Global Sustainability

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Long Form Research Paper

Cite this article: Ibarrola-Rivas M-J, Castro AJ, Kastner T, Nonhebel S, Turkelboom F (2020). Telecoupling through tomato trade: what consumers do not know about the tomato on their plate. *Global Sustainability* **3**, e7, 1–13. https://doi.org/10.1017/sus.2020.4

Received: 31 August 2018
Revised: 23 December 2019
Accepted: 7 January 2020

Keywords:
Almería; Spain; environmental effects; Germany; global drivers; global food trade; inequality; social effects; Westland; The Netherlands

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CAMBRIDGE UNIVERSITY PRESS

Telecoupling through tomato trade: what consumers do not know about the tomato on their plate

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Non-technical abstract

A large share of our food comes from international supply food chains that are difficult to trace. Therefore, consumers are not aware of their environmental and social effects. We analysed the tomato supply system for Germany. Tomatoes consumed in Germany are produced either in The Netherlands by Polish workers and using large amounts of energy, or in Spain by West African workers and depleting the aquifer. The analysis shows the long-distance effects of food consumption that should be considered when designing strategies for a sustainable global food system. Comparable results can be expected for other food products traded around the world.

Technical abstract

The environmental and social effects caused by global food trade are not evident for consumers. We use the telecoupling framework to trace these effects between consumer and producer regions. In Europe, Germany is the largest consumer of tomatoes, which are mainly imported from The Netherlands and southeast Spain. The use of agricultural resources is markedly different in the two production regions due to different local contexts and production systems. Tomatoes from southeast Spain require fewer resources per area of greenhouses, but more resources per kilogram of tomatoes produced compared with production in The Netherlands. However, both tomato production areas require the same amount of labour per kilogram of tomatoes. The workers in the greenhouses in both production regions are mainly immigrants, but their labour conditions are quite different due to the difference in application of international labour agreements. If Germany would start producing their own tomatoes in order to reduce distant effects, the local effects in Germany would be large in the context of Germany's current national resources use and CO_2 emission patterns. This study highlights the notion that taking distant indirect effects of consumption into consideration is crucial when designing global strategies that aim to achieve a more sustainable and fair global food system.

Social media summary

Environmental and social effects of tomato trade in Europe and implications for sustainable food systems are discussed.

1. Introduction

Achieving a sustainable global food system is one of the biggest challenges that humanity faces today (Davis *et al.*, 2016; Foley *et al.*, 2011; Tilman *et al.*, 2011). Food production entails global trade-offs between food security (e.g., produce enough and healthy food) and local effects (e.g., environmental and social effects associated with food production) (Tilman *et al.*, 2011). Driven by a growth in free-trade agreements, urbanization, multinational food retail companies and increased disposable income that can be used to purchase food from different regions of the world, global food trade has grown significantly over recent decades (FAO, 2018). The increase in international food trade has enlarged the disconnect between food consumers and producers. Many studies have traced and analysed the indirect effects of global trade. The 'displacement' of both environmental costs and social costs by food imports is a mechanism of the indirect effects that have been well studied in the last decade (D'Odorico *et al.*, 2019;

Lambin & Meyfroidt, 2011). Most studies have focused mainly on the environmental costs rather than on the social costs.

Concerning the environmental costs, a growing line of research has studied this displacement by tracing the use of land (Qiang *et al.*, 2013; Schaffartzik *et al.*, 2015), water (Dalin *et al.*, 2012; D'Odorico *et al.*, 2019; Hoekstra & Hung, 2005) and nitrogen (Lassaletta *et al.*, 2014) to produce food imports – what some researchers call 'virtual use of agricultural resources'. These studies illustrate that importing countries are displacing the environmental costs (land, water and nutrients use) related to their consumption of food to exporting countries. Some studies have investigated how global food trade contributes to biodiversity loss in exporting countries (e.g., Marques *et al.*, 2019). Moreover, such displacement processes can be linked with changes towards diets with high environmental impacts. This could be related to a low motivation of consumers to change consumption habits because the environmental impacts of their consumption choices are transferred to faraway places (Roca, 2003). However, with regards to global efficiency, displacement does not have to be negative. Dalin *et al.* (2012) showed that China changing from producing its own soybeans domestically to importing them from other countries resulted in global water saving, because the exporting countries could produce soya with a greater water use efficiency. Concerning the social costs, other studies have shown that food trade displaces negative effects from developed to developing countries. For instance, Simas *et al.* (2014) showed that bad labour conditions in developing countries often support export production to developed countries. Wiedmann *et al.* (2018) showed that health impacts in China due to air pollution were partly linked to production for exports to the USA.

However, insights from these studies should be considered very carefully, because food imports include multiscale and multidimensional interconnections that are not always evident or possible to include in any one analysis. For instance, food imports are usually linked to cascade effects and rebound effects (i.e., the efficiency of technology aimed at reducing the costs of consumption results in an increase of consumption; Lambin & Meyfroidt, 2011) that are not always evident or easy to trace due to the complexity of the underlying mechanisms. Understanding the indirect effects of the global food system interconnections, and bringing them into focus, is extremely important in order to move towards more sustainable and fair food systems.

Tomato production and consumption over distant regions is a good example of a rapidly changing global food system. Tomato is currently the most traded vegetable in volume; from 1961 to 2013, the annual production has increased approximately six-fold, and the amount of internationally traded tomatoes has increased approximately ten-fold (FAO, 2018). Tomato consumption is a good example of dietary changes, as it has tripled in the last 50 years: in 1960, the average global 'tomatoes and products' consumption was 8 kg/person/year, while in 2013 it increased to 21 kg/person/year (FAO, 2018).

In this paper, the telecoupling framework (Liu *et al.*, 2013) is used to discuss distant interactions and impacts related to the tomato trade in Europe. This approach focuses on understanding the socioeconomic and environmental interactions of human–nature systems across large distances by identifying and discussing the different agents, causes and effects at different scales. Telecoupling research aims to integrate the biophysical, social and economic implications of long-distance interactions such as global trade (Friis *et al.*, 2016). It has been used recently to evaluate distant interactions of the food system, such as: the land dynamics resulting from banana production in Laos for exports (Friis & Nielson, 2017); the socioeconomic, cultural and political implications of maize production for different uses in Mexico and the USA (Eakin *et al.*, 2017); the socioeconomic implications of coffee production in Colombia and Mexico for exports (Eakin *et al.*, 2017); and the socioeconomic and environmental effects of beef production in Africa driven by meat consumption in other countries (Easter *et al.*, 2018).

