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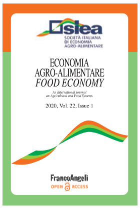

On positive externalities from irrigated agriculture and their policy implications: An overview

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Abstract

Water has important economic values, mainly in the agricultural sector. Beside enhancing agricultural output and crop diversification, irrigation generates positive externalities which have been little emphasized by the literature. The purpose of this review is to investigate the direct, indirect and potential benefits of water use in agriculture by taking an additional step towards the identification and economic evaluation of the observed positive, social, environmental and ecological effects of irrigation. Five categories of contributions are examined: irrigation returns flows for groundwater recharge; biodiversity and wildlife habitat; landscape aesthetic and cultural values; nutrient recycling and retention; and improved health, nutrition and living conditions. Knowing the economic value of such positive externalities would help to get the right policy incentives for better water use and increased water savings in a context of growing water scarcity.

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Introduction

Water is one of the most essential natural resources. It plays a main role in life's birth and evolution of all living species and ecosystems of the planet. Water utility does not cease with the fulfilment of its environmental and biological functions. Indeed, main civilizations started their development nearby rivers or water basins, becoming able to address their needs and provisions by using water resources to develop primary activities (FAO, 2011). The importance of water resources for human life has been formally underlined by the UN (2010) that have declared access to safe water as an essential human right. Water has also been recognized with the state of economic good (ICWE, 1992) which makes it suitable to be treated as any other private good (Perry *et al.*, 1997) or considered as a social good that has to be kept outside the process of market pricing (Van der Zaag & Savenije, 2006).

Nowadays, water is directly or indirectly at the core of each basic human need and is daily used in many different sectors of the economy (FAO, 2011). The agricultural sector is by far the main user of global water resources. The quantity of water consumed by agriculture covers 70% of total freshwater consumption (WWAP, 2017). However, because of climate change, the availability of water resources is destined to be reduced (FAO, 2012). Furthermore, world's population is projected to reach 9.7 billion in 2050 (UN, 2019) requiring increases in food production (Alexandratos & Bruinsma, 2012). Agriculture is the economic sector mostly affected by water scarcity (FAO, 2012) which refers to the limited amount of supply of a good or resource with respect to its demand. Since water demanded by other sectors is increasing more rapidly than that demanded by agricultural sector (FAO, 2011), it becomes increasingly important to find alternative and sustainable water management methods in agriculture (Mastrorilli & Zucaro, 2016).

Water used in agriculture is conveyed through rainfalls and precipitations (rainfed agriculture) or through irrigation techniques (irrigated agriculture). This paper specifically refers to irrigated agriculture. The primary benefit of irrigation is the increase in agricultural production. Indeed, irrigated agriculture is more productive than rainfed cropping. It accounts for 40% of total global agricultural output with only 20% of cultivated lands being irrigated (Turral *et al.*, 2011). Therefore, irrigation development is among the key actions to be undertaken in order to adequately satisfy food demand.

There is a wide debate about the existence of negative externalities of irrigation practices (Singh, 2016), but their positive externalities are much less researched and documented. This paper tries to fill this literature gap. It conducts a review to highlight the benefits of irrigation in the form of positive environmental externalities. The presence of such externalities does not automatically imply a net positive outcome for the environment as negative effects could outbalance the positive ones. Our discussion on the positive externalities from irrigation is biased since the balance between positive and negative effects is not considered. Further research is needed to assess such balance and the effects on the overall society's welfare.

The purpose of this paper is to investigate about the positive externalities of irrigation and make a step towards the complete identification and classification of such positive effects on society's welfare. The paper is structured as follows. Section 1 illustrates the conceptual framework. The methodology adopted for the review is described in section 2. Section 3 summarizes and discusses the main evidences emerging from the literature review. Conclusions are reported in the final section.

1. Irrigation externalities and ecosystem services: a conceptual framework

Irrigation has profound interactions with natural and productive ecosystems and can generate externalities, i.e. variations in the welfare level of other individuals without monetary compensations (Buchanan & Stubblebine, 1962).

The presence of externalities indicates that there are consequences of production or consumption activities which are not included in their economic values. Externalities consist of the environmental and social costs or benefits of economic activities which do not participate to the market price formation of a certain good and fall back to other subjects that are not directly included in the consumption or production activities (Turner *et al.*, 1994). Policies like command and control, taxes, cap and trade mechanisms should be implemented to internalize such costs and benefits in the price of goods. The existence of externalities makes resources allocation inefficient (Turner *et al.*, 1994) and is a cause of market failure. Economic efficiency is achieved when the net benefits deriving from resource use are maximized (Tietenberg and Lewis, 2012) and the maximum level of social wellness is reached. This corresponds to Pareto optimality, i.e. a situation when there is no resource reallocation capable to increase the utility level of society's members (Hein, 2010).

