 51% and 13% respectively (Eurostat, 2019f). Figure 9 displays the share of agricultural land dedicated to the growth of energy crops per member state. It can be argued that in comparison to forestry, energy derived from crops is less significant but, given the fact that from the period of 2004 – 2010 the production of biofuels from agriculture increased by a factor of seven, it is worthwhile of attention (Eurostat, 2019f).

2.7.5 Technologic Optimism: Increased Efficiency to Overcome Production Limitations

Science and technology have played a crucial role in the evolution of agriculture through time. In the 1960s, 'the green revolution' transformed the agricultural sector. Before the green revolution, crop yields were continuous and increasingly threatened by external and internal factors which had massive repercussions in the socio-economic context. Examples of factors threatening crops are pests – like stem rust – and suboptimal genetic characteristics, like heavy, tall and thin stalks. Therefore, the seek for crops with superior characteristics was rather a necessity.

Driven by the will to overcome the challenges imposed to crop production, a group of agricultural scientists led by Norman Borlaug started experimenting with crop crossbreeding in developing countries in order to engineer enhanced crop types. The result of such experiments delivered crops that possessed specific characteristics assorted as critical to guarantee high productivity and overcome the challenges that threatened crop production. Their techniques were not only rapidly adopted throughout the world, but also further developed. However, their success was intimately associated with a massive investment in technical inputs such as fertilizers, irrigation and pesticides, without which optimal yields are not possible. It was this event known as the green revolution which set the foundation for the movement of the genetically modified organisms (GMO) (Mann, 2018). The green revolution marked a cornerstone for agriculture where science and technology started to be conceived as a potential alternative to overcome agricultural challenges.

The research, development and implementation of technological innovations are seen as a way to overcome the ever-evolving challenges of the agricultural sector in the EU. Science and technology nowadays target the threat of scarce resources, such as land and water. Proponents of this narrative point to innovations such as advanced irrigation systems, precision agriculture, drought-resistant crops and the use of alternative sources of water, as the future of agriculture (Garnett et al., 2012). Technological innovations under this light are a way to achieve, for example, food security and sustainability (European Parliament Research Service, 2016).

Water in this narrative is a modern challenge that impends irrigated crop production; a challenge that can be overcome with the use of technology that maximizes irrigation efficiency and crop water productivity. This narrative assigns the private sector a leading role in developing and implementing agricultural technological innovations where the function of the government is to support the adoption of technology and provide farmers with the means to do so (European Parliament Research Service, 2016; Garnett et al., 2012; Smith et al., 2010). Water savings are approached from the water gains attributed to the use of technological innovations, or, in other words, increased irrigation efficiency.

Examples within the EU

The CAP promotes innovative farm technologies, such as drip irrigation and digital farming, as a way to achieve rural development through the European Agricultural Fund for Rural Development (EAFRD) (European Commission, 2018). EAFRD is built upon three pillars: (1) fostering the competitiveness of agriculture; (2) ensuring the sustainable management of natural resources, and climate action; and (3) achieving a balanced territorial development of rural economies and communities including the creation and maintenance of employment. Two of its six priorities correspond to (1) fostering knowledge transfer and innovation in agriculture, forestry and rural areas, and (2) enhancing the viability and competitiveness of all types of agriculture and promoting innovative farm technologies.

The EAFRD is the most prominent instrument of the CAP promoting the widespread adoption of irrigation technologies. Through the support offered by EAFRD, the CAP aims to contribute to specific goals related to other previously described narratives (Figure 10), namely (mentioned by order of importance), (market) competitiveness, environmental protection, low-carbon economy (climate mitigation).

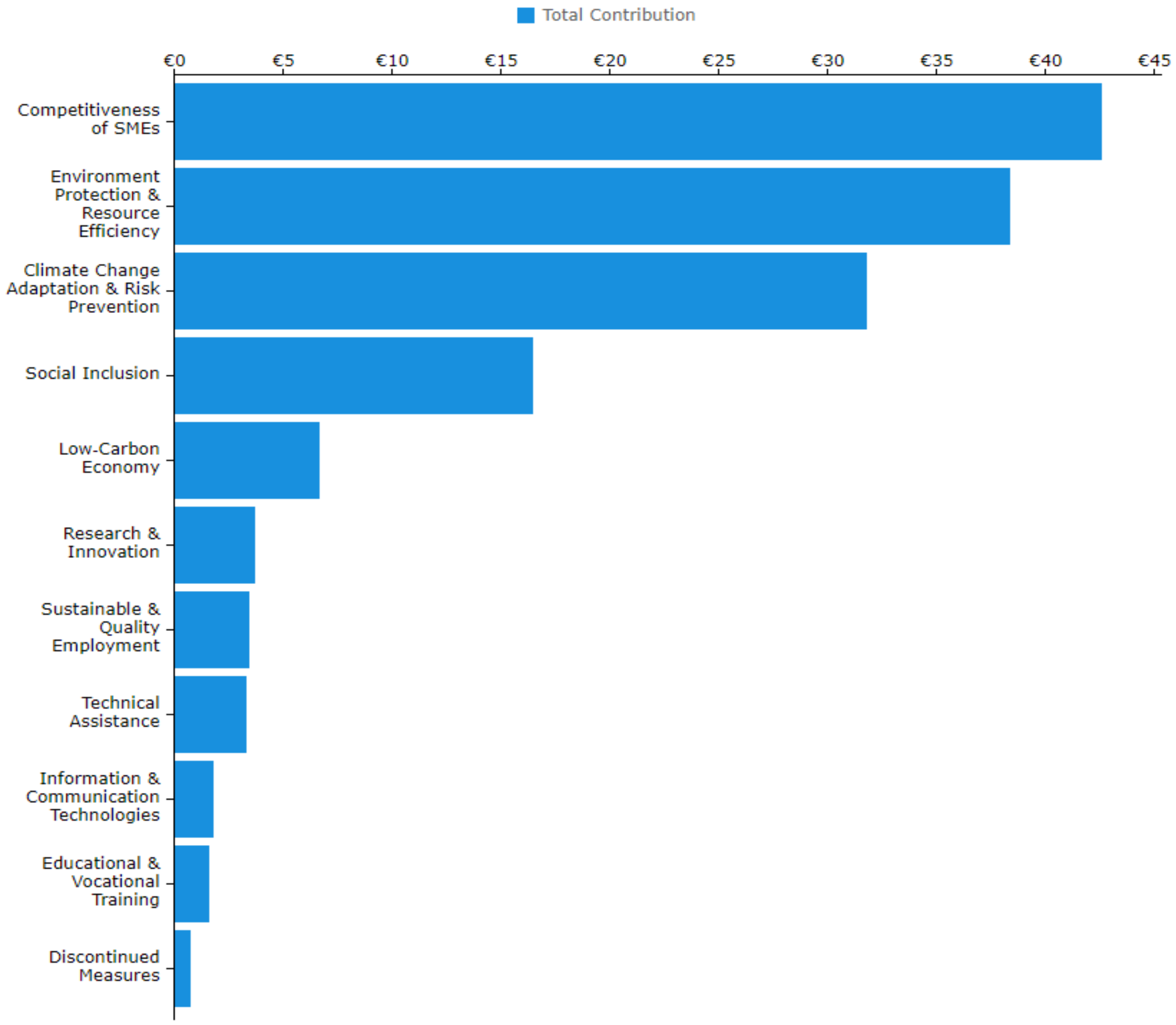


Figure 10. Total budget by theme: European Agricultural Fund for Rural Development, EUR billion. Source: (European Commission, 2020)

Another example of technological optimism in the EU is given by the Agricultural European Innovation Partnership (EIP-AGRI), in line with the Research and Innovation Policy (Horizon 2020), which promotes the digitisation of agriculture (EIP-AGRI, 2019).

2.8 Narratives – Innovations Matrix

This section couples the different innovations of Section 2.4 to the narratives identified in Section 2.7 by providing a summary overview in Table 4 and Table 5. These tables describe a narrative's general preference for (sets of) innovations that are congruent with their goals and assumptions. Note that this does not necessarily mean that narratives may not employ other innovations as well. As long as a given innovation does not oppose the central idea defining a narrative, its use cannot be ruled out.

Table 4. Summary of the narratives, including their primary goal, the water savings dimension they encompass, the role assigned to water and their innovations preferences.

Narrative	**Goal**	**Water savings dimension**	**Role of water**	**Innovations' preference**
Food security	Achieve food self-sufficiency via increased domestic crop production	Production	A flow necessary to reach/maintain high crop production flows	Water savings are achieved via innovations that favour high water productivity
Market competitiveness	Enhance economic development through agricultural trade	Production - Trade	A flow necessary to maintain steady crop production flows that are congruent with the market needs	Water savings are achieved via trade as long as it is not conflicting with the market needs, and via innovations that favour high water productivity
Environmental protection	Reduce the many environmental issues raised by agriculture	Production - Trade - Consumption	A flow that needs to be restricted to protect natural water funds	Water savings are achieved through reduced water flows per crop production flows or unit of area
Climate mitigation	Reduce GHG emissions attributed to agriculture and support the generation of renewable energy	Production	A flow necessary to support a low carbon economy through increased energy crops production flows	Water savings are achieved via innovations that favour high water productivity
Technological optimism	Overcome the challenges that impend irrigated crop production	Production	A natural fund that impends irrigated crop production	Water savings are approached through the use of technological innovations that increase irrigation efficiency

Table 5. Overview of the innovations supported by the different narratives. In bold, the central innovations associated with each narrative.

Innovations		**Food security**	**Trade**	**Environmental protection**	**Climate mitigation**	**Technological optimism**
Agricultural management practices	Mulching	X	X	X	X	X
	Tillage	X	X	X [4]	X	X
	Zero tillage			X[5]		
	Application of fertiliser	**X**	**X**	X[6]	**X**	X
	Application of pesticides	**X**	**X**	X[7]	**X**	X
	Intercropping	X	X	X	X	X
	Crop diversification	X	X	X	X	X
	Crop rotation	X	X	X	X	
Irrigation strategies	Partial root-zone drying			**X**		
	Deficit irrigation			**X**		
Irrigation techniques and technology	Surface drip irrigation	X	X	X	X	**X**
	Sub-surface drip irrigation	X	X	X	X	**X**
	Micro-sprinklers					**X**
	Precision irrigation	X	X	X	X	**X**
Socio-economic responses	Water pricing			**X**		
	Trade		X	X		
	Water regulation and allocation					
	Water auditing and benchmarking			**X**		X
	Market pressure			**X**	X	
	Raise awareness			**X**		
	Crops selection	**X**		**X**	**X**	X

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[4] *Organic farming relies heavily on tillage for weed control.*

[5] *Conservation agriculture promotes zero tillage practices to maintain soil structure.*

[6] *Natural fertilisers.*

[7] *Natural pesticides.*

3 Phase 2

This section evaluates the plausibility of the five dominant narratives in terms of water savings in irrigation. First, in Section 3.1, we provide a combined assessment. On one hand , we perform the quality check in terms of the external constraints – natural limits – hereby referred to as feasibility. On the other hand, we analyse the internal constraints – processes under human control – hereby referred to as viability. Second, in Section 3.2, we analyse the consequences of the narratives and the water-saving innovations employed on the stakeholders related to the crop production sector. For more details on the methodology used to obtain the results presented here, please refer to Section 5.2. We conclude Phase 2 with a summary of the main results of the assessment, including some recommendations (Section 3.7)

3.1 Feasibility and Viability

3.1.1 Food Security: Increased Domestic Production to Meet Demand

Intensification is often related to an increase in environmental impacts. For example, the CAP historically rewarded farmers that produced more. As a result, the CAP indirectly incentivised farmers to employ unsustainable ways to increase production like the indiscriminate use of fertilisers, pesticides and water (Eurostat, 2019c). Sustainable intensification takes a slightly different approach and aims to increase productivity to reduce environmental impacts. Nevertheless, it has been the source of increased debate since an increase in agricultural productivity to face a rising food demand is fundamentally contrary to the environmental standpoint which aims to reduce negative environmental impacts (Eurostat, 2019c). The premise, therefore, is that increased production to reach self-sufficiency may increase the water flows for irrigation and detriment the natural funds in which the flow depends imposing a risk in the feasibility of the narrative.

The point raised in the last paragraph can be illustrated by the scenario analysis provided by Krol et al. (2018). They assessed a radical scenario for 2050 based on self-sufficiency where imports flows were reduced to only 10% of the current flow, requiring the remaining 90% of the flows to be replaced by domestic production flows. The result showed that, for relatively water-scarce countries like Italy and Spain, the BWF of consumption would experience significant increments (Figure 11). Given the pressing effects that water scarcity already exerts in the region, these numbers refute the feasibility of the narrative. Furthermore, an internalization of the demands would dramatically increase the required agricultural labour which was exhibited by Krol et al. (2018). Therefore, to make internalisation viable, the CAP would have to make the agricultural sector more attractive for the EU workforce by investing more in programs such as the Young Farmers Scheme, especially considering that the agricultural labour in the EU has been experiencing a continuous downward trend (Eurostat, 2020).