In this study, we analyse the European trade of tomatoes as a case study to conceptualize and evaluate the diverse environmental and social effects associated with global food trade. We use the consumption of tomatoes in Germany as an entry point. Germany is the largest importer of tomatoes in Europe, and most of the tomatoes consumed in Germany are imported (FAO, 2018). We assess the interactions among the different systems involved in the tomato trade by using the components defined by the telecoupling framework: flows, agents, causes and effects. Three types of systems are defined: (1) the receiving system, which corresponds to Germany's tomato consumption; (2) the sending systems, which are the producer regions; and (3) the spillover systems, which we identify as the regions of origin of the agricultural workers involved in tomato production. We compare and discuss the implications of tomato production for the two main producer regions: Spain and The Netherlands. Our study adds to the telecoupling literature by comparing the implications of consumption for two different sending systems. Our main research questions are: what environmental, economic and social effects emerge from tomato consumption in Germany? How do these effects differ depending on the production system in the export region?

2. The telecoupling framework

The telecoupling framework (Liu *et al.*, 2013) consists of five main components. These are combined in order to describe and to help us understand the socioeconomic and environmental interactions between systems that are far away from each other but linked, in this case, through international trade. Table 1 shows these different components and categories for our case study. The systems include three categories: (1) the receiving system where the tomatoes are consumed, in our case Germany; (2) the sending systems where the tomatoes are produced, in our case the Westland region in The Netherlands and the region around Almería in Spain; and (3) the spillover systems that are indirectly affected by the tomato production. In our study, we have identified that the agricultural labour in the tomato production for exports depends heavily on migrant workers. So, in spillover systems are the regions of origin of the workers: West Africa for tomato production in Spain; and Poland for tomato production in The Netherlands.

Flows refer to the material, money and labour transfers among systems. Flows include the amount of tomatoes transported, the flows of money (i.e., the sale of tomatoes and remittances to the spillover systems) and the geographical movements of tomato workers. Agents are key actors that drive the dynamics of each system at either the local, regional or national scale. They include tomato consumers, tomato farmers, governments and institutions, tomato traders, supermarkets, retail companies and other agents indirectly involved. The causes are the local, regional or global factors that drive the dynamics of the international tomato trade. The global factors include: economic causes (i.e., differences between the world market prices of tomatoes and the local costs of tomato production) and social causes (i.e., dietary changes). Regional or national factors include political causes, such as

Table 1. Components and categories of the telecoupling framework (Liu *et al.*, 2013) applied to our case of tomato production and consumption in Europe.

Components	Category	Case study: tomatoes imported into Germany
Systems	Receiving	Germany's national tomato consumption
	Sending	Tomato greenhouses in Westland, The Netherlands
		Tomato greenhouses in Almería, Spain
	Spillover	West Africa
		Poland
Flows	Material	Tomato biomass
	Money	Payments for imported tomatoes and remittances from labourers
	Labour	Low-skilled workers
Agents	Local	Growers, low-skilled workers
		Tomato consumers
	Local and national	Traders, supermarkets and retail companies
	National and regional	Governments and institutions
Causes	Economic (global)	World market prices of tomatoes versus local costs of production
	Social (global)	Dietary changes, promotion of vegetable consumption
	Political (regional/ national)	Agricultural programmes and subsidies, free trade agreements, labour agreements
	Technological (local)	Farmers' access to agricultural technology and farming tradition (history of the region)
	Environmental (local)	Biophysical conditions
	Social (local)	Regional differences in labour opportunities and wages
Effects	Environmental (local)	Water depletion, CO_2 emissions, land use changes, pollution, changes in biodiversity, saving effects in consumer country
	Social (local)	Changes in landscape aesthetics, migration, poor labour conditions, nutritional benefits
	Economic (local)	Farmers' income, jobs from tomato production, remittances from migrant workers
	Economic (national)	Contribution to national economy (gross domestic product), saving effects in consumer country

agricultural programmes, subsidies and free-trade agreements. Local factors include environmental causes (i.e., biophysical conditions) and social causes (i.e., farmers' access to technology and rural labour opportunities). The effects are the local and national direct and indirect impacts of the tomato trade. The local factors include the environmental effects (i.e., water depletion, CO_2 emissions, pollution, biodiversity loss), social effects (i.e., landscape aesthetics, landscape changes, migration, poor labour conditions) and economic effects (i.e., farmers' income and jobs, remittances from migrant workers). The national economic effects refer to the contribution to the national gross domestic product (GDP).

Figure 1 illustrates the most important components of the tomato trade system studied in this paper. Figure 1 shows that the choice of tomatoes in Germany has different effects in several regions far from where the tomato was consumed. These effects differ depending on the local context where the tomato was produced due to a complex mix of social, economic and environmental factors at different scales and at different locations. They are discussed in detail in the following sections.

3. Results

3.1. Receiving system: Germany

Tomato consumption in Germany can serve as an example for global dietary trends playing out in recent decades. Average German per capita consumption of tomatoes increased almost five-fold from just below 4 kg per capita and year in 1961 to 19 kg per capita and year by 2013 (FAO, 2018). This trend shows no signs of levelling off. It is driven by increased per capita income (leading to greater affordability of tomatoes), by the year-round availability of tomatoes and by the promotion of vegetable consumption for health reasons (Gerbens-Leenes *et al.*, 2010).

The largest share of German consumption was met by imports throughout recent decades: this share increased from 82% in 1961 to 96% in 2013 (FAO, 2018). Domestic production of tomatoes has fluctuated between 0.02 and 0.10 Mt/year, while imports of tomatoes and processed tomato products increased from approximately 0.3 Mt/year in 1961 to 1.6 Mt/year in 2013. As domestic production has been negligible in this period (FAO, 2018), German tomato consumption presents a good case for studying the distant effects of imported produce. The Netherlands and Spain are the main suppliers of fresh tomatoes to Germany: in 2013, the two accounted for almost 80% of the imports of fresh tomatoes to Germany, with The Netherlands accounting for 56% and Spain for 23% (FAO, 2018). Consequently, we focus on these two countries as sending systems.

3.2. Sending systems: Westland, The Netherlands, and Almería, Spain

3.2.1. Description of the tomato production systems: historical context and current situation

Both regions – Westland in the western Netherlands and Almería in southeast Spain – are among the top 10 tomato-exporting