When the efficiency level is sub-optimal the value of production may be improved through a different allocation of inputs and resources involved in the production process (Wichelns, 2002). Inefficiency sources include market failures and property rights misspecification. Markets usually reach efficiency for private goods. Public goods and common-pool resources as water or other natural resources are managed with more difficulties. When resources are non-regulated and their property rights are not defined, the free-riding problem can cause excessive resource use and depletion. Open access resources face economic inefficiencies more frequently than the regulated ones: they are often overexploited by free riders, i.e. users which take advantage of them without paying the corresponding price (Hardin, 1968).

Negative externalities are linked to pollution and represent a cost for the entire society as they negatively affect its welfare levels. On the opposite, positive externalities are associated with an increase of social welfare and represent a benefit for the society that is not incorporated into producers' revenues (Turner *et al.*, 1994).

Positive environmental externalities coming from water use in agriculture are often in the form of enhanced ecosystem services. They are defined as an entire set of processes, conditions and ecological functions that natural ecosystems largely develop providing benefits to the environment and other living species (Daily *et al.*, 1997). They may be given an economic value (Costanza *et al.*, 1997). However, human interaction with natural ecosystems may positively or negatively affect the environment and cause modifications to the natural cycle.

Ecosystem services supply many vital functions that are often interconnected. Identification and evaluation of such functions may be useful to set up systems of economic incentives (Payment for Environmental Services, PES) to generate ecosystem functions at a larger scale. Including the real value of those services and benefits in the price of commodities would create a compensation system for their providers, many of them are farmers and land stewards, improving overall economic efficiency (Branca *et al.*, 2011).

The provision of ecosystem services related to agriculture has already been documented (Zhang *et al.*, 2007; Gordon *et al.*, 2010; Power, 2010) but there is still a lack of debate regarding positive ecosystem services specifically generated by the irrigation practices. Indeed, externalities coming from irrigation water use in agriculture are often associated with negative effects such as pollution, waterlogging or salinization that may directly contribute to land degradation (van Schilfgaarde, 1994; Hussain, 2007; Singh, 2016; Singh, 2018). However, irrigation generates positive externalities as well. They are considered in this work.

2. Methodology

This review has been undertaken through a Google Scholar and Scopus online search engines research. The Food and Agricultural Organization library focused on agricultural studies (AGRIS) was also consulted. The initial keywords used were combinations of the following terms: "positive externalities", "ecosystem services", "irrigation", "benefits", "water resources". After an initial collection and selection of resulting papers, five different categories of contributions were defined, namely: groundwater recharge, increase of biodiversity, landscape aesthetics, nutrients retention and positive impacts on human health and nutrition.

According to this classification, further investigation using the same online libraries and digital archives was undertaken.

Research has been primarily conducted in English. However, a few results in Spanish and Italian languages were also collected, due to their relevance and pertinence to the main topic. To be selected for the review, studies had to include: a discussion on the observed positive social, environmental and ecologic consequences coming from irrigation in agricultural areas in at least one of the categories identified above. Quantitative analysis and evaluations were preferred. However, a small number of qualitative studies, reviews and discussions were also considered. Most of the studies selected and cited in this review have been published in peer-reviewed journals. Additionally, the reference list of each of the selected articles was used to expand the search and potentially include additional insights, with the aim to provide a more comprehensive review about the topic.

Studies reviewed have been divided in five different categories of contributions, in order to better classify and discuss their implication. Such benefits include:

1. Irrigation returns flows for groundwater recharge
2. Biodiversity and wildlife habitat
3. Landscape aesthetics and cultural values
4. Nutrient recycling and retention
5. Improved health, nutrition and living conditions

Table 1 includes a list of the studies considered for the review.

Table 1 – Reference list by category

Category	**Reference**	**Journal**
Irrigation return flows and groundwater recharge	Maréchal *et al.*, 2003	n/a (conference paper)
	Causapé *et al.*, 2004	Agricultural Water Management
	Aizaki *et al.*, 2006	Paddy Water Environments
	Kendy & Bredehoeft, 2006	Water Resources Research
	Silva-Hidalgo *et al.*, 2008	n/a (conference paper)
	Jiménez-Martínez, 2009	Journal of Hydrology
	Kim *et al.*, 2009	Agricultural Water Management
	Lu *et al.*, 2010	National Groundwater Association
	Poch-Massegú *et al.*, 2014	Agricultural Water Management
	Zucaro, 2014	n/a (Research report INEA)
	Ebrahimi et al, 2016	Water Resource Management
	Séraphin *et al.*, 2016	Journal of Hydrology