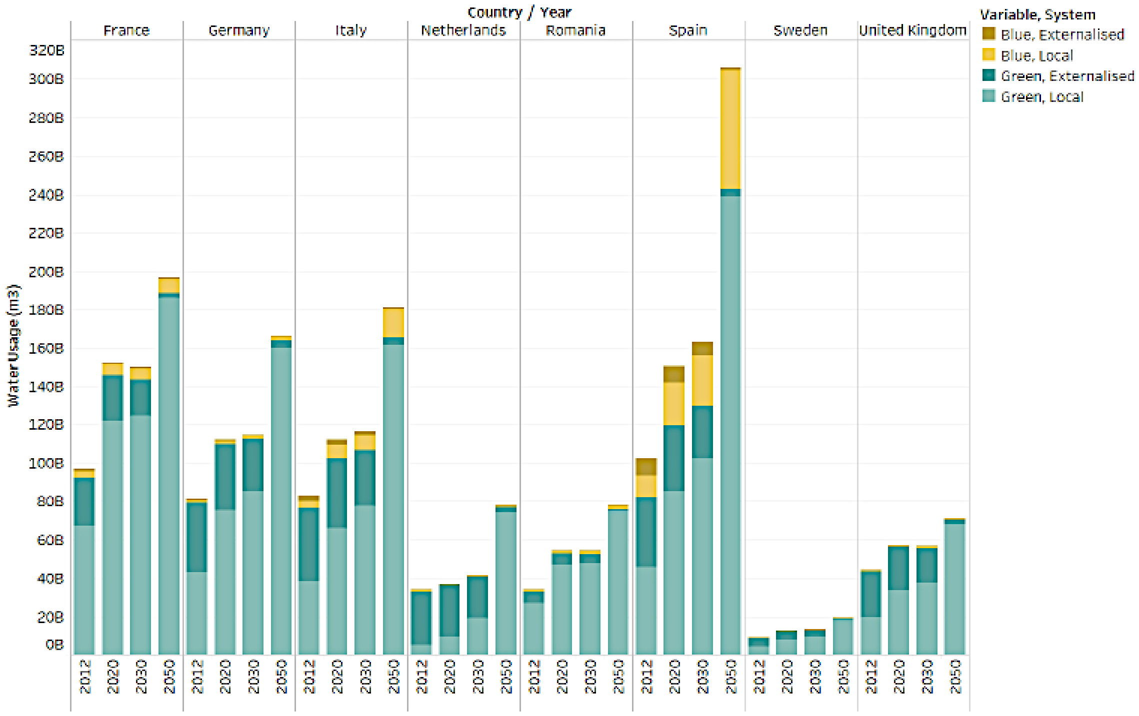

Figure 11. Comparison between water utilisation (domestic vs. externalised) under proposed scenarios. Source: Krol et al. (2018).

Assumptions behind the scenarios developed by Krol et al. (2018) assume that yield levels are restored to 2012 levels in order to include the effects of climate change, which implies a reduction of water productivity (assuming that crop water use does reduce to the same degree as yield). This rules out the influence that high productivity innovations may exert on the yield.

Schyns et al. (forthcoming) show that is is possible to reduce the BWF with limited effects on food security (yield) by applying best practices (deficit irrigation combined with organic mulching) in irrigated areas. The authors calculated the potential water savings in irrigation of maize production through deficit irrigation combined with organic mulching in water scarcity hotspots. Currently, 70% of irrigated maize is produced in such hotspots, where blue water use exceeds sustainable levels during at least one month of the maize irrigation season (Table 6). The European BWF of maize production can be reduced by 30% in these hotspots at the cost of a production loss of only 1% (Table 7). The absolute blue water savings in places where best practices are applied are shown in Figure 12 and are predominantly large (> 100 mm/y) in Southern Europe. Applying best practices in water scarcity hotspots of irrigated maize thus saves blue water and can partially alleviate water scarcity, particularly in places where maize is among the main irrigated crops. In Table 8, this is illustrated for the Garonne river basin in France. These results validate the feasibility of this narrative if such innovations are applied. An important remark for this case though is that deficit irrigation is not an innovation that strictly follows the narrative as it can lead to substantial yield drops if it is not properly managed. This statement illustrates that, at least for this case, an innovation that does not look like a good match may yield the best results however careful considerations regarding its viability must be made, such as the simultaneous employment of precision irrigation technology to carefully track the needs of the plants water-wise, and therefore highly trained farmers that can dispone of such technology.

Table 6. The fraction of irrigated maize production in Europe taking place in water scarcity hotspots. Period: 2001-2015. Hotspots are defined as places/months of the year in which maize is irrigated, and the total BWF exceeds the sustainable level. Source: Schyns et al. (forthcoming).

	Production (million tonne/year)	% in water scarcity hotspot
Northern Europe	0.0	-
Eastern Europe	3.3	54.5%
Western Europe	4.7	75.0%
Southern Europe	9.9	72.9%
Total	17.9	70.1%

Table 7. Maize production and associated BWF in water scarcity hotspots for the reference case (full irrigation, no mulching) and the case of deficit irrigation and organic mulching. Source: Schyns et al. (forthcoming).

	Production in water scarcity hotspots (million tonne/year)			BWF in water scarcity hotspots (million m³/year)		
	Reference	Deficit irrigation and organic mulching in water scarcity hotspots	Reduction (%)	Reference	Deficit irrigation and organic mulching in water scarcity hotspots	Reduction (%)
Eastern Europe	1.8	1.8	0.6%	617.4	428.6	30.6%
Western Europe	3.5	3.5	0.2%	622.0	391.0	37.1%
Southern Europe	7.2	7.1	1.7%	1898.0	1377.0	27.4%
Total	12.5	12.4	1.1%	3137.3	2196.5	30.0%

Table 8. Potential for water scarcity alleviation by applying deficit irrigation and organic mulching (DIM) in irrigated maize production in the Garonne river basin. It is shown for parts of the basin that are under different levels of water scarcity.

Water scarcity (WS) level: BWF / blue water availabitity	BWF (million m^3/year)	Blue water saving through applying DIM for irrigated maize (million m^3/year)	Blue water saving through applying DIM for irrigated maize (%)
Moderate (1-1.5)	253	29	11.4
Significant (1.5-2)	73	7	9.2
Severe (>2)	-	-	-

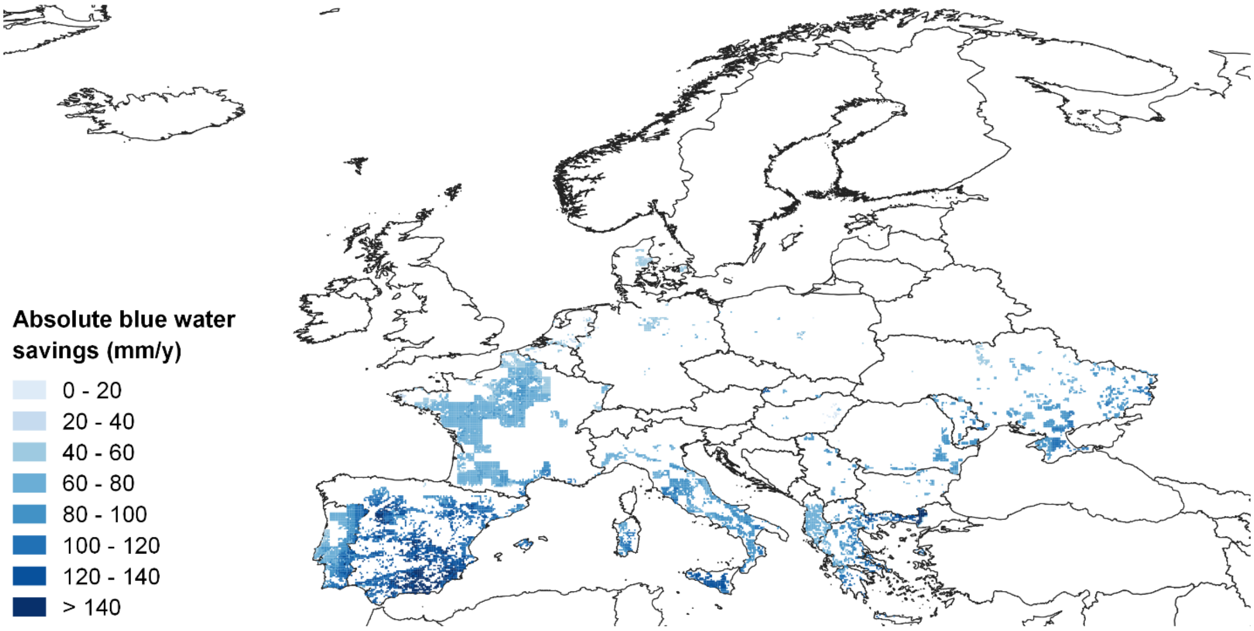

Figure 12. Absolute blue water savings (mm/y) by applying deficit and organic mulching in water scarcity hotspots of irrigated maize. Expressed as the blue water savings in m3/y divided by the harvested maize area in a grid cell. Source: Schyns et al. (forthcoming).

It is important to keep in mind that an increase in productivity does not necessarily translate into water savings. The Jevons' paradox states that whenever productivity increases, the total production is likely to increase as well, offsetting the benefits of high productivity. For irrigation and crop production, this means that the total production will rise, and the total water used may remain the same, or even increase (Hoekstra, 2020; Sears et al., 2018). Give this fact, the environmental gains calculated by Schyns et al. (forthcoming) may be offset if growth in production is not contained, which again would make this narrative unfeasible if water over extraction exists. Circumventing the rebound effect requires action by the government to limit the water flows regardless of the productivity levels. Doing so requires the use of socio-economic innovations such as water pricing and water auditing and benchmark (Freire-González & Puig-Ventosa, 2015; Hoekstra, 2020). Therefore, the institutional capacity is a factor restricting the viability of this narrative in terms of water savings. Also, the application of organic mulches increases the competition over residues, which are needed to maintain soil organic matter and for biofuels (Ripoll-Bosch & Giampietro, 2020)

Another relevant aspect to be considered for the feasibility of this narrative corresponds to the pollution of freshwater sources due to surface run-off and groundwater leaching, as displayed in Figure 13. The GrWF is considered a loading derived from the process of irrigated crop production. Intensification is a major explanation behind soil and water pollution. Water pollution is considered relevant in this context since it increases the competition for water while soil degradation negative influences crop growth. Therefore, even if BWF experiences reductions due to increased water productivity, the utilisation of resources like fertiliser and pesticides may counterweight the benefits in the future if the GrWF and the soil degradation increase. High grey water footprint and soil degradation thus are a direct threat to the feasibility of the narrative in the long term albeit quantifications to reduce uncertainties or to explore the extent of the threat are not hereby provided.

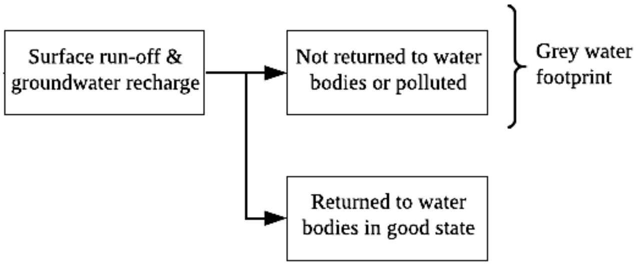

Figure 13. Representation of the GrWF in the irrigation process.

3.1.2 Market Competitiveness: Liberalisation of Agricultural Trade

Market-driven free trade has raised environmental concerns. Free trade has implications for the use of natural funds and flows and the mitigation and adaptation to climate change (Moon, 2011), implications which may jeopardize the feasibility of the narrative. Agricultural exports impose pressures on the local freshwater resources and compete with the water needed for domestic consumption (Vos et al., 2019). Krol (2019) illustrates a shifting cropping pattern towards more water-intensive crops in the Segura basin located in Spain which is translated into larger water flows to produce the same crop flows. Horticultural market opportunities with higher revenues motivated this change. This shift counterweighted the potential environmental gains that could have been attained by recent improvements in the irrigation efficiency in the area (more on this example of a rebound effect can be found in Section 3.5). These results provide us with a scenario in which seizing market opportunities results in the unfeasibility of a narrative based on EU market competitiveness, which is of particular concern in the Segura basin as it is already experiencing severe and intensifying water scarcity (Krol, 2019).

Another case that provides insights in the feasibility of a perspective governed by market competitiveness comprises the results of a study performed by Boulanger et al. (2016) involving future trade scenarios (simulating full tariff liberalisations of 97-98.5% and partial tariff cuts of 25-50% for sensitive products between the EU and developing regions). This study estimates that the most prominent economic opportunities for the EU will be found within the exports of dairy and pig meat under such scenarios. The large water footprints associated with the production of animal products (Gerbens-Leenes et al., 2013; Mekonnen & Hoekstra, 2011b) risk the feasibility of this narrative.

Trade cannot be merely based in global competitiveness from a feasibility standpoint. Actions to maintain and protect the natural funds in the metabolic process of crop production must be sought before pursuing a trade liberalization. The WTO must respond with proper strategies that foster international cooperation with an improve understanding of what agricultural sustainability entails.

This narrative can lead to a dependency on food imports leaving domestic support in the background. The case of the Segura basin provides an example where food self-sufficiency is traded for market opportunities as less staple crops are grown to give room to horticulture (Krol, 2019). Trade would impose a latent risk for food security if the products imported come from a water-scarce region. Such condition restricts both the viability of the narrative. In the face of fluctuations in the external supply, the food security of the region would be threatened, which would eventually increase the domestic production to shorten the gap between the offer and the demand. However, on the bright side, agricultural imports can relieve the pressure on the local water resources through virtual water imports. Water scarce regions may import water-intensive products from elsewhere (Chapagain, Hoekstra, & Savenije, 2006; Hoekstra, 2020). The Mediterranean region, for example, is expected to increasingly adopt such a strategy to face the water scarcity experienced (Van Grinsven et al., 2015).