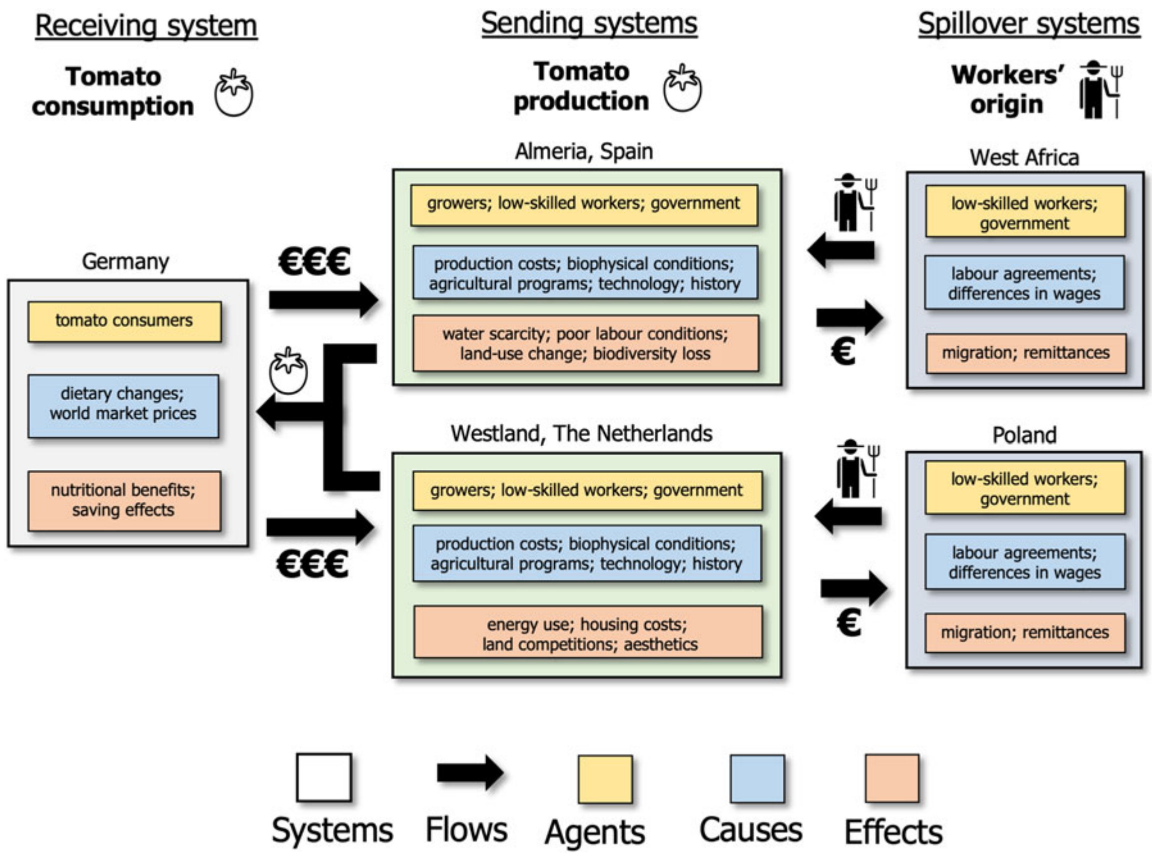

Fig. 1. Tracing the direct and indirect causes and effects driven by tomato consumption in Germany using the telecoupling framework. See text for details. Figure designed by the authors; tomato icon: Ben Davis (https://thenounproject.com); farmer icon: Symbolon (https://thenounproject.com).

nations (FAO, 2018). In the tomato-growing regions in both countries, vegetable production constitutes an important part of the local economy. Both regions have been selected as tomato-producer regions. In The Netherlands, tomato production is concentrated in the Westland–Oostland region, where 50% of Dutch greenhouses are located (SER, 2014). The municipality of Westland has the highest concentration of greenhouse horticulture in the country, accounting for 80% of cultivated land (CLO, 2018). In Spain, tomato production is concentrated in the semi-arid coastal plain of the province of Almería in southeast Spain (Castro *et al.*, 2019). This Spanish region houses the largest concentration of greenhouses in the world (Castro *et al.*, 2011, 2014; Quintas-Soriano *et al.*, 2014).

The histories of these two exporting systems show different trajectories. The Westland region in The Netherlands has been a horticultural area for several centuries, starting in the 17th and 18th centuries and expanding in the 19th century, mainly due to grape cultivation. Due to a major agricultural crisis in 1880 in Western Europe, people started looking at other crops and other sales methods. Growers started using glasshouses for the cultivation of fruit and vegetables. Grape cultivation increased enormously before the outbreak of the Second World War, but collapsed after the war because the South European countries could supply grapes much cheaper. As a substitute for grapes, the cultivation of tomatoes became important in Westland (de Ridder, 1979). In contrast, the greenhouse horticulture production of Almería in Spain started after the 1960s. The Spanish land transformation into greenhouse horticulture represents one of the fastest and most dramatic examples of land conversion in the Mediterranean basin, currently covering ten times more greenhouse area than in The Netherlands (Quintas-Soriano *et al.*, 2016a).

Since the 1980s, the number of horticulture greenhouse farms in The Netherlands has decreased by 74% from 15,800 to 4100 in 2015 (CLO, 2018). But the area of greenhouses has increased because the remaining farmers bought the greenhouses of other farmers cultivating other crops (see Section 3.3.2). Conversely, the area of greenhouse horticulture in southeast Spain continues to increase (Castro *et al.*, 2018a, 2019; Lopez-Rodriguez *et al.*, 2015; Quintas-Soriano *et al.*, 2016b). The economic contribution of the Spanish greenhouse horticulture is approximately 1800 million Euros (Giagnocavo *et al.* 2018). A total of 40,000 jobs are provided in addition to the family farmers engaged in this production activity. Within the province of Almería, greenhouse production represents 13% of GDP, as a contrast to the average of agricultural GDP in Spain of 2.5% (INE, 2016). The total economic activity surrounding the farming system contributes 40% to the GDP of the province of Almería (Giagnocavo *et al.*, 2018).

In both the Dutch and the Spanish systems, shortages of agricultural labour have attracted migrant workers. Current production largely depends on them. Workers in Almería come mainly from West Africa, while workers in Westland come mainly from Poland. In both regions, tomatoes are produced in intensive greenhouse systems; however, due to the differences in climate conditions, the technology used in both greenhouse production systems is different. In The Netherlands, glass greenhouses are adapted to a cold climate where heating and lighting are needed as the hours of direct sunlight are limited. Since the mid-1960s, greenhouses have been heated with natural gas, and waste CO_2 is used to fertilize the crops since high CO_2 concentrations increase photosynthesis. Since the 1970s, tomatoes have been grown on substrate instead of in the soil. These technological improvements have greatly increased the yields from 8 kg/m^2 in the 1961 to 50 kg/m^2 in 2016 (FAO, 2018). Note that these crop yields (500 ton/ha in 2015) are much higher than those of other crops. By contrast, the crop yields in Spain are lower and have increased at a slower rate: from 2.2 kg/m^2 in 1961 to 8.6 kg/m^2 in 2016 (FAO, 2018). The tomato yields in Spain in 2015 are similar to the crop yields in The Netherlands in 1961. The reasons for the large differences in crop yields are the differences in technology of the greenhouses.

On the Almería coast, hours of direct sunlight are much higher, so heating and lighting are not necessary. However, this is a dry region, so water availability is an important limitation. The Spanish greenhouse system uses irrigation by pumping water from aquifer systems and surrounding reservoirs (Castro *et al.*, 2014, 2015; Quintas-Soriano *et al.*, 2016a). Greenhouse technology is less intensive, as a multi-tunnel greenhouse system of polyethylene is used instead of glass. The plastic is spread over wooden posts or metal structures and is secured by wire. The transparent plastic intensifies the heat and maintains the humidity, allowing harvesting to start in December, ahead of other regions (i.e., 1 month earlier than in the open field) (Castro *et al.*, 2019). This also allows plant growth for the autumn–winter plantings until March, doubling and sometimes tripling the number of harvests. In these systems, tomatoes are still grown on the soil.