Table 1 - continued

Category	Reference	Journal
Biodiversity and wildlife habitat	Katano *et al.*, 2003	Environmental Biology of Fishes
	Renault & Montginoul, 2003	Agricultural Water Management
	Bambaradeniya *et al.*, 2004	Biodiversity and Conservation
	Mazerolle, 2004	Landscape Ecology
	Sánchez-Zapata *et al.*, 2005	Biodiversity and Conservation
	Abellán *et al.*, 2006	Journal of Arid Environments
	Aizaki *et al.*, 2006	Paddy Water Environments
	Davies *et al.*, 2008	Agriculture, Ecosystems & Environment
	González-Estébaneza *et al.* 2010	Agriculture, Ecosystems & Environment
	Sebastián-González *et al.*, 2010	European Journal of Wildlife Research
	García Sánchez, 2011	Estudios Avanzados
	Maltchik *et al.*, 2011	Revista de Biología Tropical
	Aspe Gille & Jacque, 2016	Regional Environmental Change
	Choe *et al.*, 2016	Entomological Research
	Herring *et al.*, 2019	Agriculture, Ecosystems & Environment
Landscape aesthetic and cultural values	Sayadi *et al.*, 2005	Ecological Economics
	Aizaki *et al.*, 2006	Paddy Water Environments
	Gil Meseguer, 2006	Papeles de Geografia
	Sayadi *et al.*, 2009	Land Use Policy
	Zekri *et al.*, 2012	Journal of Agricultural Research
	Thiene & Tsur, 2013	Journal of Agricultural Economics
	Zucaro, 2014	n/a (Research report INEA)
	Sánchez-Sánchez *et al.*, 2016	n/a (book chapter)
	Vivithkeyoonvong & Jourdain, 2016	International Journal of Biodiversity Science, Ecosystem Services & Management
	Tekken *et al.*, 2017	Ecosystem Services
	Jourdain & Vivithkeyoonvong, 2017	Agricultural Economics

Table 1 - continued

Category	Reference	Journal
Nutrient recycling and retention	Follett, 2001	Soil & Tillage Research
	Feng *et al.*, 2004	Agricultural Water Management
	Hitomi *et al.*, 2006	Water Science and Technology
	Gillabel *et al.*, 2007	Soil Science Society of America Journal
	Herzon & Helenius, 2008	Biological Conservation
	Wu *et al.*, 2008	Soil Science Society of America Journal
	Battacharyya *et al.*, 2013	Agronomy Journal
	Trost *et al.*, 2013	Agronomy for Sustainable Development
	Olsson *et al.*, 2014	Applied Energy
	Dollinger *et al.*, 2015	Agronomy for Sustainable Development
	Törnqvist *et al.*, 2015	PLoS ONE
Improved health, nutrition and living conditions	Lipton, 2001	Proceedings of the Nutrition Society
	Renault & Montginoul, 2003	Agricultural Water Management
	Hussain & Hanjra, 2004	Irrigation & Drainage
	Smith, 2004	International journal of Water Resources Development
	Hussain, 2007	Irrigation & Drainage
	Tesfaye *et al.*, 2008	Irrigation & Drainage Systems
	Rahman & Parvin, 2009	Journal of Water Resource and Protection
	Burney *et al.*, 2010	Proceedings of the National Academy of Sciences
	Namara *et al.*, 2010	Agricultural Water Management
	Namara *et al.*, 2011	n/a (Research report IWMI)
	Aseyehegn *et al.*, 2012	Journal of Agricultural Sciences
	Burney & Naylor, 2012	World Development
	Domènech & Ringler, 2013	n/a (IFPRI Discussion Paper)
	Dinesh Kumar *et al.*, 2014	International Journal of Water Resources Development

3. Positive externalities of water use in agriculture

This section summarizes and discusses review findings and the resulting evidence regarding positive externalities of irrigation.

3.1. *Return flows for groundwater recharge*

Groundwater surface recharge usually depends on percolation from rainfall precipitations or irrigation practices in agricultural areas. Agricultural uptakes reduce groundwater levels, but deep percolation through irrigation return flows partially compensates the withdrawals. When irrigation processes are adequately managed, irrigation return flows can be consistent and help maintain groundwater levels in a sustainable way. Plants and soil only absorb a small quantity of water, but the rest is subject to natural and physical transformations through which it returns to natural ecosystems. Remaining water continues to flow and eventually starts infiltrating underground towards rivers (horizontal percolation) or groundwater aquifers (vertical percolation). Water not consumed by crops in the fields, and not evaporated directly from the surface or through plants (evapotranspiration), will flow to stream and drainage canals, until it percolates toward groundwater reservoirs. In arid and semi-arid areas irrigation is the primary source of water distribution for cultivated crops. Water return flows generate an important service for the environment and the community particularly during the dry season (Marechal *et al.*, 2003). Such water reserves provide valuable services for the entire society by covering fundamental functions for the well-being of the environment because they help to prevent land subsidence caused by the excessive groundwater withdrawal (Galloway & Burbey, 2011). Managing and preserving groundwater reservoirs is crucial for the sustainability of the environment and under the right conditions could provide a regulating ecosystem service (MEA, 2005).