According to (Chapagain et al., 2006) the volume of global water savings achieved through international trade reaches $352x10^9$ m^3/year. This number highlights the potential of this narrative in terms of feasibility. However, achieving water savings through trade implies a change in market demand and international cooperation towards sustainable agricultural trade agreements (Hoekstra & Mekonnen, 2016; Moon, 2011) which make the narrative unviable for water savings. Crop products tied to greater financial rewards are more attractive to produce (Vos et al., 2019) and as long as trade remains solely market-driven, water savings will be restricted due to the fact that the exchange of products rarely considers sustainability aspects.

Another major requirement for the viability of this narrative lies on the need for advanced logistics and transportation services, along with storage and processing facilities that can reduce the mismatch between supply and demand (Elferink & Schierhorn, 2016).

Crop production dominated by the ideology of free trade has been catalogued as too short-sighted to confront the multi-dimensional problems associated with agriculture (Moon, 2011). The results of this assessment support those claims. It has been said that liberalised trade stimulates the consumers 'demand for improved sustainability and prompts governments to implement stricter environmental regulations as a way to improve environmental funds´ conditions (Moon, 2011). That statement is bound to be proved wrong over and over again until changes in the socio-economic context occur first (Hoekstra, 2020).

3.1.3 Environmental Protection: Sustainable Consumption and Production

Extensification implies a reduction in the total blue water consumed. With this reduction comes along a parallel drop on the yield per hectare. Extensification may not reduce water footprints if the crop yields drop extensively regardless of reduced water consumption, particularly if high meat intake diets prevail. Estimates appoint that organic farming, one of the most notorious exponents of extensification, often presents yield gaps of 20-30% in developed countries (Van Grinsven et al., 2015). Since yields are much lower from an extensification standpoint, widespread adoption of organic agriculture, for example, would require farmers to expand farming into marginal and natural areas, making a larger use of land funds, to produce the same food flows, which would offset the initial environmental gains and risk feasibility. Even though fewer resources would be used per hectare, an increase in the number of hectares combined with lower yields would result in higher BWF and would have bigger impacts on the environment.

Providing food security under this vision thus would require a change in the consumption patterns of the general European population. Eurostat's projections estimate the EU-28 population will peak around 2045, exhibiting a growth of 3.7% compared to 2016 and with an increase of overall 18.8 million persons (Eurostat, 2017). Feeding an evergrowing world requires radical changes. Healthy diets based on the recommendations issued by the German Nutrition Society (DGE by its initials in German), vegetarian diets where pulses and oil crops substitute meat products and a combination between the two diets thereof are alternatives proven to achieve substantial reductions in the BWF, reaching up to 30% decreases in the BWF (D. Vanham, Hoekstra, et al., 2013; D. Vanham, Mekonnen, et al., 2013). However, the patterns shaping required food flows are an inherent characteristic defining crop production and may threaten the viability of this narrative if consumption patterns develop towards high meat intakes. Reductions in the flood of waste would also reduce the required food flows (Poore & Nemecek, 2018; Van Grinsven et al., 2015). However, reducing the food waste in the supply chain, similar to trade, requires a robust logistics and transport infrastructure, which may be a factor that limits viability. To make a narrative focus on extensification viable, a number of socio-economic innovations must be implemented as those are the ones who are directed to the consumer and may influence a change in the consumption.

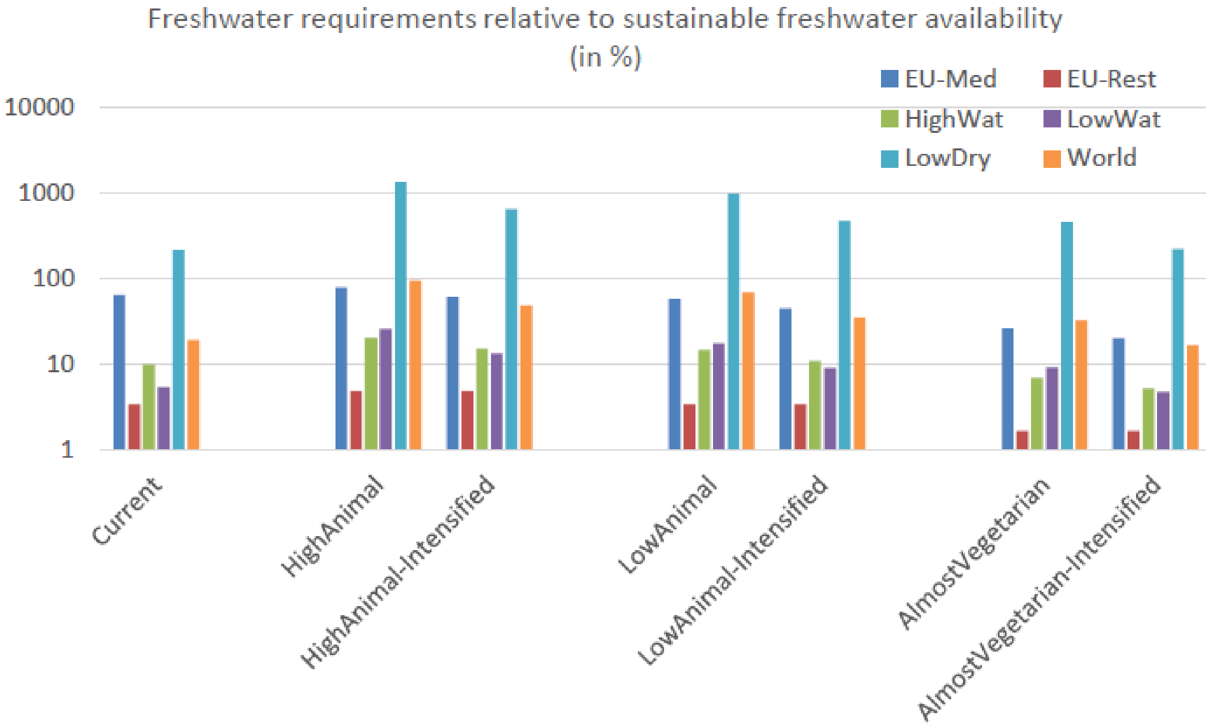

Figure 14. Assessment of freshwater requirements for domestic production to meet the required food flow relative to the limits to the sustainability freshwater availability. Source: Krol et al. (2018).

Krol et al. (2018) assess 2050-scenarios to estimate the prospect impact of different diets on freshwater resources based on the planetary boundaries concept. The results are shown in Figure 14. They indicate that all EU regions remain inside the range of feasible freshwater use regardless of the diet. However, the Mediterranean countries could be encountered close to the limit if their diets contain high levels of animal products. However, other nations present relevant feasibility issues, especially those classified within the category of low yield and water scarce. Now, to reach a fully sustainable world where feasibility is not a concern and natural limits are not surpassed, production must be downscaled. The results of the authors show that diets with high animal products intake are not viable as they fail to meet the food demand. Vegetarian and low animal products intake diets, however, are viable in terms of required food production flows as most of the world meets the food demand with the exception of the lower yield water-scarce countries. The authors also show that better results are achieved both in feasibility and viability if the rest of the world imitates the EU agricultural production methods. An important remark is that this scenario is not based in extensification related innovations.

However, considering the expected rises in the population, if consumption were to remain unchanged, is sustainable intensification the production pathway that could yield the best environmental results? Doubling agricultural production by 2050 requires an average of 2.4% growth on crop production per year (Ray et al., 2013). However, a study performed by Ray et al. (2013) shows that major global staple crops currently witness average yield increments of 0.9-1.6% per year, indicating an inevitable agricultural land expansion. Expanding irrigated areas to increase crop production should be located in water-abundant areas whereas water-scarce areas should restrict irrigation and look at trade as a possibility to fulfil their crop demands (Cao et al., 2019; Hoekstra, 2020). Ray et al. (2013) stress the importance of investing in areas where the growth meets the target of 2.4% and catalogue sustainable intensification as a necessity rather than an option. However, they fail to link the environmental impacts associated with intensive crop growth. The results from (Tilman et al., 2011), nevertheless, indicate that the sustainable intensification of croplands with current sub-optimal yields, assisted by high yield agricultural management and technological innovations, could meet the 2050 global food demand with less environmental impacts than a combination between intensification in industrialized countries and extensification in developing countries. These results are aligned to those provided by (Schyns et al., forthcoming), described in Section 3.1. Potential water savings expressed as a reduction of 30% in BWF highlight the potential of the sustainable intensification oriented innovations to reduce environmental impacts. Following this pathway thus proves feasible for an environmental protection narrative. This narrative may also be more viable, given the fact that the consumers' behaviour is no longer requiring radical changes.

3.1.4 Climate Mitigation: Agriculture as a Low Carbon and Circular Economy Agent

This narrative employs measures that are related to a sustainable intensification vision. Land funds availability is a factor that risks the feasibility of this narrative. Conventional biofuels production often takes place on former food production cropland (Muscat et al., 2019). Otherwise, energy crops must be grown in non-cropland and cause an indirect land use change (ILUC). This can result in a release of CO_2 if forest, wetlands and peatlands undergo a process of ILUC, which in turn would result in increased GHC emissions (European Commission, 2019g; Hoekstra, 2020). Given the land restrictions that threaten the feasibility of the narrative, larger crop flows per unit of land is imperative. Water is also a factor of risk for this narrative, since not only land, but also green (Schyns et al., 2019)and blue (Mekonnen & Hoekstra, 2016)water availability are limited. The water footprint of bioenergy is substantially larger compared to other forms of energy (Ripoll-Bosch & Giampietro, 2020; Davy Vanham et al., 2019). Energy crops and wood (Schyns & Vanham, 2019) are associated with large water footprints. Rapeseed and jatropha are common energy crops, both of which have very low water productivity requiring around 400m3/GJ (Gerbens-Leenes et al., 2009b). Future biofuels scenarios indicate that, under an optimistic scenario, bioenergy would require 11-14% of the global arable land and would account for 17-25% of the total water footprint. The main question derived from this narrative remains "Whether, or to what extent, we should apply scarce land and water resources for producing biomass for energy?" (Hoekstra, 2020, p.103)

In the case of second-generation biofuels, preliminary results of Ripoll-Bosch & Giampietro (2020) indicate that when all the agricultural waste in the EU is destined to the production of biofuels, only 3.44% of the energy consumption of the transport sector of the EU is produced, when the EU target is actually 3.5%. The production contemplates a very large investment for a relatively small return. The main conclusion of the deliverable suggests that biofuels, either conventional or second-generation, are not plausible in the broader context of the EU. For a more robust QST analysis on the plausibility of biofuels in the EU please refer to Ripoll-Bosch & Giampietro (2020).

Regarding a reduction in the GHG emissions associated with agriculture, the institutional framework limits the viability of the narrative. Critics of CSA, for example, argue that the regulatory body lacks monitoring and accountability mechanisms regarding climate mitigation in agriculture to implement this narrative successfully (Schmitt, 2016).

3.1.5 Technologic Optimism: Increased Efficiency to Overcome Production Limitations

In terms of feasibility, an increase in irrigation efficiency does not necessarily result in a decreased water consumption. This phenomenon is commonly known as the rebound effect or Jevon's paradox. Efficient irrigation technology may lead to profit-maximization behaviour by, for example, the use of higher revenue but more water-intensive crops (see Section 3.2), or an increase in irrigated area. Such actions override the potential reductions on water consumption in irrigation[8] (Hoekstra, 2020; Sears et al., 2018) and are a direct threat to the feasibility. If improved efficiencies aim to provide environmental gains and counteract the Jevons' paradox, they must be accompanied by socio-economic innovations such as regulatory instruments like water pricing and increased awareness, as demonstrated by Freire-González & Puig-Ventosa (2015) on the case of energy policies.

Krol (2019) found that an increase in the application of drip irrigation technology in the Segura Basin located in Spain during 2010 and 2015 reduced the pressure of water extractions on water resources. However, the environmental gains were fully offset because of shifting cropping patterns. It is unresolved though whether technical innovations in the region encouraged producers to seek better market opportunities or because it is not economically viable to adopt technological innovations in the production of staple crops. Another noteworthy remark is that the shift to higher-profits crops,

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[8] See Sears, Caparelli, et al. (2018) for a review of studies regarding Jevons' paradox and efficient irrigation technology.

from staple crops to horticulture, reduces self-sufficiency although it may improve the market competitiveness of the region.