3.2.2. Resource use efficiency in tomato production

These important differences in tomato production systems translate into a different use of agricultural and natural resources to produce 1 kg of tomatoes. Torrellas *et al.* (2012) provided an extensive environmental analysis of various tomato-growing systems, including the systems in Spain and in The Netherlands. In this paper, these studied systems are used in order to estimate the agricultural resource use in the greenhouse systems of Almería and Westland (Table 2).

The requirement of land in order to produce 1 kg of tomatoes in Spain is 3.4 times larger than in The Netherlands (Table 2). The use of water and fertilizer per kilogram of tomatoes produced is larger in Spain than in The Netherlands: the use of water in Spain compared to The Netherlands is 2 times higher, while the use of fertilizers is 1.6–4.0 times higher in Spain compared to The Netherlands. In contrast, the use of energy is much higher in The Netherlands because of the large requirement of natural gas for heating, and consequently the CO_2 emissions are eight times higher in The Netherlands. Furthermore, the total costs in The Netherlands are twice those in Spain, and the largest difference relates to energy costs. Note that the labour (in hours) required to produce 1 kg of tomatoes is the same for both systems. Tomato production is generally labour intensive, mainly for harvesting the tomatoes, which is done by hand. Thus, whether a tomato consumed in Germany originates from Spain or from The Netherlands has different consequences for the hidden effects on resource requirements.

3.3. Local effects of tomato production

The greenhouse systems in Spain and in The Netherlands are located in different climatic, demographic and sociocultural contexts. Therefore, both production systems have produced different local environmental and social effects over recent decades.

3.3.1. Environmental and economic effects

The use of resources per area of both systems shows a different pattern than the use of resources per kilogram of tomatoes produced (see Tables 2 & 3). This is mainly because the Dutch system achieves three times higher crop yields than the Spanish system. As a result, the Dutch system is more efficient than the Spanish system in terms of the use of resources per kilogram of tomatoes produced (Table 2), but not in terms of the resources per area of greenhouse (Table 3).

In general, the use of resources per area is larger in The Netherlands than in Spain. This indicates that the system is more intensive and consequently achieves higher crop yields. For instance, water use per square metre is 60% larger in The Netherlands. The application of nitrogen fertilizer is also two times higher in The Netherlands, but the application of P_2O_5 and K_2O is comparable. Labour (in hours) is almost four times higher in The Netherlands than in Spain, although, as mentioned above (Table 2), the hours of labour per kilogram of tomatoes are similar, showing that labour needed is related to the amount of tomatoes produced. Energy use in The Netherlands is higher because of the need for heating with natural gas. As a result, CO_2 emissions in The Netherlands are 28 times higher per area of greenhouse than in Spain.

In terms of production costs, both systems also differ significantly. Table 3 shows the total economic costs per greenhouse area and the breakdown in the main components (i.e., equipment, labour, plant material, fertilizers, energy, crop protection and others). In both regions, the share for labour represents approximately a third of the total costs. In The Netherlands, energy costs represent the highest share (30%), while in Spain, they only represent 2%. It should be noted that the total production costs per area in The Netherlands are six times higher than in Spain (Table 3), but the costs per kilogram of tomatoes produced (Table 2) are only twice as high in The Netherlands: costs per kilogram are €0.56 for Spain and €1.03 for The Netherlands. The higher values in The Netherlands can be explained by the greater consumption of energy needed for heating.

Finally, water and soil pollution are attributed to agricultural intensification (e.g., pesticides, fertilizers, tillage). The application of nitrogen fertilizers in The Netherlands is greater than in Spain. Nevertheless, in The Netherlands, fertilization and irrigation are performed by dripping in a closed system, while in Spain, an open system is used (Table 3). The closed irrigation system in The Netherlands results in no leaching of agrochemicals into waterbodies or into the soil (Torrellas *et al.*, 2012). In contrast, the open system in Spain causes high eutrophication due to nitrogen leaching (Torrellas *et al.*, 2012). In addition, the use of fertilizers, electricity consumption and plastic waste (6000 metric tons per year) are among the major environmental impacts in the Spanish system (Castro *et al.*, 2019; Quintas-Soriano *et al.*, 2016a).

3.3.2. Land use change effects

The implications of land use change in the Dutch and Spanish systems are different due to historical, economic and sociopolitical factors. In The Netherlands, the high pressure on land in urban areas has resulted in a dichotomy between growers. Some growers gave up the struggle for space and decided to sell their land at a high price. This created space for growers in the other category, who chose to invest in the expansion of their

Table 2. Resource requirements per kilogram of tomatoes produced (adapted from Torrellas *et al.*, 2012).

Agricultural resource or related effects	Units	Almería, Spain	Westland, The Netherlands
Land use	m^2/kg-tomato	0.06	0.02
Water use	L/kg-tomato	28.8	14.1
Energy use (heating with natural gas)	m^3-natural gas/kg-tomato	0.00	0.74
Nitrogen fertilizers	g N/kg-tomato	5	3
P_2O_5 fertilizer	g P_2O_5/kg-tomato	3	1
K_2O fertilizer	g K_2O/kg-tomato	9	3
CO_2 emissions	kg CO_2/kg-tomato	0.25	2
Labour	Hours/kg-tomato	0.02	0.02
Total costs (euros per metric ton)	Euros/ton-tomato	545	1032
Equipment costs	Euros/ton-tomato	180	237
Labour costs	Euros/ton-tomato	147	268
Plant material costs	Euros/ton-tomato	33	31
Energy costs	Euros/ton-tomato	11	320
Fertilizer costs	Euros/ton-tomato	38	21
Crop production costs	Euros/ton-tomato	22	10
Other costs	Euros/ton-tomato	180	237

Table 3. Resources use per area of tomato production (adapted from Torrellas *et al.*, 2012).