Ebrahim *et al.* (2016) point out that recharge models often account only for recharges coming from rainfalls, or do not distinguish between rainfall and irrigation return flows. However, in many basins, irrigation return flows represent a consistent source of groundwater recharge. The quantification of irrigation-driven recharges is therefore crucial to guarantee an adequate management of groundwater resources and allow evaluating the real value of water use in agriculture. To quantify such effects, evidence about separated rainfalls from irrigation return flows is needed. Their study was conducted the Mosian aquifer of Western Iran. Results show that 15% and 10% of irrigation water and rainfalls water respectively reached back the aquifer, proving that irrigation can contribute to the water balance of the area. Also, Lu *et al.* (2010) distinguish between irrigation and rainfall return flows. They look at five different agricultural areas (piedmont, alluvial and lacustrine, coastal plains) situated in the Hebei plain of China. Water used in agriculture resulted to be a consistent contributor to aquifer recharge since groundwater from irrigation accounted for about 27-49% of the total recharged amount. Studies quantifying the percentage contribution of irrigation to groundwater reservoirs were carried also in Korean paddy fields (Kim *et al.*, 2009), where the estimated average irrigation return flows from 1998 to 2001 was 25.7% of the annual irrigation amount; and in Mexico (Florido river basin), where this value reached 30% (Silva-Hidalgo *et al.*, 2008). The rate of return of water resources may vary depending on the crop types, depending on the rates of transpiration and percolation (Ali-Askari & Shayannejad, 2015).

Evidence from case studies in the Mediterranean areas also exists. In the Campo de Cartagena in South-Eastern Spain, irrigation is simultaneously a cause of freshwater withdrawals and an important source of aquifer recharge. Infiltrations from fields covered by melon and lettuce crops showed different rates of recharge, confirming that return flows may also depend on the crop types (Jiménez-Martínez *et al.*, 2009). However, despite the consistent levels of irrigation return flows in various fields in different agriculture areas of Spain (Poch-Massegú *et al.*, 2014), nitrate concentration has also increased. Causapé *et al.* (2004) suggest that irrigation management is fundamental to control the amount of fertilizers in return flows: careful and flexible irrigation management together with improved fertilization practices is crucial to contain negative effects of nutrient leaching and percolation. Consistent groundwater contributions were highlighted also in Southern France (Crau basin), where irrigation channels used for cultivations make irrigation activity to be the main contributor of the underlying groundwater aquifer (Séraphin *et al.*, 2016).

An interesting perspective is given by Kendy & Bredehoeft (2006). Their study suggests a possible existence of a trade-off between irrigation technical efficiency and groundwater recharge. Technical efficiency concerns the capacity to obtain a maximum output from a given set of inputs (output-oriented measures) or to use a minimal input mix to generate the same level of output (input-oriented measures) (Kijne *et al.*, 2003). This is linked to physical water productivity defined as the ratio between outputs and inputs, where the output is identified with farmers' yield and the input with the amount of water used to obtain such yield. Water productivity represents the "net return for a unit of water used" and is achievable by raising production keeping the same amount of water or maintaining the same volume of production after a decrease of water inflows (Molden *et al.*, 2010). Water used for irrigation is an input in agricultural production. On-farm efficiency depends on how irrigation is managed and varies by crop type (Benedetti *et al*., 2019; Laureti *et al*., 2020). Kendy & Bredehoeft (2006) found that water savings coming from an increase in water use efficiency may happen at the expense of reducing or eliminating irrigation return flows that mainly contribute to groundwater recharges. A simple increase in irrigation efficiency is associated with a lower amount of water withdrawals which should compensate the missing return flows from agriculture. However, if farmers decide to increase the cultivated areas, freshwater withdrawals may increase as well, leaving few or no space for deep aquifers recharge. Moreover, downstream users of return flows such as living species of the surrounding aquatic ecosystem would not be able to survive without them.

Scarce attention has been put to measuring the economic impact of groundwater recharges. Aizaki *et al*. (2006) estimate the economic value of groundwater recharge in a case study in Japan, by using a contingent valuation method. In the study, they asked to Japanese responding households to report their willingness to pay for different services provided by agriculture. They resulted to be willing to pay 4.63$ per household (in 2003) in order to maintain groundwater recharges in place. In Italy, a similar experiment has been conducted to assess the willingness to pay for the positive externalities coming from irrigation. Groundwater aquifer recharge externalities were valued and a sample of interviewed Italian citizens asserted to be willing to pay 1.65$ per household each month (in 2014) in addition to their water bill consumption (Zucaro, 2014).

3.2. *Biodiversity and wildlife habitat*

Through irrigation systems, water is conveyed towards agricultural lands which become more productive. Ecosystem services associated to landscape changes and to the interaction between water and crops are generated (García Sánchez, 2011). They are relevant for many living species, altering the biodiversity level of the flora and fauna surrounding agricultural crops. Indeed, biodiversity in irrigated lands is maintained, improved or even enhanced through agricultural water management.