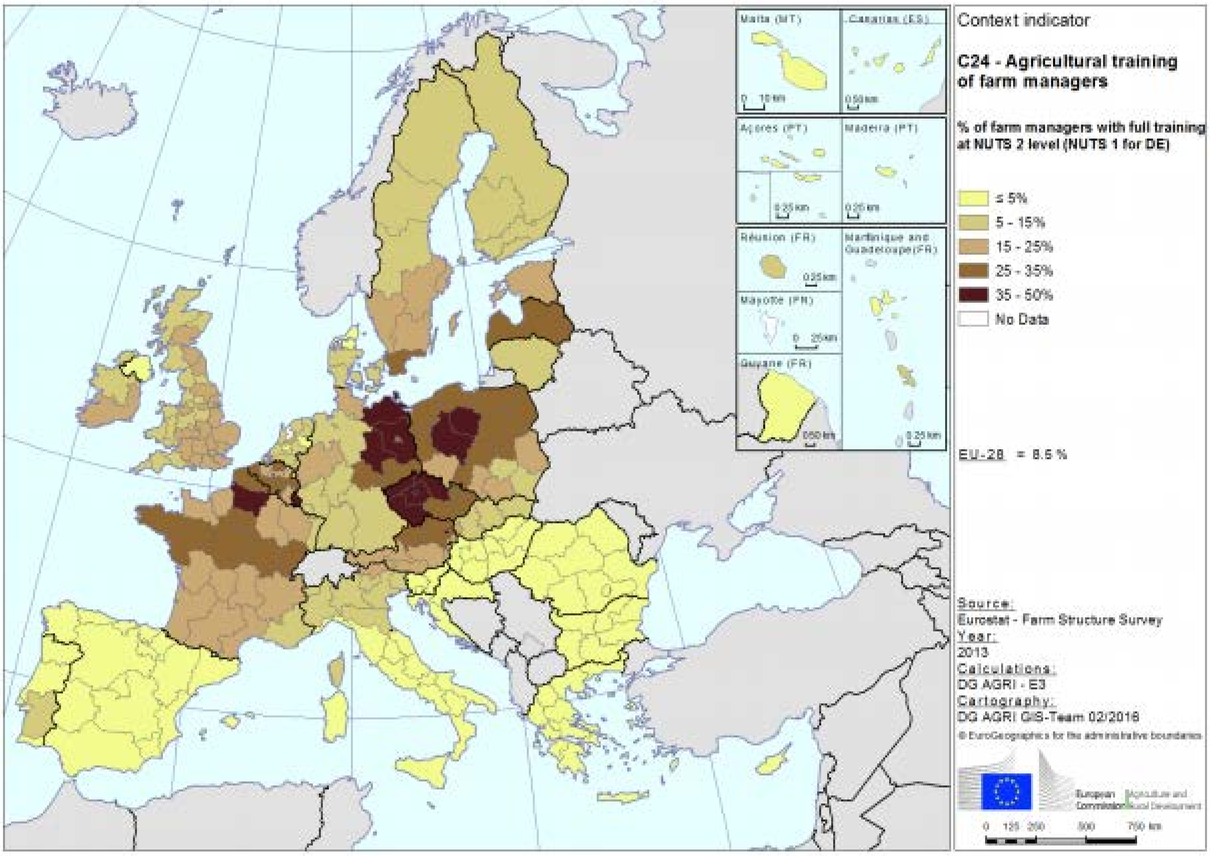

Figure 15. Share of farm managers with full agricultural training, 2013 (Eurostat, n.d.).

In terms of viability, the use of advanced farming techniques is constrained by the level of training of farm managers (European Commission, 2019i). In 2013, 69.8% of the EU farm managers had not received any kind of training (European Commission, 2017). Figure 15 displays the share of farmers with full agricultural training per state as 2013. Implementing technological innovations such as precision irrigation calls for highly trained farmers. This threatens both the success and the implementation of such measures within the EU.

A factor that increases the viability of this narrative is attributed to the fact that the EU government has increased its support to agricultural research and development in the last years (Figure 16). However, research and development have seen ups and downs over the past years, which makes this assumption exclusively more certain if the trend seen over the last ten years is maintained.

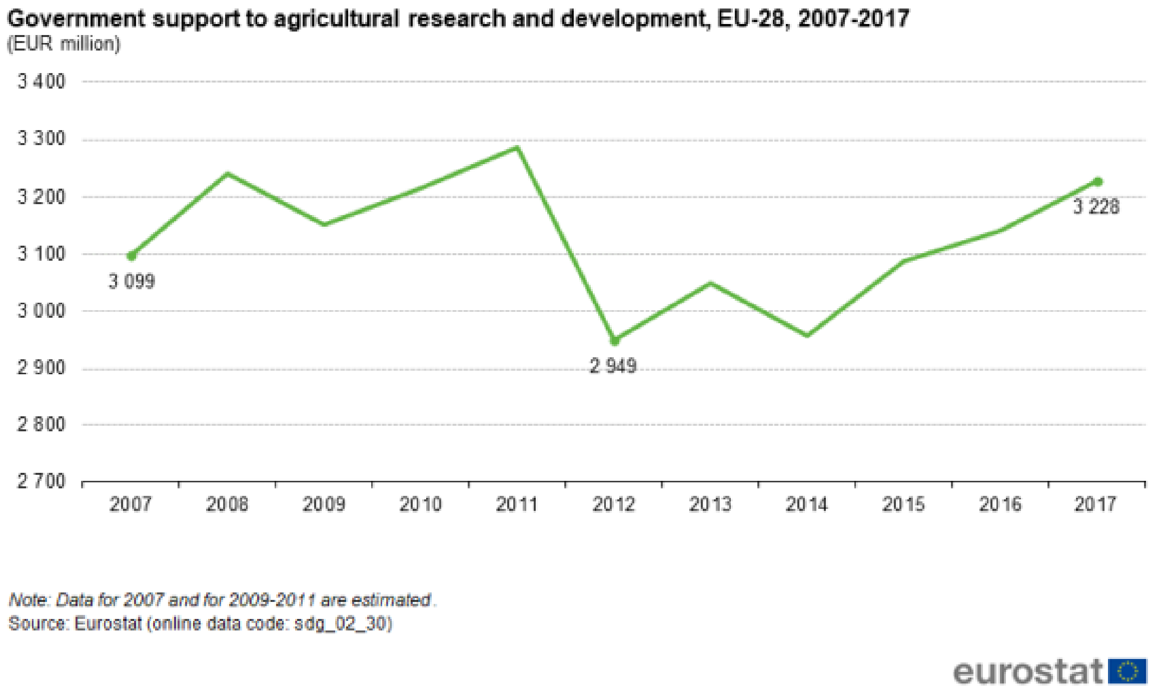

Figure 16. Support for agricultural research and development. Source: Eurostat (2019h).

3.2 Desirability

Given the many users of the (irrigated) crop production, desirability is complex to assess. In the following sub-sections, we provide examples of the ‘winners’ and ‘losers’ that may originate in the different narratives. This section does not aim to provide all the potential effects on the stakeholders but rather its aim is to exemplify a few examples to understand how the logic of ‘winning’ and ‘losing’ works. ANNEX III, however, contains a table with extended information that categorizes the ‘winners’ and ‘losers’ that may originate by the use of groups of innovations according to the different narratives as perceived by different stakeholders. To learn more about the stakeholder engagement, please refer to Section 4.

3.2.1 Food Security

In a narrative that is driven by food security, the overall winners are the consumer as a steady and sufficient food supply is the primary goal. Agricultural input manufacturers and irrigation technology suppliers are winners as well since their sales would increase derived from a widespread adoption of their products and services with the aim of increasing food production.

Farmers are a special case. Their sales and therefore their revenue would be drastically affected as reaching self-sufficiency means that their exports would likely decrease. However, increased internal trade between the state members of the EU may counteract the adverse effects of the decreasing exports. Another important remark is related to the increased production of staple crops. Staple crops usually constitute the dominant portion of a diet. In a food security narrative, therefore, the growth of staple crops would be preferred, otherwise, food security would be compromised (Krol, 2019). However, staple crops may not be the most profitable crops which supposes market opportunity losses for the farmers.

3.2.2 Market competitiveness

In a narrative-driven by marker competitiveness, the farmers who are able to compete are the winners as they will be maximizing their profits. However, small farmers who are not able to compete could be severely affected. Again, agricultural input manufacturers and irrigation technology suppliers are winners as well since their sales would increase derived from a widespread adoption of their products and services to keep production flow levels high.

Organic farmers are also potential winners here. Agricultural crop products are on increasing demand in the EU (European Commission, 2011a) which may suppose environmental benefits driven by the market. However is important to keep in mind that, if the domestic demand for these products increases, we could be looking at potential threats to the feasibility of the narrative. Losers that can be derived from the increased consumption of organic products are the fertilizer, pesticides and plastic mulches manufacturers, as their sales would decrease.

The consumer is here in a special position. On one side, they are winners as their variety of crop products choices is improved. On the other, they are potential losers if food security is threatened due to unreliable import dependency.

3.2.3 Environmental Protection

In this narrative, the obvious winner is the environment represented, for example, by the European Environmental Agency (EEA), as environmental protection targets could be meet. Losers, therefore, would be the fertilizer, pesticides and plastic mulches manufacturers, as their sales would decrease because such practices are no longer supported. Conversely, irrigation technology suppliers are potential winners as well since their sales would increase derived from a widespread adoption of their products and services to reduce the use of water for irrigation. However, the argument of who can afford the technology and who cannot is essential for the desirability of the farmers, and as well their level of training.

At first sight, the consumer is also a potential loser at the long-term as diet patterns would progressively change, and, although this is not precisely bad, change resistance may arise (Shepherd, 2020). However, consumers, as the general population, are benefited by this narratives as the socio-economic consequences derived from a degraded natural environment, such as water scarcity, are ameliorated.

3.2.4 Climate mitigation

From this narrative, the major winners would be the biofuel producers as their prime input would be steadily and increasingly available in the market. Agricultural input manufacturers and irrigation technology suppliers are also winners since their sales would increase derived from a widespread adoption of their products and services with the aim of increasing the production of energy crops. For a more detailed analysis of biofuels please refer to (Ripoll-Bosch & Giampietro, 2020).

Focusing in CA and CSA, a winner could be the scientific community, as they would have a critical scientific gap to fill regarding the operationalization of the concepts behind the movements. This gap also opens market opportunities for the private sector which in a sense makes the private sector a winner. On the losing side, we can zoom into the supply-chain behind the provision of the agricultural inputs. Earlier in this document, we learnt that the production of mineral fertilizer accounts for a significant percentage of the total CO_2 worldwide. Therefore, following the ideology of CA and CSA, the use of such products would not be supported, which implies that mineral fertilizer producers would be losers.

3.2.5 Technological optimism

In a narrative dominated by technological optimism, the biggest and apparent winners would be the irrigation technology suppliers since their sales would increase derived from a widespread adoption of their products and services to overcome the water limitations. Other examples of technological developers would be big biotechnology companies (e.g. Monsanto) – due to their capacity to engineer drought-resistant crops – and companies developing water desalinization or treatment technology – due to their capacity to 'create' water.

The potential losers here are the farmers as they have to absorb the cost of such technologies to operate under environmental constraints. Low-income farmers are the most vulnerable group. The consumers may be probable losers as well, since the costs of absorbing the technology may be reflected at the price of the commodities.

3.3 Summary, Conclusions and Recommendations

In the past sections, we have performed a quality check of the five overarching narratives that shape crop production in the EU and the innovations they assert to reach water savings. Table 9 provides a summary of the viability and feasibility analysis, which highlights the main results. Desirability is not included here as the results indicate that desirability is, especially, very complex as it comprises many different stakeholders and communities with divergent views and, moreover, depends completely entirely on the specific path and responses taken.

In terms of feasibility, we can conclude that all the different innovations have the potential to reduce the use of water for irrigation to different extents; however, this does not necessarily imply that water savings will be attained. Among the most significant factors restricting the feasibility of water savings, we found the rebound-effect, which is heavily influenced by the goals of the different narratives. To exemplify this point let us use two cases. From a food security standpoint, increased water productivity may imply that the positive balance on the water used for irrigation should be seized for the growth of more crops that contribute to the food supply. This, as a result, would cause a rebound effect and the water gains would be ‘lost’. Yes, the food flow would increase and food security would be benefited, which is an indicator of viability, but at the cost of no water savings. However, from an environmental point of view, the gains would theoretically stand and water savings would be achieved because the main focus of the narrative revolves around reducing the environmental impacts associated with irrigation. The narratives, therefore, exert a big influence in the success story of a given innovation.

If we look at the last example, we can argue that the viability of the environmental protection narrative is jeopardized. Yes, the focus is on environmental protection and water savings are attained; however, crop production still has functions to fulfil, such as the provision of sufficient food. If the current trends of food consumption remain and food supply is not met, the narrative, albeit feasible would still be unviable. Nevertheless, the simultaneous use of innovations may turn the tables on the viability. If socio-economic responses such as market pressure and increased awareness were to be implemented and, as a result, consumption patterns towards a diet with fewer animal products were gradually accomplished, we would be looking at viability at the long term. We can determine then that viability, for the case of water savings, is a constraint that can be overcome via the parallel implementation of innovations of socio-economic character.

The parallel implementation of socio-economic responses would also benefit feasibility. To illustrate this, let us address the example of food security and the rebound effect again. If an increase in the production originated by increased water productivity results in unsustainable use of water and therefore unfeasibility, the use of socio-economic responses may come useful. Employing innovations like water regulation and allocation may restrict the potential growth concerned in the rebound effect. Water savings thus could be achieved and the innovations would be feasible and, as long as food security isn’t compromised, viable too.

The last examples and their conclusions stress the importance of being congruent with the innovations that you select and the goals that you are seeking. There is no debate in the fact that some innovations and some narratives are more consistent than others. However, being coherent proves to be more important. Coherence in this context means that whichever the innovations to achieve water savings are, they must be in line with the narrative in which it they are encountered. Water savings cannot be achieved with extensive practices if the diets keep evolving towards high animal products consumption in the same way that savings cannot be achieved in the purse of self-sufficiency as long as agricultural expansion is not controlled. The creation and implementation of sound policies and instruments that consider water savings in irrigation, must understand the main constraints for its success. To do so, they must evaluate their actions in accordance with their goals. Granted the broad scope of crop production and the many narratives that influence them, instead of looking for the best choice, we should be looking for coherence in the choices that we make.

Table 9. Main results obtained from the feasibility and viability analysis.