Technological variable	Units	Almería, Spain	Westland, The Netherlands
Crop yield	kg/m^2/year	16.5	56.5
Crop period	Weeks	52	52
Water use	L/m^2	475	794
Water source		Well	Rainwater
Energy (heating)	m^3-natural gas/m^2	0	42
CO_2 emissions	kg CO_2/m^2	4.1	113
Nitrogen fertilizer	g N/m^2	79.8	168.8
P_2O_5 fertilizer	g P_2O_5/m^2	50.6	40.6
K_2O fertilizer	g K_2O/m^2	156.2	185.5
Substrate		Soil and perlite	Rockwool
Fertilization – irrigation		Open loop	Closed loop
Labour	Hours/m^2	0.255	0.95
Total costs	Euros/m^2	9	58.3
Equipment costs	Euros/m^2	3.0	13.4
Labour costs	Euros/m^2	2.4	15.2
Plant material costs	Euros/m^2	0.5	1.7
Energy costs	Euros/m^2	0.2	18.1
Fertilizer costs	Euros/m^2	0.6	1.2
Crop production costs	Euros/m^2	0.4	0.6
Other costs	Euros/m^2	1.9	8.2

companies. Competition for land has also forced producers to make more efficient use of their available land. This has resulted in high production per square metre and the current trend of multilayer use of space (Breukers *et al.*, 2008), but surprisingly, this strong land competition because of the proximity to urban areas has not forced farmers to move to other regions. Some of the reasons for this follow. (1) High crop yields: high production per area allows farmers to afford high costs compared to farmers who produce other agricultural commodities. (2) Sunlight: light is a critical input for tomato production, and even low differences in light availability have significant consequences for total production. The annual availability of sunlight in this area is higher compared to other areas of the country. (3) Central location: companies consider the proximity of supplying, trading and transporting agribusinesses, as well as knowledge, to be a competitive advantage. (4) Social aspect: horticultural producers often feel emotionally attached to the region in which they have grown up (Breukers *et al.*, 2008). Moreover, regions with low spatial competition are often less urbanized and therefore less attractive for family members.

The greenhouse horticulture production in Almería started after the 1960s and currently houses the largest concentration of greenhouses in the world. Since 1960, development strategies and the lack of land use planning resulted in socioeconomic development in coastal areas and caused one of the most dramatic land use transformations in Europe (Quintas-Soriano *et al.*, 2019), currently representing approximately 4% of the provincial surface area. The promotion of greenhouse horticulture has resulted in very significant social and economic benefits for the Almería province, while also having important negative impacts on native biodiversity and natural resources (Quintas-Soriano *et al.*, 2016a; Requena-Mullor *et al.*, 2018), as well as creating social challenges (Aznar-Sánchez *et al.*, 2011; Muñoz-Rojas *et al.*, 2011; Quintas-Soriano *et al.*, 2018a, 2018b). The economic contribution of the greenhouse horticulture sector represents approximately 13% of the GDP of Almería, in contrast with the agricultural sector in Spain that represents 2.5% of the national GDP (Castro *et al.*, 2019). The total economic activity surrounding the greenhouse production of Almería is 40% of the GDP of the province of Almería; however, it has a relatively equitable distribution of wealth due to the fact that 95% of farms are family owned (Castro *et al.*, 2019).

3.3.3. Effects on biodiversity

While the economic effects have had both positive and negative social consequences in both the Dutch and the Spanish systems, greenhouse horticulture has produced significant negative impacts on biodiversity. In The Netherlands, these impacts are mainly associated with the introduction of alien species by biological pest control strategies. In the Spanish system, ecosystem fragmentation due to land use change by greenhouse horticulture has threatened a unique biodiversity of arid and semi-arid European environments (Castro *et al.*, 2011, 2019; Mota *et al.*, 1996).

In The Netherlands, the effects on local biodiversity have been limited, as the region has already been under horticultural cultivation for the last few centuries. However, two trends are likely to affect the biodiversity in the region. First is the ever-increasing intensification of horticultural cultivation. Second is the use of alien species to control pests of horticultural crops: the area utilizing biological pest control for vegetable production under glass in The Netherlands increased by 10% from 2000 to 2012 (CBS *et al.*, 2015). The introduction of alien species can become a threat to indigenous biodiversity, as alien species can predate on them, compete for food or space or transmit diseases to indigenous species (Noordijk *et al.*, 2010; Oerlemans *et al.*, 2015; Smaal *et al.*, 2009). For instance, the harlequin ladybird (*Harmonia axyridis*), released in the 1990s as a predator of aphids in glasshouses and open fields, has become one of the most common beetles in The Netherlands (Noordijk *et al.*, 2010). Farmers in The Netherlands have planted flowers in and around glasshouses to stimulate biological pest control organisms (Janmaat *et al.*, 2014). Pollinators such as honeybees (*Apis mellifera*) and bumblebees (*Bombus terrestris*) are introduced into glasshouses to improve the pollination of crops (Brink, 2015).

The Almería region is a unique region where conservation efforts have coexisted and coevolved with intense human developments (e.g., urban and agricultural expansion) over recent decades (Castro *et al.*, 2018a, 2019). This region has been recently included among the 25 worldwide biodiversity hotspots and supports high levels of biodiversity, with numerous endemic species and habitats of priority interest at European levels (Armas *et al.*, 2011; López-Rodríguez *et al.*, 2015; Requena-Mullor *et al.*, 2014, 2016). Historically, the conditions for human occupancy have been unfavourable, marked by scarce rainfall, rough land and frequent strong winds (Quintas-Soriano *et al.*, 2018a). The development model was fundamentally limited by water scarcity, and it was dedicated to subsistence dryland agriculture characterized by low yields (Quintas-Soriano *et al.*, 2016a). It was not until the 1970s that this socioeconomic model changed, led by the development of greenhouse agriculture, the tourism sector and the construction industry (Aznar-Sánchez *et al.*, 2011; Muñoz-Rojas *et al.*, 2011; Quintas-Soriano *et al.*, 2016b; Requena-Mullor *et al.*, 2018). In particular, the rapid development of greenhouse agriculture has produced the alteration and fragmentation of the habitats of numerous plant species, such as *Maytenus senegalensis* subsp. *europaeus* and *Juniperus phoenicea* subsp. *turbinate* (Mota *et al.*, 1996; Rodríguez-Caballero *et al.*, 2018).

3.3.4. Effect on landscape aesthetics

The effects on landscape aesthetics by greenhouse development have been negative both in The Netherlands and in Spain. Often located close to urban areas, greenhouse sites come into conflict with urban uses (Rogge *et al.*, 2008; van den Berg, 1993). Developments in the sector itself (tall and large greenhouses) have resulted in a physical appearance that does not blend easily into the landscape, and greenhouses are less visually accepted than other agricultural landscapes. Sprawling greenhouses rank as one of the worst blots on the Dutch landscape. van den Berg describes the area between Rotterdam, The Hague, Zoetermeer and Delft as a "rural–urban no-man's land," a combination of 3000 ha of greenhouses, multiple dwellings and major infrastructure (van den Berg, 1993, p. 36). Large-scale greenhouse development may encounter opposition on a par with the opposition to wind farms (Rogge *et al.*, 2011). Up until the second half of the 1980s, most local land use plans did not differentiate between types of agricultural use. Since the second half of the 1980s, the development of greenhouses has been considered inappropriate outside of existing greenhouse areas. Present plans distinguish more clearly between two different agricultural uses for which specific areas were assigned: (1) greenhouses; and (2) open agricultural areas with specific landscape and nature values assigned (Korthals Altes & van Rij, 2013).