Strong evidence relating water and increased biodiversity in irrigated agroecosystems is found in the irrigated rice fields of Asia. Studies prove that water used in such fields create environmental benefits by providing a living habitat to plants and animals. Bambaradeniya *et al*. (2004) consider irrigated rice fields as temporary wetland ecosystems and report that the number of living species and organisms found in irrigated rice fields of Sri-Lanka is extremely high, consisting of about five hundred different species, including invertebrates, vertebrate, macro- and micro-phytes. Most importantly, fifteen new species were recorded for the first time in the irrigated fields. Authors claim that traditional irrigated rice field ecosystems may contribute to the achievement of high biodiversity levels and are among the most sustainable forms of agriculture. Similarly, in reviewing the positive externalities of rice-based irrigation in Sri Lanka, Renault & Montginoul (2003) highlight that water effectively consumed by crops only accounts for a small part of the total amount of water available for irrigation, and most of its uses are related to the provisions of positive externalities such as the perennial vegetation growth besides rice plants. Perennial vegetation consumes part of the water destined to rice fields and plays an important role for the local community because it is used to feed cattle and is fundamental to balance high temperatures in tropical areas. In many cases, perennial vegetation provides additional sources of food as well as medicinal plants, wood and other raw materials. Rice fields in Japan have also been proved to host a high level of fish diversity: as plankton and aquatic invertebrates usually develop in irrigation water, fish may eat them and continue to grow, moving throughout irrigation ditches especially when they are connected to rice crops (Katano *et al.*, 2003). In some cases, fish may also be used as food source by the local communities (Renault & Montginoul, 2003).

The connection between rice field irrigation and increased biodiversity have also been documented in other parts of the world. For example, Maltchik *et al.* (2011) found that in Southern Brazil around 160 living species were hosted in irrigation channels. Herring *et al.* (2019) linked rice field irrigation to the presence of water birds in Australia. Choe *et al.* (2016) found that irrigation channels and ponds are an effective way to enhance biodiversity in Korean paddy fields. Davies *et al.* (2008) compared five different European locations observing a significant contribution to biodiversity from agricultural water ponds and ditches.

Evidence regarding the association between irrigation and increased biodiversity is found also in the Mediterranean area. Indeed, the crucial importance of irrigation is noticeable in arid and semi-arid regions where rainfall is scarce. Under these conditions, every single aspect concerning irrigation is fundamental to help plants growing in a hostile environment. Consequently, new species of plants and trees rise in the newly created wet areas benefiting of a more favorable climate conditions (Gil Meseguer, 2006). In Southern Spain, water irrigation flows in arid agricultural areas had many positive effects in terms of plants variability and diversification (García Sánchez, 2011). Irrigated agriculture fields in the semi-arid Mediterranean landscape represent functional habitats for many different species of water birds (Sánchez-Zapata *et al.*, 2005; Sebastián-González *et al.*, 2010) and other living species such as invertebrates and amphibian (Abellán *et al.*, 2006). González-Estébaneza *et al.* (2010) have also found that irrigated farmlands provide more favourable conditions for butterflies which are considered a good environmental indicator of biodiversity mostly being very sensitive to air pollution and climate shocks. Butterfly diversity was expected to decrease due to agriculture intensification, but irrigation has been effective in reversing this trend. They conclude that, since water and rainfall shortages are common in the Mediterranean area during the dry season, irrigation constitutes a way to maintain green vegetation along cultivated crops, which positively affects butterflies' living conditions.

Irrigation may introduce infrastructures and technologies in natural landscapes and ecosystems altering water natural cycles and diverting the resource toward farmed areas. However, in some cases infrastructures built for water distribution could increase ecosystems' protection. For example, channels and ditches used for water transportation can connect different water basins creating a hydrological network which offers a safe passage from one place to another to some aquatic species (Mazerolle, 2004; Aspe, Gille & Jacque, 2014).

Limited evidence about the economic implications of such outcomes can be found in the literature. Aizaki *et al.* (2006) estimate that the willingness to pay for the environmental conservation function of rice fields and for the wildlife protection service provided in Japan in 2003 was approximately equal to 5.90$ per household. However, there is no clear definition of what the category "environmental conservation" includes or excludes. Further economic evaluation is needed to better assess the positive externalities of irrigation in terms of biodiversity maintenance, diversification and increase.