Narrative		Feasibility	Viability
Food security	+	(1) Deficit irrigation, although not initially considered as supported innovation, achieves good results in water -savings at practically no cost of the production.	
	-	(1) Internalizing the food demand significantly increases water consumption in Southern Europe. (2) Rebound effect (3) Achieving high intensities with intensified agricultural inputs application detriments soil and water quality.	(1) Internalizing the food demand significantly increases the labour requirements. (2) The allocation of socio-economic responses that may counteract the rebound effect requires a robust institutional framework context.
Market competitiveness	+	(1) Imports externalize the use of water elsewhere, which in turn save water resources at the local scale. (2) Globally, trade is responsible for a significant amount of water savings.	
	-	(1) Under the current dietary trends, exports of animal products from the EU, which are highly water-intensive, will increase in the future, increasing the demand for water for production. (2) Market dynamics may unchain shifting cropping patterns towards the growth of water-intensive crops	(1) Sustainable trade requires international cooperation and concrete actions. (2) Sustainable trade needs robust logistics and transport infrastructure.
Environmental protection	+	(1) Changes towards fewer animal products consumption reduce water consumption for crop production and place the EU within sustainable limits of water extraction.	(1) The EU's current production methods are considered sustainable in comparison to the rest of the world.
	-	(1) Drop yield attributed to extensification practices may result in extensions in the agricultural area, which can be limited by the availability of land funds. (2)	(1) Practices of extensification, such as organic farming, present significant drops in yield which threatens essential functions of crop production like the provision of food. (2) Changing diets towards fewer animal products consumption places much weight in the behaviour of the consumers.
Climate mitigation	+		
	-	(1) Energy crops production is water-intensive. (2) Energy crops compete for land with food crops and expansion is limited by the availability of land funds. (3) Land expansion can produce GHG emissions if areas that sequestrate carbon are changed to agricultural land.	(1) Second-generation biofuels do not meet the energy targets set by the EU. (2) The return does not justify the investment. (3) Lack of monitoring mechanisms regarding climate mitigation in agriculture.
Technological optimism	+	(1) Drip irrigation can achieve a substantial reduction in the water used for irrigation.	(1) The governmental budget has been assigned to the support of agricultural research and development.
	-	(1) Rebound effect.	(1) High costs associated to the implementation of technological innovations. (2) Farmers require high levels of training to employ technological innovations. (3) The allocation of socio-economic responses that may counteract rebound effect requires a robust institutional framework context.

Derived from the quality check analysis, we provide examples of recommendations for the different stakeholders that we assorted as required to reach the goals represented in the different narratives and the parallel achievement of water savings through innovations, or, in other words, improve their feasibility and viability. These interventions are described and appointed in Table 10.

Table 10. Exampled of potential Implications for stakeholders in the function of the different narratives to improve viability.

Narrative Stakeholder	Food security	Trade	Environmental protection	Climate mitigation	Technological optimism
Government	(1)Policies that support increased water productivity for crop production. (2) Reinforce policy instruments that control and regulate the use of water for agriculture and irrigation.	(1) Policies that incentivize and/or support (sustainable) agricultural trade.	(1) Employ socio-economic responses that control and regulate the use of water for agriculture and irrigation. (2) Promote a change in European diets towards a vegetable-rich diet with a less environmental burden.	(1) Policies that incentivize and/or support farmers to grow energy crops.	(1) Policies that incentivize and/or support farmers on the adoption of irrigation technology and what it entails (training).
Private Industry	(1) Ensure a constant and adequate supply of irrigation technology. (2) Provide training courses for the farmers to guarantee the adequate use of the technology.	1) Ensure a constant and adequate supply of irrigation technology. (2) Provide training courses for the farmers to guarantee the adequate use of the technology.	1) Ensure a constant and adequate supply of irrigation technology. (2) Provide training courses for the farmers to guarantee the adequate use of the technology.	1) Ensure a constant and adequate supply of irrigation technology. (2) Provide training courses for the farmers to guarantee the adequate use of the technology.	(1) Ensure a constant and adequate supply of irrigation technology. (2) Provide training courses for the farmers to guarantee the adequate use of the technology.

Research Institutions	- Research to maximize water productivity through yield increases.	- Research an optimal allocation of crop production from an environmental standpoint.		(1) Research to maximize land and water productivity for energy crops.	(1) Develop and enhance new and existing irrigation technologies to overcome water challenges.
Farmers	(1) Adopt high water productivity innovations.	(1) Grow crops with the best water productivity – revenue ratio.	(1) Adopt innovations that reduce the use of water per hectare.	(1) Adopt high water productivity innovations.	(1) Adopt irrigation technology and undergo the proper training entailed.
Consumer	(1) Consume domestic produced crop products.	(1) Adopt an ethical consumption behaviour which favours the production of less water-intensive crops. (2) - Consume imported crop products to stimulate the global market. (3) Consume imported crop products to stimulate the global market	(1) Change to vegetable-rich diets with a less environmental burden. (2) Consume sustainably produced crop derived products. (3) Adopt an ethical consumption behaviour which favours the production of less water-intensive crops		

4 Stakeholder Engagement

Our stakeholder engagement was conducted in two stages. In stage one, we focused on Phase 1 and used it to support the extraction of the main overarching narratives shaping crop production in the EU, focusing on water savings in irrigation. The results of the stakeholder engagement provided the basis to the build-up of the overarching narratives on crop production. In stage two, we focused on Phase 2 and used it to assist the assessment of the different narratives via contributions to the QST analysis (for more info about QST please refer to Section 5.2.1). The results, however, helped us to confirm the information that we used in Phase 1. This section describes the stakeholder engagement activities and explains how they contributed to our findings.

The two stages of the engagement had a common denominator: the stakeholders that participated were addressed through the Water Footprint Network (WFN). WFN is a network organization with a broad international network of stakeholders in the agricultural and water sectors. The network includes 100+ partners from includes business, governments, NGOs, and academia, many of which are in the agri-food or apparel industries.

The first stage of the stakeholder engagement was of an explorative character and had as objective to pinpoint the different stakeholder communities that are of interest for the topic of water savings in irrigation and crop production altogether. To do so, we directly engaged with representatives of the Water Footprint Network (WFN). The experts we spoke to have frequent engagement with the WFN network partners and hence a good overview of the main stakeholder communities we should include in our narrative-building approach. The talks took place in September 2019 and the discussion revolved around the main groups of stakeholders related to crop production, water and irrigation in the EU and their interests.

Based on their inputs, we identified the following stakeholder communities to further explore:

- EU Institutions and agencies
    - EEA (European Environment Agency)
    - European Commission
    - JRC (Joint Research Centre)
- Global organizations and agencies
    - FAO (Food and Agriculture Organization of the United Nations)
    - WTO (World Trade Organization)
    - IFOAM (International Federation of Organic Agriculture Movements)
    - IFA (International Fertilizer Association)
- EU Unions
    - Irrigants d’Europe
    - COPA-COGECA (Committee of Professional Agricultural Organisations - General Confederation of Agricultural Cooperatives)
- Private industry

  - Irrigation companies – Netafim, Mega Group, G. Magnano, etc.
  - Fertilizer manufacturers – Yara, Nutrien, The Mosaic Company, etc.
  - Herbicides/pesticides manufacturers – BASF SE, Bayer Crop Science, Dow Agro Science, etc.
- Scientific community
- Consumers

Once the stakeholder communities were identified, we proceeded to gather relevant publications that provided information that represented the interests and views of these communities. This exercise allowed us to identify and develop the five main narratives presented in Section 2.6 shaping crop production within the EU. For more information regarding the full process of demarcation and description of the narratives, please refer to Section 5.1. The conclusion of this task marked the end of Phase 1 of the present document.

The second stage of the stakeholder engagement targeted the quality check on the narratives by assessing the coherence between the way in which they save water through the innovations that they employ and the goals that they pursue. The engagement contributed to the assessment by exploring the different views of experts in agriculture and water. Following a survey strategy, we designed a questionnaire directed to the WFN professionals and partners. We selected the potential respondents of the questionnaire according to their areas of academic and professional expertise. We were interested in their expert view on the different innovation categories that were identified in this project that can help save water in irrigation. We wanted to learn how each perceives these innovations' benefits, potential downsides, and the implications they may have for various stakeholders.

We developed five primary sets of 12 questions, one for each narrative. Within each set, we developed three secondary sets of questions, one for each group of innovations. To ensure a moderately high response rate, we decided to merge two innovations categories in the questionnaire, namely 'irrigation strategies' and 'irrigation techniques and technologies' as the both were directed exclusively to the action of irrigating. This allowed reducing the overall number of questions significantly. The four questions in which the whole questionnaire was based are presented next:

1. What are the significant points of criticism or dismissal (cons) of this innovation category within the narrative?

2. What are the significant points of benefit or approval (pros) of this innovation category within the narrative?

3. Which stakeholders are most affected in a positive way (winners) by the implementation of these innovations within this narrative and why?

4. Which stakeholders are most affected in a negative way (losers) by the implementation of these innovations within this narrative and why?

The questionnaire was sent to 16 different people in January of 2020. The response rate was 50%, with a total of eight responses. The different answers received allowed us to grasp the different potential conflicts among stakeholders about the priorities given to certain innovations against others concerning the different narratives and the reasons behind it. Furthermore, it provided information of the latent trade-offs and points of criticisms and approval that can be derived from the use of certain innovations under the context of a certain narrative identified in Phase 1. The results of the survey enrichened our QST analysis, especially for the desirability dimension (which was mostly evaluated by means of the results of the survey), and confirmed many of the assumptions and decisions made for the development of the five overarching narratives that shape crop production in the EU. Table 5 presents the different implications for different stakeholders if the visions behind the differences were to be implemented. For more explicit information regarding the results of the survey, refer to ANNEX II where we compiled the overall answers of the survey in a narrative - innovations matrix.

5 Materials and Methods (M&M)

5.1 M&M Phase 1

In phase 1, we inventoried and described the most prominent measures that could potentially result in water savings. To do so, we relied on the scientific body of literature, official publications, and grey literature (e.g. Eurostat and EEA reports) regarding the topics of irrigation, irrigation efficiency, water savings in crop production, BWF reduction, and topics alike. We explained how the measures could result in water savings through the concept of water footprint and drew on their potential constraints. This section explicitly describes the research methodology that we followed to fulfil the objectives related to Phase 1.

First, aided by the first stage of our stakeholder engagement, we demarcated who are the main stakeholders related to water savings in irrigation. This activity set the starting point of the research. The results indicate that given the broad nature of our research, identifying and describing the overarching narratives on crop production within the EU is related to a large number of stakeholder communities. Within such communities, the views of individual stakeholders will certainly differ, but we are interested in the prevailing views that best represent the views of a stakeholder community. The logical next step was to derive their views on the matter by scrutinizing their published reports and literature. We searched for existing documents (e.g. policies, scientific papers, reports, position papers, etc.) coming forward out of each stakeholder community, which provide an excellent opportunity to distil the different and prevailing narratives. The key categories of literature that we scrutinized are listed next:

- Official governmental publications (e.g. CAP documents.)
- Newspaper articles which reflected the position of certain groups.
- Scientific articles and reports based on real case studies or direct stakeholder engagement activities.
- Publications by big organisations that shape agriculture worldwide (e.g. FAO and WTO).

These documents are representative of the stakeholder community because they are built upon engagement with multiple individuals within those communities. We systematically searched these documents for stakeholder opinions and information regarding the intrinsic motivations behind them. This analysis gave answers for each stakeholder community to questions such as: What exerts an influence on crop production? What is influenced by crop production? What are the main functions that crop production fulfils in the EU? What has defined agriculture through time in Europe?

The main challenge related to this task lies in the broad nature of the research: the agri-food and water-environment sectors touch upon a vast community with different stakes in the matter. Given a large number of stakeholders and their related visions on the topic, directly addressing them would have imposed very complex and intensive labour. Therefore, rather than personally engaging them, we saw an opportunity in referring to publications that represent their opinion and are publicly available. This decision yielded the expected results and provided the information necessary to fulfil our objectives.

The main challenges related to our decision lie in the fact that stakeholders are not exclusive for one narrative. Most of them fit them all. For example, the EU government, through the Common Agricultural Policy's related instruments, targets objectives related to all the overarching crop production narratives. The analysis of the vast amount of information thus came as a challenge. Furthermore, we are looking at different ways to save water in irrigation rather than a single innovation. This aim implies that the different measures can be part of more than one narrative in most of the cases, which also increases the complexity of the task of distilling the narratives and their implications in terms of water savings.

5.2 M&M Phase 2

In Phase 2, we coupled the visions on water-related to the different narratives to the potential measures for water savings in irrigation. Also, we identified and qualitatively and quantitatively assessed certain factors that may limit the feasibility, viability and desirability of crop production narratives. Using QST as the backbone of our analysis, we were able to incorporate the main elements in the system's metabolism and employ them to evaluate the plausibility behind the narratives and their course of action towards water savings in irrigation. This section describes the QST methodology as applied for this study and brings to light the considerations and assumptions made regarding its employment.

5.2.1 QST Analysis

QST in this study is employed to assess if water savings under the context of different irrigated crop production narratives are plausible on a broader context with nexus considerations. The focus is set in direct and indirect factors influencing the use of water for irrigation and vice-versa. QST does not envisage to provide an exact solution, but rather to offer a better understanding of the irrigated crop production patterns and its trade-offs by exploring the consistency of each of the five narratives. This section will introduce the QST methodology and describe its main components in the way that they were considered for this study. **The entirety of this section is based on the information provided by Giampietro, Aspinall, et al. (2013).**

The QST methodology is used to improve the understanding of the operation of a system and its metabolic pattern to understand its current and future constraints. QST inquires into the robustness of the dominant narratives that govern the system at hand. Narratives, also known as storylines, dictate the framing of a particular situation. Single framings often highlight only one dimension based on one representation of reality. Representing reality requires a combination of several different points of view with the aim of reducing uncertainty. However, it is the goals, assumptions and stakes behind a given narrative which explain and 'justify' their existence. In this report, the system at hand is the European irrigated crop production.