Almería's greenhouse sector has shown great strength in recent decades, becoming an internationally recognized exporter of horticultural products. The great social support received by a large part of the population of Almería is because local farmers' greenhouse production is associated with improvements in quality of life and economic development. However, recent studies have shown that the overall local population of the Almería province also recognizes the negative effects that greenhouses produce on landscape aesthetics (Castro *et al.*, 2018a, 2018b; Quintas-Soriano *et al.*, 2018a) and the urgent need to improve the visual impact and reduce the pollution produced by the image of these greenhouses (Castro *et al.*, 2019). Examples of these aesthetic impacts are the disturbing image of ephemeral streams (i.e., *ramblas* in Spanish) overflowing with a tide of garbage due to deficient rural hygiene plans or the need to implement a management model for organic waste (e.g., plants) and inorganic waste (e.g., plastics) (Castro *et al.*, 2019).

3.3.5. Labour conditions

Both the Dutch and the Spanish tomato production systems are supported by migrant workers. This is driven by the large requirement for low-skilled labour. However, the different socio-economic conditions and historical backgrounds shape different labour conditions in each system.

Dutch horticulture employs both high-skilled personnel for specialized jobs and low-skilled labour for routine jobs. Greenhouse horticulture has a negative image with the Dutch public due to low payment rates, and the high level of social care discourages unemployed persons to seek employment in this sector (Breukers *et al.*, 2008; Engbersen *et al.*, 2011). Job vacancies are therefore commonly filled by foreign temporary employees, mostly from Poland (Breukers *et al.*, 2008; SER, 2014). Almost 50% of the employed personnel in the greenhouse horticultural sector comprises temporary employees (Breukers *et al.*, 2008), who are recruited via Dutch employment agencies (Engbersen *et al.*, 2011; SER, 2014). A current issue regarding foreign labour is housing, as foreign labourers often become victims of 'rack-renters', who offer housing in poor conditions for relatively high rental payments (Breukers *et al.*, 2008). Local governments try to solve this problem by offering housing of an acceptable quality and by stimulating the integration of Polish employees into Dutch society (Breukers *et al.*, 2008). In recent years, the shortage of low-skilled employees has resulted in an increasing level of automatization via technology, which relies less on human labour.

Despite the fact that the Spanish system has a relatively equitable distribution of wealth (Giagnocavo *et al.*, 2018), another important issue related to the image of the agricultural sector is the need for fair labour conditions (Castro *et al.*, 2019). Since 2000, when conflicts concerning immigrants occurred in El Ejido, Almería's image has deteriorated and has been associated by national and especially international media with the poor treatment and living conditions of migrant workers, thereby turning this into a subject matter of debate (Pumares *et al.*, 2003). The Spanish greenhouse horticulture family farms started in the 1970s. They required large amounts of labour, which were initially supported by the local families of greenhouse owners (Giagnocavo *et al.*, 2018). Since the end of the 1980s, the increasing intensification of the family farming model has resulted in the need for more labour, which mainly comes from different African countries (Roquero, 1996). Currently, Almería's greenhouse sector has over 110 nationalities working within it, and it requires two types of labour. First, skilled workers in charge of managing and maintaining the technology of the greenhouses (Valera *et al.*, 2016). Second, low-skilled workers, mainly migrants from West Africa, who do the routine physical work under poor and precarious labour conditions (Garcia-Caparros *et al.*, 2017). When family farms have no succession, efforts are being made to pass on both farms and farming knowledge to immigrant families. Currently, between 5% and 10% of farms are owned and managed by immigrants (Giagnocavo *et al.*, 2018).

3.4. Effects in the spillover systems

Wages are the main cause of agricultural workers migrating into the greenhouse production regions. Wages for tomato production are much higher compared with domestic wages for comparable jobs. In addition, the limited availability of domestic labour opportunities is a reason for migration. For instance, in Poland, the statutory minimum wage in 2012 was €353 per month, while in The Netherlands it was more than four times larger (€1456). Even after correction for the higher costs of living, the statutory minimum wage in The Netherlands is more than double that in Poland (SER, 2014). This driver can change due to the social and economic dynamics of the region of origin of the workers. The growing labour market in Poland and improvements in the national economy have resulted in an increase in wages in Poland, which reduces the likelihood that Polish employees would accept low-wage jobs in The Netherlands (Breukers *et al.*, 2008). Therefore, these economic dynamics in Poland could change the availability of Polish workers in The Netherlands. Furthermore, the risks and social costs that West African migrants experience are higher than the risks and social costs of Polish migrants. The migrant situation for Polish migrants is easier due to the labour agreements between The Netherlands and Poland. In contrast, the Almería greenhouse labour market has mainly attracted migrants from Morocco and several West African countries whose living conditions have been defined as poor and precarious, with processes of labour segmentation, residential segregation, substandard housing and the existence of scattered settlements (Castro *et al.*, 2019; Garcia-Caparros *et al.*, 2017; Santos, 1996). Thus, the social sustainability of both of the tomato-producing regions is questioned, despite the importance of the economic benefits that both systems of production provide for their local and national economies.

3.5. Distant implications of German tomato consumption

Germany imported 738,000 metric tons of fresh tomatoes in 2016. This is the most recent year reported by the FAO (Trade Matrix of the FAO available at: FAO, 2018). From this amount, 54% came from The Netherlands (402,000 metric tons) and 25% from Spain (188,000 metric tons). In order to assess the magnitude of the distant effects of this amount of imported tomatoes, we discuss the resource requirements to produce the tomatoes imported by Germany and produced in The Netherlands and Spain.

Table 4 shows the distant effects and their relative implications in the producing country. Table 4 compares these effects with the availability of the resources and total CO_2 emissions in Spain and in The Netherlands. Table 4 shows the distant effects caused by the production of tomatoes imported by Germany from The Netherlands and Spain in 2016. The values divert due to the different requirements of resources by the Dutch and the Spanish systems (see Table 2) and by the different amount imported from each country. The total national availability, use of each resource or emissions is also shown in Table 4. We use these values to discuss the relative effect on the production region, which is shown in the last two columns of Table 4. These values illustrate that the German consumption of imported tomatoes can

Table 4. Implications of German consumption of tomatoes imported from The Netherlands and from Spain in 2016.

	Distant effects of German imports		Total availability, use or emissions in the country		Share of country's availability or use for German imports	
Agricultural resources and emissions	Spain	The Netherlands	Spain	The Netherlands	Spain	The Netherlands
Land use (ha): area under cover agriculture	1129	804	45,200[a]	9330[a]	2.5%	8.6%
Nitrogen use (metric tons of nitrogen fertilizer)	941	1,207	961,507[b]	201,997[b]	0.1%	0.6%
Total CO_2 emissions of the country (million metric tons of CO_2 eq)	0.05	0.80	260[c]	170[c]	0.02%	0.47%
Labour (workers): employment in agriculture	1505	3217	736,600[b]	162,800[b]	0.2%	1.9%

Values of the first column were calculated using Table 2 and the amount of tomato imports from The Netherlands and from Spain in 2016 (FAO, 2018). The values of the last column were calculated using the first and second column.
Sources of data: [a]EIP-AGRI (2018), [b]FAO (2018), [c]PBL (2019).

result in relatively large use of land and nitrogen, CO_2 emissions and agricultural labour in both Spain and The Netherlands, especially considering that these effects are related to only one crop exported to only one country (Germany). The relative effects are larger for The Netherlands than for Spain. However, it is necessary to consider that Dutch imports in Germany are larger than Spanish imports, and that the land area of Spain is 14 times larger than that of The Netherlands (FAO, 2018).