3.3. *Landscape aesthetics and cultural values*

Irrigation is one of the main responsible of the changes in agricultural landscapes, which are often enjoyed by individuals and families for outdoor activities or recreational purposes (MEA, 2005). For instance, in the Mediterranean area, agriculture often implies the establishment of terraces, canals or ditches for water conveyance. This has helped farmers in managing fields also in places with irregular morphology due to the presence of hills and mountains; and helped creating suggestive landscapes. In Southern Spain there are traditional irrigated lands called Huertas that have been shaped by agricultural activities and especially from irrigation practices. Gil Meseguer (2006) and Sánchez-Sánchez *et al.* (2016) both provide an interesting historical description of the area. They specifically ascribe the landscape evolution of the agricultural views of Murcia's region to water used in irrigation. Huertas sometimes incorporate archaeological sites and ancient ruins from roman's age that once were used to convey water. Albeit despite having been replaced by modern irrigation infrastructure, they continue to be important as a part of the historical capital of the region. Similar values may be found in completely different areas. For example, Tekken *et al.* (2017) have conducted a qualitative assessment of farmers' perception of rice cultivations in Vietnam and the Philippines, confirming that the cultural identity and the heritage value of rice cultivations is a crucial feature of rice production.

Cultural or aesthetic ecosystem services provided by the implementation of irrigation practices should be considered when evaluating water use in agriculture (MEA, 2005). To understand the relevance of the provision of landscapes aesthetic and cultural services, their economic value must be estimated. Since there is no market of landscape provision, some evaluation methods are available, e.g. the contingent valuation method. Individuals may be willing to pay for the provision and preservation of ecosystem services provided by irrigated agriculture and their willingness to pay (WTP) can be quantitatively estimated trough surveys (Spangenberg & Settele, 2010). For example, Sayadi *et al.* (2005; 2009) have highlighted that the provision of landscape amenities produced by farmers in Southern Spain can contribute to revise agriculture's role in the society in addition to the economic function of producing food. They proved that irrigated landscapes provide more beauty and aesthetic values than drylands. Through a survey conducted in 2002, they estimated people's WTP to enjoy the landscape features existing in the area by showing pictures to a sample of interviewed persons asking their WTP to pay for enjoying that view. Some of those landscapes were irrigated. Individuals have decided to assign a higher value to enjoy the view of irrigated farmlands (between 28$ and 31$), because they judged them more aesthetically pleasing (Sayadi *et al.*, 2009). A similar pattern can be found in Italy: the WTP for a typical irrigated agricultural landscape was estimated at 9.5$ per month for each household (in 2014) in addition to their bill for water consumption (Zucaro, 2014). Landscape provision was the most valued positive attribute among those that irrigated landscapes can provide to society.

Similar studies have been conducted in other geographical areas. For example, Zekri *et al.* (2012) find that the role of desert oases in Oman is to provide a positive amenity value beside being a source of food to residents. In their study, 64% of the visitors (mostly foreign visitors that entered the oasis in 2008) declared that they would have been willing to pay $8.6 per visit (per group) to enjoy the scenic view of the oasis. Even if revenues coming from the touristic activity would only represent 6% of farmers' incomes, a wise use of such earnings could be done, such as maintaining the irrigation infrastructures. Aizaki *et al.* (2006) estimated that the WTP for landscape provision and recreation services coming from rice cultivations in a case study of Japan is approximately equal to 3.61$ and 2.66$ per household (in 2003).

The WTP for rural landscape provision also depends on the respondents' social status. When they are given a choice to decide whether to contribute for the preservation or the intensification of such ecosystem services, lower income respondents confirm their willingness to pay only for essential services while upper income respondents are more willing to declare that they would also contribute to non-essential services (Vivithkeyoonvong & Jourdain, 2017). The WTP for mitigating droughts in rice cultivation in Thailand has been estimated to be 4.8$ per household per year (in 2013), while the WTP for environmental, recreational and aesthetic rural landscape functions was oscillating between 20$ and 25$ per household per year (in 2013). Results also depended on socioeconomic characteristics of respondents (Jourdain & Vivithkeyoonvong, 2017).

Thiene & Tsur (2013) confirm that the market equilibrium and the social equilibrium differ when externalities are detected. Northern Italy (Vicenza province) farm landscape values range 9,197-57,664 $/ha for vineyards and 10,204-63,980 $/ha for orchards. Afterwards, such values are used to calculate the WTP for amenity services generated by the agricultural landscape, which represents the social demand for water. It is computed by dividing the WTP per hectare by the quantity of water used by crop and is expressed in terms of $\$/m^3$. For vineyards cultivations it varies between 10 and 64 $\$/m^3$, while for orchards it resulted between 5 $\$/m^3$ and 32 $\$/m^3$. The difference is explained by the different minimum water requirements of the different crops.

3.4. *Nutrient recycling and retention*

Irrigation helps soil nutrient retention, i.e. conservation and recycling of land and crops' nutrients and pollutants attenuation. Functioning irrigation systems provide regulating ecosystem services due to the set of channels and ditches used to convey water resources (MEA, 2005). Besides offering safe habitats for aquatic living species, they contribute to nutrient and sediment retention recycling or temporary nutrients storage. In reviewing potential ecosystem services originating from irrigation ditches, Herzon & Helenius (2008) and Dollinger *et al.* (2015) have found that adequate management of ditches vegetation can increase recirculation and recycle of soluble nutrients such as phosphorus and nitrogen. Such flows are also useful to help mitigating the amount of pollutants, sometimes leading almost to their complete removal. Well-maintained wildlife and vegetation that spontaneously grows inside the channels and ditches destined to convey water flows can effectively drain and retain plants nutrients and pollutants, reducing their excessive accumulation and associated negative environmental effects. Using recycled water to irrigate fields may reduce the overall amount of water and fertilizers used in agriculture.