The metabolic pattern of the crop irrigated production is characterized by different funds and flows. On the one hand, fund elements are used yet not consumed as they remain constant across the analysis and represent what composes the system. Examples correspond to permanent elements such as land, soil, and water bodies. On the other hand, flows elements are intermittent as they can experience changes during the analysis and represent what the system does in relation to the environment. Examples correspond to food production, use of water, and GHG emissions. They are expected to comply with fixed requirements/constraints or reference values. These elements set the base for the analysis.

A QST analysis is composed of the assessment of three criteria: feasibility, viability, and desirability. Feasibility refers to external factors that dictate the compatibility of the narrative with biophysical processes outside human control. It looks at the gross requirements of natural flows and funds to produce and the sink capacity, where the latter refers to the effects of the irrigated crop production on the environment. Viability covers internal factors which reflect on the compatibility of the narrative with processes under human control, concerning both the economic and technical dimensions. A metabolic pattern is viable if it is able to produce an adequate internal supply of the flows consumed. In this case, for example, irrigated crop production must be able to produce enough food flows for the EU society, or sustainable water flows. Desirability is based on the societal dimension and comprises actors or groups of actors that are directly or indirectly affected, either positively or negatively, by a particular narrative. It evaluates the compatibility of the narrative with a multitude of normative considerations, such as values, goals and expectations, that are relevant to a plurality of actors.

An important component of this deliverable is the inclusion of the WF as a concept to measure water savings. We integrated the WF concept into the categories of flow fund, loading and outputs illustrated in Figure 17. WF can be expressed both as a flow/flow and flow/fund ratio. The water flow that is consumed in the irrigated crop production processor is extracted from a natural resource (fund) and has as output a crop production flow. This water flow then can be compared against the land fund to understand the impacts per unit of area, or compared to the crop production flow to understand the impacts per unit of production. In the case of biofuels, it can be compared to water flow necessary to produce a unit of energy. Or, in the case of competitiveness, for example, the water flow to produce a financial unit. In climate mitigation, to the GHG emissions per water flow. Now, for water pollution, the GrWF can be used to express the loadings that cause water pollution.

Figure 17 represents the processor irrigated crop production following the MuSIASEM approach. This processor receives a variety of human-controlled inputs in the form of flows (consumed and transformed) and funds (inputs maintained by the society) to generate certain outputs. Natural resources and loading are outside human control and refer to inputs taken, and effects produced from and to the environment, respectively. Water (in black) is accounted for in every dimension. Water for natural resources comprises the utilization of freshwater for irrigated crop production; water for flows involves the extraction and application of water in irrigation for crop production; water for funds means that the state of the natural freshwater resources must be maintained for irrigation to produce crops; water in loadings comprises the effects of the extraction and application of water in irrigation on the state of the natural freshwater resources, namely the depletion of such bodies; and water in outputs corresponds to the potential protection that may be achieved in the metabolic process of irrigated crop production when water savings are achieved. In addition, the main ideas behind the overarching narratives (in bold) are located within the outputs and funds dimension. This model was used for illustrative purposes only to further understand the metabolic patterns of irrigated crop production.

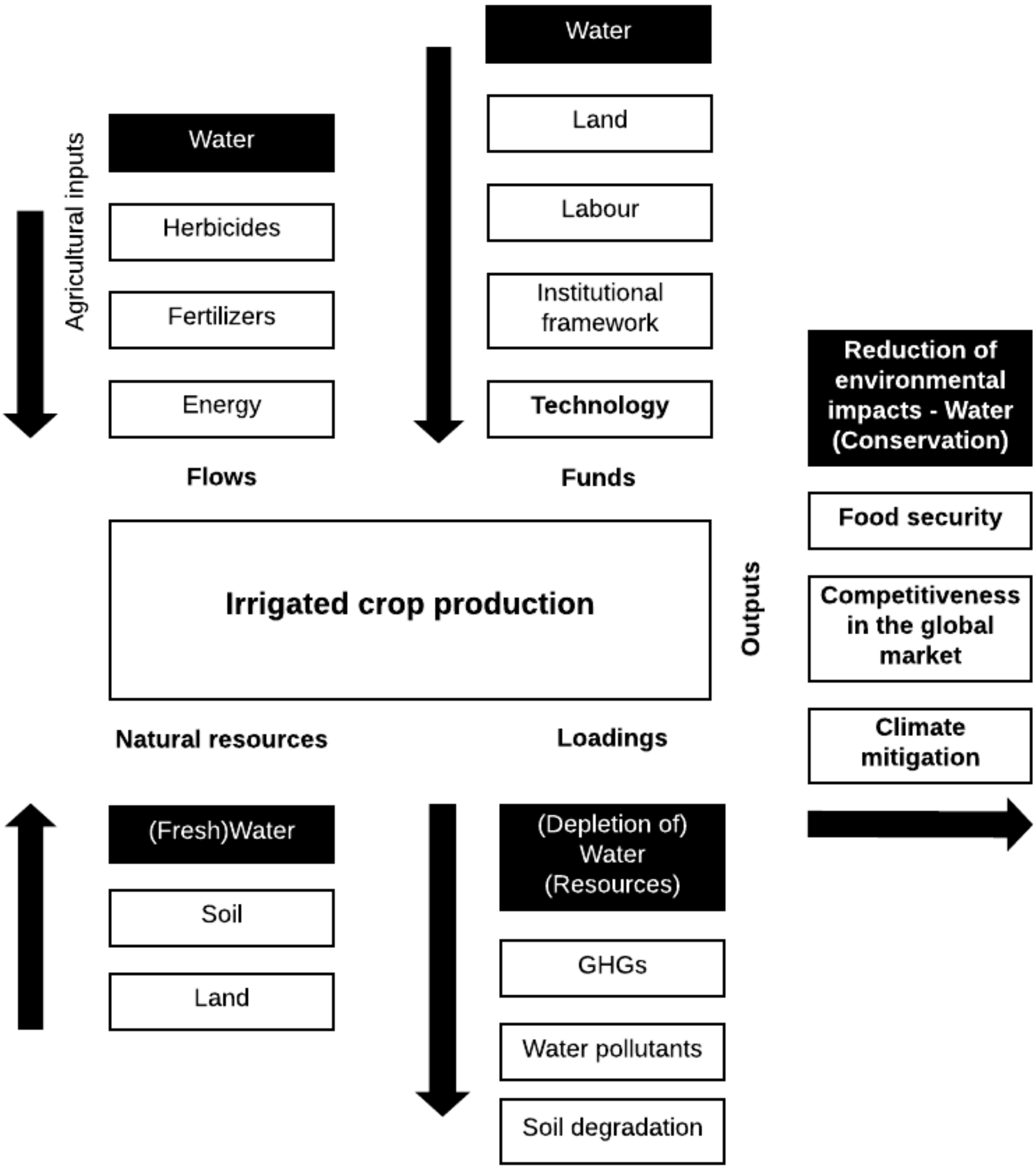

Figure 17. Representation of the system´s metabolism of irrigated crop production as a 'processor'.

Based on the processor model of irrigated crop production, we were able to identify the main factors to consider for the feasibility and viability analysis. Desirability, on the other hand, discusses how different actors are affected by a narrative and was approached through a stakeholder engagement.

For more information about the assessment of the desirability, please refer to Section 4. Next, the assessment criteria and the materials used for its assessment will be explained.

5.2.1.1 Feasibility

Feasibility refers to external factors by capturing the compatibility with processes outside human control, or system boundaries. For this study, it refers explicitly to the feasibility of a particular narrative regarding how water savings are approached and what they may entail for the rest of the environment. Examples of such are the availability of land, water and soil. We also consider the sink capacity, which refers to the adverse effects that irrigated crop production exerts in the environment.

To assess it, we made use of existing scientific studies, previous MAGIC deliveries, and data provided by the Eurostat, EEA and the European Commission. This analysis of literature allowed us to provide a quantitative evaluation of the feasibility of the five different narratives. However, part of our assessment was qualitative as we could not find specific numbers to support particular arguments. However, the statements provided in the qualitative part were substantiated by relevant literature.

5.2.1.2 Viability

Viability encompasses internal factors by addressing processes under human control, related to the economic and technical dimensions. We assorted variables such as financial capacity, level of training of farmers, technological supply, labour requirements, and similar, as important for the assessment of the viability in the context of irrigated crop production.

To assess it, we made use of existing scientific studies, previous MAGIC deliveries, and data provided by the Eurostat, EEA and the European Commission. This analysis of literature allowed us to provide a quantitative evaluation of the viability of the five different narratives. However, part of our assessment was qualitative as we could not find specific numbers to support particular arguments. However, the statements provided in the qualitative part were substantiated by relevant literature.

5.2.1.3 Desirability

Desirability involves the position of the main actors with a stake in the different narratives, depicting the compatibility with a multitude of normative considerations relevant to a plurality of actors. For this study, it refers explicitly to the desirability of a particular narrative for different stakeholders regarding how water savings are approached.

To assess it, we used the results originated by stakeholder engagements. For more information related to the stakeholder engagement please visit Section 4.

6 Reflections on the Learning Experience

In this study, we set out to identify and assess the coherence between the main overarching narratives influencing crop production in the EU and the innovations that they endorse to achieve water savings in irrigation. We identified several innovations with the potential to achieve water savings in irrigated crop production, and we coupled them with five dominant narratives on crop production in the EU. Furthermore, we assessed the consistency behind the narratives and their different courses of action. The implications for water savings of each narrative then were assessed considering nexus thinking, and we found out what may restrict the water savings of the narratives and what the water savings may restrict. This section discusses the primary learning outcomes of the quality check of the five overarching narratives regarding crop production and what they conceive as applicable to achieve water savings.

Several studies assessed water saving potential of particular innovations, such as (Chukalla et al., 2015; Nouri et al., 2019). This study built on such findings and aimed to investigated what reasonings and storylines may be behind the selection of such innovation over another. Doing so helps understand more holistically the chain of thought from conception to implementation.

For Phase 1, one of the main challenges that we encountered in the development of this study is that, given the broad nature of our research, identifying and describing the overarching narratives on crop production within the EU is related to a large number of stakeholder communities. Within such communities, the views of individual stakeholders will certainly differ, but we were interested in the prevailing views that best represent the views of a stakeholder community. We searched for existing documents (e.g. policies, scientific papers, reports, position papers, etc.) coming forward out of each stakeholder community, which, albeit labour intensive, provided an excellent opportunity to distil the different and prevailing narratives. Linking them with the different narratives, however, was a more organic task that was validated and verified by the stakeholder engagement. Although stakeholders were not directly addressed to develop the narratives and linking them to the different water-saving innovations, the results of the engagement applied for Phase 2 confirmed our results. Examples of result that were confirmed were the goals behind the different narratives and the way in which water savings could be approached.

For Phase 2, the main challenge was the limitability of literature regarding certain topics. Although there literature regarding water use for irrigation is gaining momentum, specific data, especially scaled to the EU, is scarce. Furthermore, the EU official statistics are not up to date. In some cases the last actualization was relatively close to the present day, but in some others, it was in the range of 10 years before. That hinders an accurate representation of the current EU situations. The same case is true for some of the results of the scientific studies that we employed. The information that we retrieve, nevertheless, was sufficient to substantiate the feasibility and viability in a quantitative manner though qualitative assessments were also an important part of the analysis.

Desirability was proven to be very complex to assess given the broad nature of the crop production sector, which involves many users and uses. Furthermore, the desirability comprises many ‘If’ scenarios, where different actors can be both ‘winners’ and ’losers’ at the same time. Take for example the farmers, in a technological optimism perspective, they are winning if they can afford the technology and losing if the cannot. But if, for example, the EAFRD provided the resources to implement such technology then they are winning. Evaluating the desirability is therefore nearly impossible, at least doing it in a concrete manner is. However, we see the added value of adopting desirability thinking, where you can easily spot where the conflict may arise.

QST provided the opportunity to assess the narratives in terms of the metabolic patterns of the system. By examining a number of different variables in terms of flows, funds, loadings and outcomes that were successfully linked to the water footprint concept, we identified a number of different elements that may constrain and be constrained by irrigated crop production in a broader context considered of potential nexus issues. We learned that implementing innovations that strive for water savings have many potential effects both for water and interconnected domains. The choices must be widely informed to improve the feasibility, viability and desirability of the selection. We also learnt that the narratives assigned to crop production in the EU have variations in consistency, and some may be perceived as more plausible than others related to different goals. Understanding this goals is crucial.

To finalize, we would like to remark that for the case of water savings in irrigation there is no silver bullet. Instead, one needs to be aware of the existence of overarching narratives and what they entail raising awareness of self-biases caused by an inherent preference for either narrative. Only then can we systematically start building compounded sets of innovations to support desired narratives and discuss trade-offs and synergies with other narratives where possible.