The nitrogen fertilizer demands represent 0.1% and 0.6%, respectively, for the total Spanish and Dutch use of nitrogen fertilizer in their countries. Similarly, the CO_2 emissions related to tomato production for German demand represent 0.02% of the total Spanish emissions and 0.47% of the total Dutch emissions. The large effect in the Dutch CO_2 emissions is driven by the large use of energy for heating the greenhouses and is thus related to energy-intensive agricultural production. Changing Dutch legislation in order to limit these emissions could reduce these impacts, but would also affect tomato exports.

The total demand of workers in Table 4 was calculated using the values of working hours per kilogram of tomatoes (Table 2) and assuming one worker works 2500 hours per year. These values were compared with the most recent values of total employment of agriculture in Spain and in The Netherlands reported by the FAO (values in 2013; FAO, 2018). The shares of labour demand for tomato exports to Germany are 0.2% and 1.9%, respectively, for the total agricultural labour in Spain and The Netherlands. The relatively large shares are because vegetable production is labour intensive as many activities are done by hand (e.g., picking the tomatoes) compared with other agricultural activities that can be mechanized more easily (e.g., harvesting cereals and potatoes with machinery or livestock keeping) (Ibarrola-Rivas *et al.*, 2016).

The use of water has different implications in both regions because of differences in water availability. Comparing the water demand of tomatoes for German consumption with national water availability (as was done in Table 4 for the other resources) can be misleading, because water for food production should be locally available for agriculture. The water availability of the regions strongly differs because of climate: Almería has a dry climate, while the Westland region has a wet climate. The Almería region, with a very low annual precipitation of approximately 230 mm, requires 475 L of water per square metre (Table 3), which is double the total water precipitation. This means that (at least) half of the water use must be extracted from the aquifer, causing strong water depletion in the area. In contrast, water use of the Dutch system is almost twice as high (approximately 800 L/m^2; see Table 3), but this amount equals the total annual precipitation of the region, which is 778 mm (FAO, 2016). Therefore, in The Netherlands, water depletion is not a major issue, while it is a critical issue in the Almería region.

4. Discussion

4.1. What do the telecoupled impacts of domestic tomato consumption mean for Germany?

Food production requires large amounts of inputs. This can have negative and positive environmental and social effects in the producing regions. Therefore, food imports can result in social and environmental controversies because all of these environmental and social implications are located in the exporting countries. However, food imports are only possible when it is economically profitable for the exporting countries, which is presently the case for the tomato production systems in Spain and in The Netherlands. It is realistic to assume that in the near future prices of water and energy could rise due to shortages or environmental taxes. Consequently, the Dutch and the Spanish production systems would become less profitable. In The Netherlands, awareness regarding the environmental impacts of agriculture is growing, and reducing Dutch production for export is frequently mentioned as a solution for reducing several environmental impacts (Partij voor de Dieren, 2019). Comparable signals can be recognized in other crop-exporting countries. With regards to this, we showed that the labour involved in these systems is fulfilled by immigrants, which can have positive or negative effects depending on several issues, such as the conditions available to workers and governmental agreements.

Food imports result in natural resource savings (water, land, nutrients) in the importing country (D'Odorico *et al.*, 2019). In the case of our analysis, the indirect effects of tomato production by tomato imports in Germany is resulting in such savings. With regards the scenario that tomato exports from The Netherlands and Spain would stop, Table 5 shows the possible local effects in Germany when tomatoes are produced domestically in order to cover German national consumption. Since the climate of Germany and its production technology is similar to the Dutch situation, we thus assume that the production systems in Germany will require a similar amount of natural resources to

Table 5. German savings of agricultural resources and emissions by tomato imports.

Agricultural resources and emissions	Total availability or use in Germany	Requirements for German tomato consumption	Relative 'savings' in Germany by importing tomatoes
Land use (ha): area under cover agriculture	3110[a]	3146	101%
Nitrogen use (metric tons of nitrogen fertilizer)	1,675,289[b]	4719	0.3%
Total CO_2 emissions of the country (million metric tons of CO_2 eq)	780[c]	3	0.4%
Labour (workers): employment in agriculture	571,800[b]	12,584	2%

The demand for resources for German consumption was calculated assuming the values of the Dutch production system from Table 2. The values of the second column were calculated using the Dutch production system from Table 2 and the total German consumption of tomatoes. The values of the last column were calculated using the first and second columns.
Sources of data: [a]EIP-AGRI (2018), [b]FAO (2018), [c]PBL (2019).

the Dutch system (Table 2). Consequently, if Germany would grow its own tomatoes, the area of domestic greenhouses would need to double, the required nitrogen fertilizer would need to increase by 0.3%, the total national CO_2 emissions would increase by 0.4% and 12,600 extra workers would be required, which would account for 2% of the total German agricultural workforce (Table 5). Following the Dutch trend, these workers would probably need to be recruited from other countries. However, emissions and air pollution from transport would be reduced. Overall, this overview shows the relatively large 'savings' in terms of environmental and social costs Germany achieves by importing almost all of the tomatoes that are consumed domestically.

Regarding the water requirements for tomato production, the climate in Germany is similar to that of The Netherlands, with precipitation of 700 mm in most regions of the country (FAO, 2016). Therefore, water availability would not be an issue in Germany compared to the water scarcity of the case study in Spain.

4.2. Reflection on the telecoupling framework and our approach

4.2.1. New insights from this study

The telecoupling framework is an optimal approach to conceptualizing and discussing complex effects of consumption choices, which are often difficult to grasp. This study shows that imports of tomatoes have cascade effects in distinct regions and on their populations. These effects not only appear in the producing regions, but also in the spillover regions, including impacts on the environment, such as biodiversity loss, land use change and effects on landscape aesthetics, and impacts on society, such as labour conditions and human migration.

Our study adds new insights to the telecoupling literature. Previous studies have been mainly focused on identifying and understanding the distant effects of a certain system. In this paper, we discuss and compare two sending systems. Our results show that, even though both sending systems produce tomatoes in intensive greenhouses systems, the environmental and socio-economic implications are very different due to local socio-economic and ecological characteristics and to the type of production system. Therefore, the consumer choice of tomatoes in Germany can have different distant effects in the producing regions. In addition, we make visible the variety of social impacts associated with the two spillover systems (i.e., Eastern Europe and West Africa), which is a starting point to discuss the social inequality associated with food trades.