Evidence regarding nutrient retention has been found in Japanese rice fields. Paddy areas performs well in removing nitrogen and phosphorus through recycling irrigation water systems, proving that nutrient retention ability may successfully be employed in those crops where there is a recycling irrigation system managing water inflows and outflows (Feng *et al.*, 2004; Hitomi *et al.* 2006; Törnqvist *et al.*, 2015).

Irrigation practices fall within the agricultural management practices which positively affect soil conservation and enhance soil carbon content, mitigating the amount of CO_2 emissions in the atmosphere (Olsson *et al.*, 2014). Follet (2001) highlights that large-scale cultivations and intensive agricultural practices have led to the erosion of soil carbon content. He finds that the efficient water use in agriculture increases soil carbon content and balances the losses caused by intensive farming. Additional evidence regarding the increase in soil organic and inorganic carbon content is documented by Gillabel *et al.* (2007) and Wu *et al.* (2008) which compare carbon storage processes in irrigated and dryland crops. Their results confirm that carbon sequestration in irrigated lands is higher than in drylands. More recently, Trost *et al.* (2013) show that irrigation generates positive impacts in carbon storage particularly in arid and semiarid areas, while its benefits are not very significant in humid areas. Positive effects on carbon storage potential due to irrigation practices have been highlighted in diverse geographical areas and confronting a variety of different crops such as rice and wheat (Battacharyya *et al.*, 2013) or in grasslands (Olsson *et al.*, 2014).

Irrigation might help establishing and maintaining good soil conditions. Further research on irrigation potential in nutrient recirculation and recycling is needed to completely evaluate them from an ecological and economic perspective. If nutrient cycles become more efficient due to irrigation practices, farmers will decide to reduce the amount of fertilizers used generating positive externalities in terms of reduced fertilizers' production, water pollution, and greenhouse gas emissions.

3.5. *Improved health, nutrition and living conditions*

The link between irrigation and improved human living conditions is particularly evident in developing countries which rely on agriculture as their main source of income. In these countries, farm households find challenges in securing enough food availability due to erratic rainfalls and increasing water scarcity, recently worsened by climate change (FAO, 2016). However, enhancing agricultural production may improve living standards especially in the poorest countries (Smith, 2004) and irrigation plays a crucial role.

Irrigation has both direct and indirect effects on poverty. Direct effects mainly consist in the increase of farmers' income due to enhanced crops' productivity: irrigation makes water supply more reliable and allows for higher food production levels and for the diversification of cultivated crops (Turral *et al.*, 2011). This is particularly important during the dry season, when water resources are less available or during weather extreme events such as droughts and floods (Hussain & Hanjra, 2004; Burney & Naylor, 2012). There is evidence that water may improve life conditions increasing nutritional intakes and health conditions both in the African and Asian continents (Smith, 2004; Hussain & Hanjra, 2004; Tesfaye *et al.*, 2008; Rahman & Parvin, 2009; Burney *et al.*, 2010; Namara *et al.*, 2011; Aseyehegn *et al.*, 2012).

Besides enhancing agricultural yields, water management in agriculture is associated with the provision of positive side effects. Namara *et al.* (2010) and Doménech & Ringler (2013) highlight that direct irrigation benefits provide secondary effects related to food nutrition. Households have direct access to a larger variety of food products, including fruits and vegetables, ensuring a more balanced diet with a net improvement in the amount and variety of micronutrients and calories intakes (Lipton, 2001, Hussain & Hanjra, 2004).