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ANNEX I. Water-Saving Innovations Explained

Innovations		Explanation
Agricultural management practices	Mulching	Mulch is a material placed around or over a plant. They are applied to the soil surface to reduce non-beneficial water uses, suppress weeds, and regulate temperatures. Mulches can be divided into organic and synthetic. When the former contain higher nitrogen levels, crop productivity can be improved (Zane, 2015). From a water point of view, the mulching practice affects soil cover, which helps to preserve soil moisture by reducing non-productive evaporation (Morison et al., 2008). This decreases the required amount of water that is required from irrigation (Chukalla et al., 2015; Zane, 2015). Organic mulches are associated with a substantial reduction in the water footprint, and synthetic, with an even larger reduction (Chukalla et al., 2015).
	Tillage	Tillage refers to the preparation of the land for crops by agitation and manipulation of the soil. On one hand, low-tillage practices improve the properties of the soil and its water retention capacity thus substantially reducing soil evaporation (Morison et al., 2008; Nouri et al., 2019). High tillage has been said to affect the ability of the soil to hold moisture and withstand erosion (FAO, 2011). From a water standpoint, low tillage is translated into a reduction of the field evapotranspiration hence reducing the water footprint.
	Application of fertiliser	The use of fertilisers significantly increases crop yield hence production. They provide nutrients to the soil necessary for plant growth. The consumption of fertilizers is dictated by the nutrient requirements or each crop and the yield expectations, which are both influenced by land management, soil type and climate (Eurostat, 2019e). For irrigation, an increase in yield improves water productivity hence decreases the water footprint. The fertilisers can be classified into natural and mineral. While organic fertilisers contain all the elements necessary for plant growth, mineral fertilisers have a higher content of nutrients. The former consist of manure, compost and

		sewage sludge; and, the latter, in artificially produced nitrogen and phosphorus (Eurostat, 2019e). Residual nitrogen and phosphorus from agriculture contribute to water pollution. Nutrients leaching due to agricultural activity is one of the main causes of non-point source pollution of both surface and groundwater (Mekonnen & Hoekstra, 2011b). This leads to severe adverse environmental impacts such as acidification and eutrophication. The Nitrate Directive and the WFD have established regulations and measures to limit nutrient losses to water bodies, both of which are captured by the cross-compliance scheme of the CAP. This may explain a 19% reduction in the use of nitrogen mineral fertilisers in the EU during the period of 1990 – 2010 (Eurostat, 2019e). Among other environmental effects, the application and production of mineral nitrogen fertilisers by agriculture is associated with GHG emissions, which makes agriculture an important driver for climate change (Eurostat, 2019e). The use of nitrogen mineral fertilisers is responsible for 17% of the volatile ammonia emissions (Fertilizers Europe, 2019). Furthermore, the production of mineral fertilisers accounts for 1.2% of the total energy consumed (International Fertilizer Association, 2014), which generation also exerts pressure on natural resources.
	Application of pesticides	The use of natural and artificial pesticides protects the crop against diseases and predators. The term covers a wide range of products among which insecticides, fungicides, herbicides and rodenticides. Their use prevents losses reductions on the total crop yield. For irrigation, the use of pesticides improves yields (Eurostat, 2019b; Morison et al., 2008) which in turn decreases the water footprint. The use of pesticides, however, raise a debate given the undesirable impacts it concocts (Morison et al., 2008). The environmental impact due to pesticide use depends on the type, application method, crop and soil type, etc. Pesticides can impact water quality and biodiversity through run-off and leaching.
	Intercropping	Intercropping comprises the activities or growing two or more crops in proximity. It supports higher yields through better utilisation of resources (Lithourgidis et al., 2011). For

		irrigation, this practice improves yields which in turn decreases the water footprint.
	Crop diversification	In the EU, the greening obligations of the CAP state that farms with more than 10 ha of arable land have to grow a minimum of two crops; and, those with more than 30 ha, a minimum of three crops. The main crop must not exceed more than 75% of the land (European Commission, 2019h). Crop diversification helps to maintain soil health and therefore influences crop yield.
	Crop rotation	Crop rotation refers to the activity of growing different types of crops in the same area in sequenced periods. Some of its benefits correspond to the reduction of soil erosion, improved soil fertility, and increased yields. Furthermore, it enhances resilience to water scarcity (Nouri et al., 2019). For irrigation, this practice improves yields which in turn decreases the water footprint (Eurostat, 2019b). Crop rotation is addressed by the cross-compliance scheme of the CAP's GAEC as an optional standard to maintain soil structure.
Irrigation strategies	Partial root-zone drying	Irrigation strategies refer to the quantity of water applied and the periodicity of the irrigation. Examples of different types of irrigation strategies correspond to full when the all the evaporative demand is met; deficit, when the irrigation supply is slightly below the required amount (it can be regulated or non-uniform, and sustained or uniform); supplementary, when a limited amount of water is supplied when rainfall is scarce; and no irrigation, when the totality of the water comes from rainfall (Chukalla et al., 2015). Partial root-zone drying, a type of deficit irrigation, has also been associated to reduced water use with non-significant penalties on the crop yield (Berman et al., 2012; Karandish, 2016; Morison et al., 2008).
	Deficit irrigation	In terms of reduction of water footprint, deficit irrigation always scores better compared to full irrigation due to its capacity to increase water productivity (Chukalla et al., 2015; Nouri et al., 2019). Deficit irrigation provides water below the water requirement and avoids the excessive use of water (Morison et al., 2008). However, if it is not applied effectively, yields can be substantially decreased and even ravaged (Berman et al., 2012).

Irrigation techniques	Sub-surface and surface drip irrigation	Irrigation techniques refer to the way in which irrigation is applied to the crop field. Their differences, for example, correspond to the percentage of surface wetting each one provides. This percentage in turn influences evapotranspiration (Chukalla et al., 2015). Classification of techniques corresponds to surface irrigation (furrow, border and basin), trickle irrigation (drip and subsurface drip) and sprinkler, each one with a different percentage of wetted surface area (Chukalla et al., 2015). Trickle irrigation practices are associated with the biggest reductions on the water footprint due to their capacity to maximize the water that reaches the plant (Chukalla et al., 2015; Nouri et al., 2019). Surface irrigation consists of the application of water by gravity flow to the surface of the field. It is categorised by the way in which water is fed into the field: basin (the entire field is flooded), furrow (small channels) and border (strips of land) (Berman et al., 2012). Drip irrigation wets the immediate root-zone of the plants via drippers where water conveyed under pressure through pipes drips slowly (Berman et al., 2012).
	Micro-sprinklers	Sprinkler irrigation simulates rainfall by pumping water through pipes into sprinkler heads that spray the crops (Berman et al., 2012).
Irrigation technology	Precision irrigation	Precision farming revolves around the use of specific locations and crops real-time data for agricultural production and management. By applying the optimum amount of irrigation throughout fields, most researchers expect a reduction in water use on at least parts of fields and in the total application, if not a reduction aggregated over entire fields. Results from case studies of variable rate irrigation showed water savings in individual years ranging from zero to 50%, and savings averaged over a number of years from 8 to 20% (Smith et al., 2010). Irrigation aspires to be and should be a precision activity involving both the accurate assessment of the crop water requirements and the precise application of this volume at the required time (Smith et al., 2010). Precision Irrigation is not a specific technology but an approach. Crop yields are optimised through systematic gathering and handling of information about the crop and the field. A range of irrigation management and application

		technology, sensing, modelling and control technologies are suitable for use in a Precision Irrigation system.
Socio-economic responses	Water pricing	Charging water use may encourage farmers to restrict their consumption. It can promote a more careful use of water (Arcadis, 2012; Berman et al., 2012)
	Water regulation and allocation	Water regulations target an organisation of water among different users whereas water allocation consists of the assignation of a certain amount of water per fixed amount of time to the users (Berman et al., 2012)
	Water auditing and benchmarking	Includes measures to let the water users be aware of their water consumption, for example by measuring the water footprint (Berman et al., 2012)
	Market pressure	It involves actions taken from part of the consumers that cause producers to change practices. This requires work in traceability and labelling (Berman et al., 2012)
	Raise awareness	This measure targets a collective consciousness about the water consumption behind the production of a given product that may change production and consumption behaviours (Berman et al., 2012)
	High water productivity crops selection	This practice includes the grow of selected crop types. The selection is driven by different factors; for example, the market, increase demands for a specific product or, environmental benefits. The last one corresponds to the identification with lower environmental (i.e. water) footprint but capable of providing the nutritional requirements. If the former governs, a water footprint reduction is not the focus. For example, a report regarding the future of the CAP propose the substitution of irrigated maize by less water-demanding crops (e.g. irrigated sorghum) as a potential action to reduce irrigation water use (European Commission, 2019i). Drought-resistant crops improve resilience and climate adaptation. Such plants have a higher dehydration tolerance and avoidance mechanisms. However, they are often linked to a lower yield (Morison et al., 2008). Drought-resistance requirements are defined by the context. In some areas, drought is experimented constantly over a specific period of the growing season whereas in others, drought is experimented in different periods of the crop development. Furthermore, some plants are reliant on

		the soil water stored and/or rainfall and/or irrigation. Such variations are behind the complexity of drought resistance (Morison et al., 2008).

ANNEX II. Desirability check

Narrative	Agricultural management		Irrigation strategies		Irrigation techniques and technology		Socio-economic responses	
	Winners	*Losers*	*Winners*	*Losers*	*Winners*	*Losers*	*Winners*	*Losers*
Food security	(1) Agricultural inputs manufacturers as their sales increase. (1) Government as they provide food security.	(1) Organic farmers as their yields are smaller. (2) WTO as agricultural trade is reduced.		(1) Farmers, especially low trained, as they risk their production levels. (2) Consumers as their supply is at risk.	(1) Irrigation solutions companies as their sales increase. (2) Irrigant's d'Europe as this is their vision	(1) Farmers as the initial costs temporary make them non-competitive (2) Consumers as they would have to pay for the costs of the technology.	(1) The government as these innovations are often preferred by high-level stakeholders	(1) Farmers as they need to produce with less water
Market competitiveness	(1) Farmers as they can increase revenues derived from increased production. (2) Organic farmers if the demand for their products increase.			(1) Farmers, especially low trained, as they risk their production levels. (2) Consumers as their supply is at risk.	(1) Irrigation solutions companies as their sales increase. (2) Irrigant's d'Europe as this is their vision	(1) Farmers as the initial costs temporary make them non-competitive (2) Consumers as they would have to pay for the costs of the technology.		(1) The farmers as their crop production prices increase, and their water use is restricted. (2) The consumers as the prices may increase, and their supply of crop products may be restricted

Environmental protection	(2) Organic farmers because the demand for their products would increase. (2) Government as they reach increased GAEC compliance	(1) Agricultural inputs manufacturers as their sales decrease.		(1) Farmers, especially low trained, as they risk their production levels. (2) Consumers as their supply is at risk.	(1) Irrigation solutions companies as their sales increase. (2) Irrigant's d'Europe as this is their vision	(1) Low-income farmers cannot afford the technology. (2) Low-trained farmers as they cannot use the innovations. 3) The consumers as the prices may increase	(1) The government as these innovations are often preferred by high-level stakeholders. (2) FAO as this will improve their influence on policymaking	(1) The farmers as their crop production prices increase and their water use is restricted. (2) The consumers as the prices may increase and their supply of crop products may be restricted
Climate mitigation	(1) The scientific community as it provides research opportunities	(1) Agricultural inputs manufacturers as their production is associated with GHGs emission. (2) Farmers as they have to change their production to reduce GHGs emissions. (3) Biofuel producers		(1) Farmers, especially low trained, as they risk their production levels. (2) Consumers as their supply is at risk.	(1) Irrigation solutions companies as their sales increase. (2) Irrigant's d'Europe as this is their vision	(1) Low-income farmers cannot afford the technology. (2) Low-trained farmers as they cannot use the innovations. 3) The consumers as the prices may increase		

Technological optimism	(1) Agricultural inputs manufacturers as to if their sales increase	(1) Agricultural inputs manufacturers as to if their sales increase		(1) Farmers, especially low trained, as they risk their production levels. (2) Consumers as their supply is at risk.	(1) Irrigation solutions companies as their sales increase. (2) Irrigant's d'Europe as this is their vision	(1) Low-income farmers cannot afford the technology. (2) Low-trained farmers as they cannot use the innovations. 3) The consumers as the prices may increase		

ANNEX III. Full Extract of the Answers of the Questionnaire

Narrative	Agricultural Management Practices			
	Question 1	Question 2	Question 3	Question 4
Food security	(1) The use of fertilizers and herbicides may cause water pollution which threatens long-term food security; (2) the use of fertilizers increase irrigation water demands; (3) The use of fertilizers and plastic mulches may cause soil degradation which threatens long-term food security; (4) This innovations often target small holdings with little impact in food security; (5) Intercropping may prompt yield reductions if blue water is restricted; (6) Zero tillage may prompt yield reductions; (7) Crop rotation may prompt soil degradation if crops that detriment the soil fertility are chosen.	(1) Fertilizer reduce yield gaps; (2) organic fertilisers improve soil fertility; (3) Improved water productivity reduces water use; (4) High yields require less land to produce; (5) Mulching and zero tillage save more blue water during the growing season; (6) Pesticides reduce the risk of yield drops; (7) Optimal crop rotation may reduce the need for fertilizers.	(1) Agricultural input manufacturers as their sales will increase; (2) Farmers because they get higher revenues for increased production and can produce more with less; (3) EU government for providing food security	(1) Downstream users, (2) Farmers as yield will temporarily decrease, (3) EEA because of rising risk to the environment; (4) Other water users; (5) General populations as drinking water quality may be degraded; (5) WTO because food trade may be restricted; (6) Technical developers as farmers may switch to this innovations instead of those.
Market competitiveness	(1) These measures may increase production costs and make it difficult to compete in the market; (2) environmental risks; (3) zero tillage and crop rotation may reduce	(1) Eco brands may increase product competitiveness as there is growing environmental consciousness; (2) more crop production, higher revenue; (3) high-water productivity	(1) Agricultural input manufacturers; (2) consumer because of improved quality production; (3) government because of improved economic	(1) EEA because of environment risk at fields

	yields which mar reduce gross revenue	for any crop lets product be more competitive	development; (4) WTO for the role it plays in the balance	
Environmental protection	(1) Pollution due to agricultural inputs; (2) plastic mulching damages soil; (3) crop rotation may result into poor soil condition	(1) This measures holistically take care of soil health and the ecosystem; (2) reduce ET will save water	(1) European Environment Agency since their advices will be adopted	(1) Traditional private farmer due to their small scale yield
Climate mitigation	(1) Focusing in energy crops promotes monoculture and its conflicting with crop diversification; (2) increased emissions	(1) Increasing yield of energy crops could provide more bioenergy; (2) improving field practices may improve crop yield, and reduce carbon footprint per unit of crops yield	(!) Scientific community because they could help finding a sustainable pathway for agricultural management.	(1) Fertilizer manufacturers because they need to improve their own competitiveness by cleaning production and sustainable usage.
Technological optimism	(1) Zero-tillage may reduce water productivity through reducing crop yield; (2) intercropping may reduce crop water productivity through yield reduction; (3) crop rotation may result in a reduction in the overall water productivity if crops with low water productivity are embedded in the chain, or when soil nutrition is fully depleted by a(some) crop(s) and is not supplied for the other crops	(1) These are low tech measures which are easy to implement; (2) applying fertilizers and pesticides may improve water productivity through improving crop yield	(1) Private industry like mulch suppler because it is eco-tech, and has a wide demand.	(1) Private self-contained farmers because they don't have technique qualified.