4.2.2. Limitations of our data source

Our data source of resource use in tomato production systems is a study of different greenhouses technologies in Europe (Torrellas *et al.*, 2012). The aim of Torrellas *et al.*'s study was to compare horticultural practices in cold and warm climates in Europe by means of a life cycle analysis of a stylized farm in each focus region, including Almería and Westland. They calculate average farm values using several data sources from the literature, including experimental farm stations in Almería, a farmers' data network in The Netherlands and other scientific studies (see section 2.3 in Torrellas *et al.*, 2012). Such stylized data synthesizing detailed knowledge about the local production systems are ideal for our study compared to individual farm-level data because, first, agricultural practices and resource use patterns vary among individual farms, and second, detailed data on resource use are difficult to obtain at the individual farm level. Since the Torrellas *et al.* study describes stylized, typical farms for the focus regions, their data reflect typical resource use patterns, resource efficiencies and costs in these regions. Thus, the values in Tables 2 and 3 should not be considered as specific values for individual farms. Rather, they should be considered as indications of the differences in management practices due to climate and environmental conditions. The large differences between the regions shown in Tables 2 and 3 highlight the different conditions and trends in both regions. Comparable differences are therefore expected if individual farm data were used, which would lead to comparable insights and conclusions being obtained.

4.2.3. The need for further research

Global trade is a complex system resulting in multidimensional and multiscale indirect effects. In this study, we have identified and discussed the most relevant social, environmental and economic effects resulting from tomato imports in Germany. However, several indirect effects were not considered because they are the result of cascade effects that are not visible with our approach. For example, migrant workers in Spain and in The Netherlands might have important 'remittance effects' in their country of origin. Lambin and Meyfroidt (2011) highlight that the income flow due to remittances from rural migration can have different effects in their regions of origin, such as: (1) decreasing land pressure, as family members at home engage in the non-farm economy and increase the wealth of rural households; or (2) increasing land pressure, because the migrants acquire land, thereby increasing investment in mechanization and agricultural intensification (Lambin & Meyfroit, 2011). These two scenarios would result in different environmental and social effects in the short and long run for the local community. In our study, these remittances effects driven by the migrant tomato workers were not identified.

In addition, we discussed the implications of whether Germany were to produce domestically all of the tomatoes presently imported (Section 4.1). However, not all effects of tomato production in Germany are included in this analysis (e.g., soil, air and water pollution and the use of pesticides were beyond the scope of our analysis). In addition, the post-harvest effects are not considered, such as the effects related to transport, storage and retail services. Further studies should analyse whether it is realistic to assume that tomato production in Germany would result in similar effects to the Dutch tomato production system. Another possibility for reducing these effects would be to change consumption patterns in Germany by reducing tomato consumption or importing tomatoes from another region that can produce tomatoes in a more profitable way. The latter option should be further analysed in order to consider all of the direct and indirect effects in the production and spillover regions.

Finally, we discussed the environmental, economic and social effects independently. Often these local effects have positive or negative feedback loops with each other. For instance, large water use by greenhouses in Almería could result in a strong reduction in freshwater availability in the region, which would worsen the living conditions of the workers (Castro *et al.*, 2014; Quintas-Soriano *et al.*, 2018a).

4.3. Global implications and possible solutions

4.3.1. Other regions with similar situations

The tomato trade in Germany is only an example for visualizing and understanding the direct and indirect effects of global trade. Situations in other regions of the world show similar dynamics. For instance, the tomato supply in the USA changes depending on the season. From November to April or May, tomatoes mainly originate from Mexico and Florida, while from May or June to October, tomatoes mainly originate from California and Canada (SAGARPA, 2010). A person in a US supermarket could choose to buy a tomato that was produced in Florida or in Mexico, resulting in different local effects due to the type of production system and the local context in the production region. Further local studies should be conducted in order to analyse the different effects of the production regions and to identify spillover regions that are affected. Thus, the local effects of global food trade are context specific, driven by a cascade of social, economic, environmental and political causes, and they should be analysed case by case.

4.3.2. Global implications and possible solutions

Global markets are complex. Food products can be produced in different regions with long and complex supply chains before they reach consumers. Tomatoes consumed in Germany mainly originate from The Netherlands or Spain, while the (low-skilled) labour required for their production is mainly conducted by migrant workers coming from Poland or West Africa, respectively, resulting in different social implications. The implications of imported goods are usually not evident to the consumer, and the consumer does not face the direct consequences of their consumer choice, as they appear only remotely (Balvanera *et al.*, 2017). For instance, tomatoes coming from The Netherlands and Spain look very similar to the consumer. Nevertheless, the faraway and indirect consequences of the choice of the consumer can be significant. The implications in the production area depend on the local context, such as: (1) the type of production system combined with the biophysical conditions of the region (climate, local natural resources), resulting in different environmental effects and biodiversity losses; (2) the social, economic and historical context of the region, resulting in different land use change dynamics, biodiversity losses and social perception and levels of acceptance; and (3) labour availability and governmental labour agreements, resulting in different labour conditions for workers.

This study is an example of the application of place-based social–ecological research towards global sustainability (Castro *et al.*, 2018a). These studies make visible the effects associated with global food trade by using local knowledge in order to find global solutions (Balvanera *et al.*, 2017; Castro *et al.*, 2018a). Place-based social–ecological research can help us to explore pathways in order to understand the interplay between the local and global scales by recognizing the importance of including knowledge from local systems while addressing the impacts of global food system dynamics (Norstrom *et al.*, 2017; Quintas-Soriano *et al.*, 2018a).

5. Conclusions

The growth and complexity of global markets has increased the disconnect between consumers and the remote local effects on the producer side. Visualizing and understanding the direct and indirect relationships between the different factors of global trade is a first step towards overcoming this disconnect and towards identifying ways to achieve more sustainable and more fair global food systems. The pathways could be both at the local level (e.g., campaigns targeting consumers in order to increase their awareness of the remote effects of their food preferences) and at the national and international level (e.g., legislation for environmental and/or social standards, certification of acceptable environmental impacts and social standards and labour agreements among countries).

Acknowledgments. The research reported in this paper contributes to the Programme on Ecosystem Change and Society (www.pecs-science.org). We thank the organizers of the II PECS conference in November 2017 for promoting the collaboration for this paper.

Author contributions. All authors conceived and designed the study, gathered the data and wrote the paper. MJIR coordinated the project.

Financial support. This project was partly funded by the PAPIIT programme (Programa de Apoyo a Proyectos de Investigación e Innovación Tecnológica) of UNAM project number IA300219 and the Vienna Science and Technology Fund (WWTF) project number ESR17-014.

Conflict of interest. None.

Ethical standards. This research and article complies with *Global Sustainability*'s publishing ethics guidelines.

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