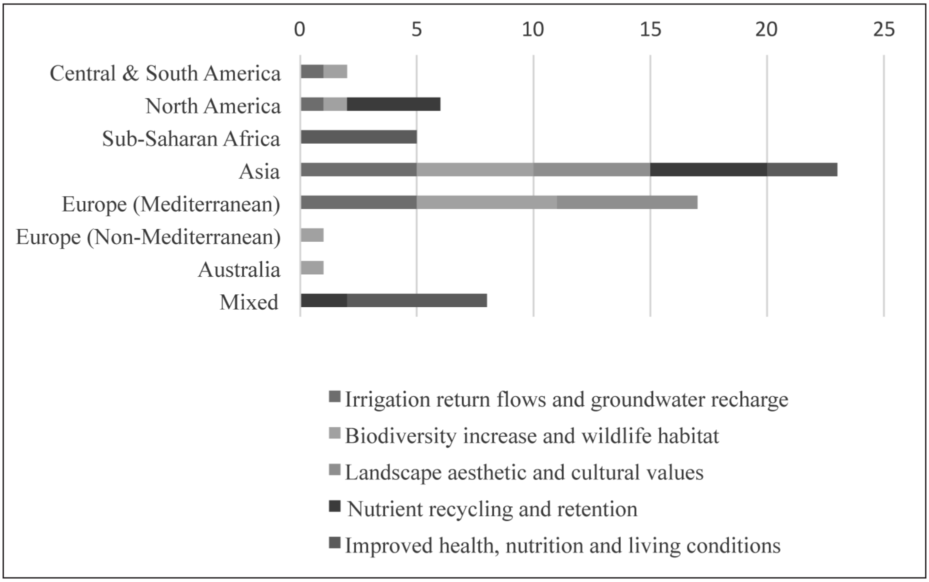
Further benefits coming from irrigation may derive from the multifunctionality of water resources conveyed by irrigation infrastructures and systems. Poor rural households could take advantage of increased water supply by using it for additionally purposes other than irrigating crops (Hussain, 2007; Dinesh-Kumar, 2014). In some cases, they may even use water flows as a mean of transportation (Renault & Montginoul, 2003).

3.6. *Some geographical considerations*

A geographical assessment of the evidence reviewed is helpful for making additional considerations on the distributional patterns of positive externalities resulting from water used for irrigation. Figure 1 reports the geographical origin of the case studies by sub-areas. The studies reviewed refer to different areas: North America, Central and South America, Asia, Europe (especially from the Mediterranean area) or sub-Saharan Africa. Results comparison is difficult due to diverging agro-ecologies and socio-economic conditions.

As concerns the Mediterranean area, documentation available refers to the following categories: groundwater recharge from irrigation return flows, biodiversity increase, and landscape aesthetics. Most references are based on case studies in Spain. However, a relatively smaller number of contributions relates to France and Italy. This indicates that further research should be conducted to assess whether the results from the case studies in Spain can

Figure 1 - Geographical distribution of case-studies considered in this review



be extended to similar contexts in the Mediterranean area. Also, additional data about nutrients retention, storage and recycle due to irrigation are needed for this region. In Asia, comprehensive case studies are available including all benefits categories examined in this review. In sub-Saharan Africa a few studies are available, accounting only for the contributions to health, nutrition and food security category.

Results reported in this review refer to a range of various climate conditions and geographical areas, which may represent a limit of the work. However, despite such differences, there is evidence of at least one of the irrigation benefits in each geographical area, suggesting that agriculture could claim to generate such positive externalities in a global context.

4. Conclusions

Irrigation is necessary to guarantee crop production in dry areas and obtain higher and more stable yields. Food demand is expected to increase due to population growth. Considering the high competition for water resources combined with the increasing water scarcity also due to climate change, serious concerns regarding the availability of water resources in the future arise. To get the right policy incentives for improved water use and increased water savings, total economic value of water should be estimated. The value of the ecosystem services generated by irrigation must be included in the computation. Such services are positive externalities which are often underestimated because of assessment difficulties due to the numerous variables involved and data scarcity. In most cases, economic values can only be approximated by analysing how people perceive them and by estimating the willingness to pay for their preservation.

This paper has described the results of a literature review about the known evidence about such positive externalities and their value. Information available has been classified considering the following categories: 1) groundwater recharges through irrigation return flows; 2) increase of biodiversity trough wildlife habitation and vegetation growth in agricultural areas; 3) landscape aesthetic value where the creation of suggestive landscapes can generate environmental systems that individuals can enjoy; 4) nutrient and sediment recycling and retention through ditches and other irrigation infrastructures; and 5) impacts on socio-economic conditions such as human nutrition increase and health improvements.

Results show that there is a wide ecological recognition for some of the ecosystem services originating from irrigation. Nutrient retention, groundwater recharges through irrigation return flows and biodiversity conservation have been extensively studied from an environmental perspective. Evidence of economic evaluations is lacking, probably due to the estimation difficulties. Cultural services such as landscape provision have been better analysed from the economic point of view, sometimes considering their strong correlation with non-agricultural sectors of the economy (e.g. tourism). Irrigation indirect effects on nutrition and health have also been largely studied, together with their economic implications.

Knowing the total economic value of water resources would help policy makers introducing the right incentives to enhance water use efficiency and obtain water savings. Through the Dublin Statement on Water, the international community has recognized that "managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources" (ICWE, 1992). Appropriate measures to reward farmers for the positive externalities generated should be introduced. For example, payments for ecosystems services programs can be used to compensate farmers for the positive externalities provided to the society (Branca *et al.*, 2011). In the water pricing approach considered in the European Water Framework Directive (WFD) (EC, 2012) the proper identification and evaluation of the positive externalities of irrigation would be necessary for setting equitable pricing systems.

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