Narrative	Irrigation Strategies and Techniques			
	Question 1	Question 2	Question 3	Question 4
Food security	(1) May cause violation of environmental flows; (2) Rebound effect; (3) Needs precise equipment; (4) requires farmers' training; (5) May be non-affordable; (7) Crop prices may increase due to the high investments; (8) Deficit irrigation may result in yield reduction; (9) Drip irrigation may cause soil salinization; (10) High maintenance costs	(1) Reduced water consumption due to increased irrigation efficiency; (2) yield increases	(1) Irrigation companies as their sales will increase; (2) Farmers at the long-term because of higher yields and reduced water costs; (3) Irrigant's d'Europe	(1) Other water users; (2) Farmers as implementing these technologies requires a large investment; (3) EU government because it may have to implement price support; (4) Low income farmer since they cannot justify the adoption of these technologies; (5) Organic farmers because they produce smaller yields
Market competitiveness	(1) These measures make production expensive; (2) operation requires labour which increases economic cost; (3) need of highly educated farmers; (4) the increased costs by the costly techniques may not be justified by the obtained revenue and the net benefit will be restricted; (5) deficit irrigation may prompt yield drops and reduce gross revenue	(1) High techniques will bring high income; (2) deficit irrigation reduce blue water cost increasing net benefit; (3) water savings may use to produce more with the same and gross revenue may increase	(1) Irrigation companies	(1) Consumers because the price of the irrigation technology will be reflected on the prices; (2) Farmers because the initial cost makes them temporarily non-competitive; (3)

Environmental protection	(1) Only focused in water reduction; (2) rebound effect; (3) drip irrigation and soil salinization; (4) micro-sprinkler may disturb soil structure; (5) precision irrigation is only based on CWR and does not consider leaching	(1) Water savings	(1) Other water uses; (2) Irrigation companies	(1) Traditional private farmer due to their small scale yield
Climate mitigation	(1) Biofuel water consumption might be high and can be a factor to deplete water resources and violate environmental flows; (2) drip irrigation, and micro-irrigation, which are usually depended on energy-consumed systems, will end up with larger emissions	(1) Precision irrigation may reduce resource use and results in reduced emission	(1) Irrigation companies because they have wide market demand.	(1) Private self-contained farmers because they don't have technique qualified.
Technological optimism	(1) water efficient technologies might be useful to protect the environmental flows. However, generally a combo of technology, adequate policy, capacity building is needed; (2) these measures need a sound technical knowledge of the workings of these irrigation methods and also the data related to crop growth and soil moisture content; (3) labour requirement and the cost; (4) Deficit irrigation may reduce water productivity through significant yield reduction	(1) These technologies are critical in reducing the water use; (2) Precision irrigation, drip irrigation, and micro-irrigation may increase water productivity through reducing blue water consumption and improving crop yield	(1) Irrigation companies because they have a huge applied demand.	(1) Private farmers because their irrigation technology was far behind.

Narrative	Socio-Economic Responses			
	Question 1	Question 2	Question 3	Question 4
Food security	(1) Water pricing does not account for temporal and spatial water availability; (2) equity issues because water is a right not a commodity; (3) Time of implementation as they require policy support; (4) water pricing implies higher costs for farmers; (5) highly water-productive crops may produce smaller yield which threatens water security; (6) water regulation and allocation may provide more water to higher value sectors; (7) Water pricing may extinguish agriculture altogether in poor areas	(1) Government can make money; (2) These measures will induce a more judicious use of water which will encourage efficient water use which will increase water productivity; (3) these measures are low cost; (4) socio-economic measures are more attractive for high level stakeholders; (5) raising awareness may provide benefits at the long-term regarding the use of water; (6) water pricing may indirectly promote a shift towards higher revenue crops to increase the cost benefit ratio	(1) Government, (2) other water uses as less water in agriculture means more water for them; (3) scientific community as socio-economic responses give many opportunities for investigation; (4) the environment	(1) Final consumers as they will pay the water costs; (2) farmers because of the increased water costs; (3) low income farmers that cannot justify the imposed costs; (4) traditional farmers as their farming methods result in more water use
Market competitiveness	(1) Water pricing may reduce net water benefit; (2) market pressure may not be aligned with the production of high value crops which result in less revenue; (3) highly water-productive; (4) water regulation and allocation may result in producing less-value crops; (5)	(1) Could increase the market weight of water productive crops; (2) water pricing together with raising awareness may help farmer with selecting crops with higher economic value, and end up with higher gross value; (3) if water relocation is done based on	(1) Productive crop development organisation because they have a wide market.	(1) Agricultural input manufacturers; (2) traditional farmers due to poor yield and water waste

	rising market pressure will transfer the pressure to the final consumer	economic issue, more benefits would be expected.		
Environmental protection	(1) Water price would be a sensitive factor to be discussed, it is highly related the daily life of famers and other residences; (2) highly water-productive crops could be highly economic benefit or highly yield benefit; (3) water pricing for instance may force producing crops with higher economic value, while not being environmentally ensured (for instance, producing crops with higher grey WF).	(1) Such techniques may end up with less blue water consumption in general; (2) water regulation and allocation as a policy will make sense to environment protection	(1) Food and Agriculture Organization of the United Nations will improve their influence on policy making.	(1) Consumers will pay more for what they need
Climate mitigation	(1) Consideration the life condition in different regions, water-deficit VS water adequate, how to balance the water use in these regions, with crop trade, would be critical; (2) such strategy may result in selecting high-value crops which may also have high carbon footprint	(1) Awareness of recycling waste would benefit circular economy development; (2) water pricing may reduce resource use and results in reduced emission	(1) irrigation companies because they do well in improve food productivity and reduce water usage.	(1) Fertilizer manufacturers because not a sustainable choice to develop circular economy.

Technological optimism	(1) Market pressure could be an obstacle to produce crops with higher water productivity; (2) market pressure because market is closely linked to consumer, should improve from tech-based perspective.	(1) Highly water-productive crops may improve water productivity; (2) raising awareness may help farmers with cultivating crops with higher water productivity; (3) water pricing may help with selecting crops with higher economic water productivity (more economic yield per drop of water); (4) water auditing and benchmarking, based on the analysis could put forward related technology.	(1) Scientific community because they are the solid part to have innovative technologies.	(1) Fertilizer manufacturers as well as pesticides manufacturers because it will replaced by new technology.

ANNEX IX. Policy Brief

H2020 MAGIC PROJECT POLICY BRIEF / FEBRUARY 2020

Saving water in EU agriculture

What are plausible alternative pathways?

Overview

Irrigation is one of the main drivers behind a number of environmental challenges related to water. While there are many benefits associated with irrigated agriculture (most notably increased food security), across the EU irrigation is also negatively contributing to over-exploitation and degradation of precious but limited local water resources [3].

In the EU, irrigation practice is mainly governed by the Water Framework Directive (WFD) and the Common Agricultural Policy (CAP) (see box on the right). However, a comprehensive integration of the two policies has not been fully achieved and the water challenges prove persistent [4]. The major question that still stands, therefore, is how the EU can effectively save water in irrigated agriculture?

EU Context

Where is the use of water for irrigation captured in the EU policies?

- The Water Framework Directive (WFD) is an instrument of the European water policy that prescribes a basis to ensure the long-term sustainable use of the water bodies across Europe [1]
- The Common Agricultural Policy (CAP) shapes the course of agriculture. It seeks to inegrate the WFD objectives by influencing the use of water in agriculture [2]

Narratives on crop production & irrigation

Effective adoption of particular water-saving innovations depends on more than their water-savings potential alone. Uptake and acceptance varies as a function of the narrative or perspective one holds on the way crops should be produced and which role irrigation ought to play therein. Given the inherent complexity of interlinked water systems and the wide spectrum of narratives that exist, a careful understanding of both is crucial or order to make informed policy choices.

Our analysis identified five overarching narratives that govern crop production in the EU. Each narrative assigns a specific role to water and irrigation, and hence promotes uptake of different water-saving innovations.

1. Food Security – Irrigation is a mean to meet EU food demand. Innovations that increase yield and water productivity of food crops are the focus.
2. Market Competitiveness – Irrigation is a means to increase the global competitiveness of the European agricultural market and improve the EU economy. Innovations that enhance market opportunities and maximize profit are the focus.
3. Environmental Protection – Irrigation is a primary cause of the degradation of natural resources. Innovations to reduce the use of water are preferred.
4. Circular Economy – Irrigation is a means to support a low carbon economy based on the production of biofuels. Innovations that support reduced greenhouse gas emissions and increase yield and water productivity of energy crops are the focus.
5. Technological Optimism – Irrigation is a technological challenge that may boost crop production. Innovations based on the use of technology that maximizes irrigation efficiency and crop water productivity are the focus.

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Towards effectively saving water in EU agriculture

There are many innovations that have been developed with the potential to achieve water savings in agriculture. In the first place, agricultural management practices can significantly influence both crop water use and water productivity. In the second place, smart irrigation strategies can promote reductions in the application of water in the field - without significantly lowering yields (Figure 1). Moreover, there are efficient irrigation techniques and technologies that facilitate crop water uptake and reduce water use. Lastly, particular socio-economic responses can support water savings in irrigation as well, by steering changes in behaviour among producers and consumers.

Our analysis found that there are trade-offs in selection of particular innovations between the different narratives and that socio-economic innovations form an important part of any innovation mix. The path towards effectively saving water in EU agriculture therefore requires both clarity on the goals sought (here framed through the lens of dominant narratives) and coherence between these goals and the innovations that support them. Following a food security or market competitiveness, we face a real possibility of experiencing a rebound effect, where the improved productivity originates a growth in production that offsets the intial gains.

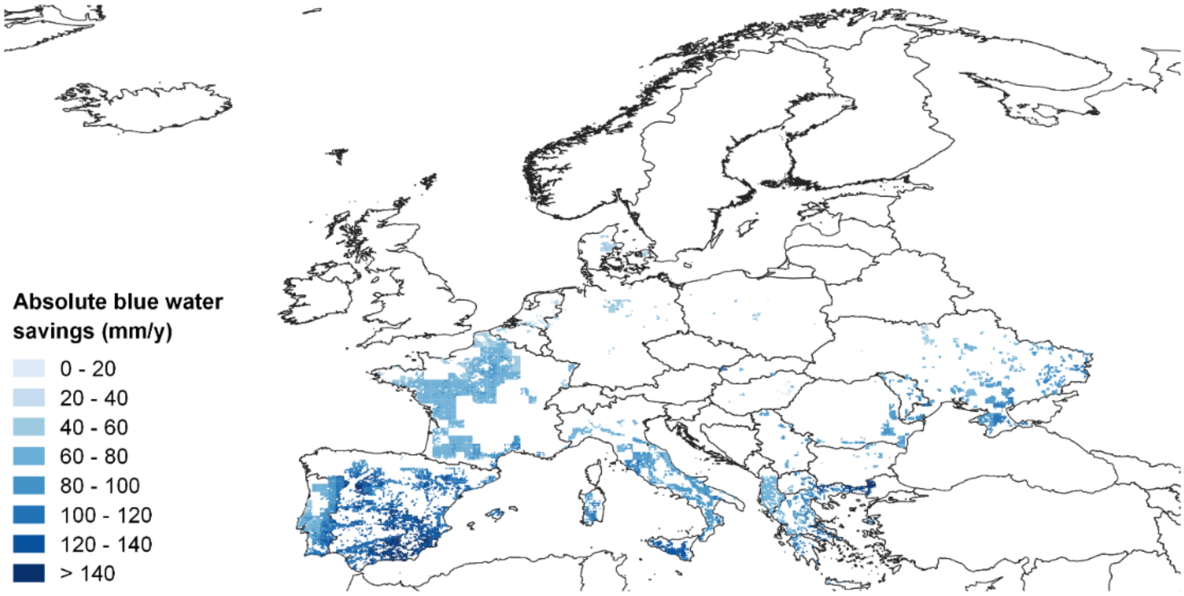

Figure 1. Absolute blue water (surface- and groundwater) savings that can be achieved by employing agricultural management practices (mulching) and irrigation strategies (deficit instead of full irrigation) in water scarcity hotspots of irrigated maize in the EU. Overall, this management package could save 30% of the water consumed for irrigating maize at a minor drop in maize yield (1%). Source: [5].

Conclusion

The broad spectrum of goals currently portrayed by the CAP and the incomplete integration with WFD objectives illustrate such clarity and coherence is still lacking in EU policy. The increased understanding through this work on viable narratives and their preferred innovations contributes towards drafting more effective EU policies that help solve the persistent environmental challenges related to water.

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