Can a Shift to Regional and Organic Diets Reduce Greenhouse Gas Emissions from the Food System? A Case Study from Qatar

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Research

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Can a shift to regional and organic diets reduce greenhouse gas emissions from the food system? A case study from Qatar

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Abstract

Background

Qatar is one of the countries with the highest carbon (C) footprints per capita in the world with an increasing population and food demand. Furthermore, the international blockade by some countries that is affecting Qatar – which has been traditionally a highly-dependent country on food imports – since 2017 has led the authorities to take the decision of increasing food self-sufficiency. In this study we have assessed the effect on greenhouse gas (GHG) emissions of shifting diets from conventional to organic products and from import-based diets to more regionalized diets for the first time in a Gulf country.

Results

We found that considering the production system, the majority of the emissions come from the animal products, but the differences between conventional and organic diets are very small (738 and 722 Kg CO_2-eq capita^{-1} yr^{-1}, of total emissions, respectively). Conversely, total emissions from plant-based products consumption are one order of magnitude smaller, but the differences in the emissions between the two systems were higher, leading to a decrease in 88 Kg CO_2-eq capita^{-1} yr^{-1} when changing from conventional to organic consumption. Regarding the change to 100% regionalized diets, we found that packaging has a small influence on the total amount of GHG emissions, whereas emissions from transportation would be reduced in 780Kg CO_2 capita^{-1} yr^{-1} for the business as usual scenario of 2015.

Conclusions

Due to the extreme adverse pedoclimatic conditions of the country, commercial organic regional livestock would not be possible without emitting very high GHG emissions and just only some traditional livestock species could be farmed in a climate-friendly way. On the other hand, organic and regional low-CO_2 emission systems of plant-based products would be possible by implementing innovations in irrigation or other innovations whose GHG emissions must be further studied in the future. Therefore, we conclude that shifting towards more plant-based organic regional products consumption by using climate-friendly irrigation innovations in combination with a decrease in the total meat and dairy consumption and a shift to traditional livestock species farming is a suitable solution to both increasing self-sufficiency and reducing C footprint.

Keywords: CO_2 emissions; C cycle; organic production; regional production; agri-food system; arid areas; global food supply chains

1. Background

Food systems (FS), which include all processes and actors involved in the production, aggregation, processing, distribution, consumption and disposal of food products (FAO 2018a), are currently responsible for up to 37% of global greenhouse gas (GHG) emissions (SAPEA 2020), playing a key role in driving climate change [3]. Improving the sustainability of FS would require deep transformations comprising consumption patterns, system changes (e.g. management practices and distribution processes) and changes in the FS-environment interactions (e.g. governance).

Among all these processes involved in FS, shifting diets are one of the most important as climate change mitigation option. More plant-based, organic and regional-based diets have been proposed as a way to decrease GHG emissions (Tilman and Clark 2014; Ulaszewska *et al*. 2017; Kevany *et al*. 2018; Irz *et al*. 2019; Mbow *et al*. 2019; Willett *et al*. 2019). In this line, the IPCC after comparing emissions from scenarios assessing different diets in the literature found that the mitigation potential of alternative diets would be between 3-8 $GtCO_2$-eq yr^{-1}.

There are different approaches and tools to estimate GHG emissions from the FS. Some of them include life cycle assessments (LCA), for specific crops, products or production systems (Gunady *et al*. 2012; Clune *et al*. 2017; Bosona and Gebresenbet 2018; Pérez Neira *et al*. 2018). However, when assessing the entire supply chain, LCA are not suitable and the lack of data becomes a problem. For instance, FAO estimations of GHG emission intensities for the different food products are calculated considering only "emissions generated within the farm gate". Therefore, emissions from other upstream and downstream consumption and production processes are not included in the assessment (FAO 2019). An intermediate solution to address this fact is to consider many processes by using default data in order to create "calculators" or tools to estimate the environmental impacts of different production systems in specific places, assessing specific crop types or consumption patterns (Torrellas *et al*. 2013; Ledo *et al*. 2018; Mansard *et al*. 2018; Vetter *et al*. 2018; Buhl *et al*. 2019), even though these calculations might be not entirely precise (Kim and Neff 2009; Peter *et al*. 2017).

However, these calculators might be useful when comparing systems (e.g. conventional vs organic) or to assess and develop policy instruments (Elizondo *et al*. 2017; Coderoni and Esposti 2018; Moinuddin and Kuriyama 2019), or even to be linked with bioeconomic models [24]. Despite the fact that meanwhile some data are available to estimate GHG emissions from fresh products (Clune *et al*. 2017) via LCA methodologies, a shortcoming of these studies is that they do not distinguish between different production systems or do not consider downstream processes (e.g transportation, refrigeration and packaging), what is a relevant requirement when assessing FS at country level (Manzone and Calvo 2017; Heldt *et al*. 2019; Hu *et al*. 2019; López-Avilés *et al*. 2019). In the case of our research, the objective was to carry out an assessment of GHG emissions of Qatar, a very particular FS, at national level.

Due to the extreme arid climatic conditions and water constraints, Qatar has limited agricultural production mainly based on date palm and some vegetable crops. Furthermore, soils are of very poor quality and conventional agriculture is possible only in rodat soils, those located in depressions and made up of calcareous loam, sandy loam and sandy clay loam with depths between 30 and 150 cm (FAO 2008), covering a surface of around 28,000 ha, of which 23,000 are silty clay loam to clay loam and 5,000 ha belong to sandy loam to sandy clay loam textures (Al-kubaisi 1984).

Currently agriculture in Qatar comprises 67,000 ha of land, of which 25% are croplands (17,000 ha) and the remaining 75% pastures (50,000 ha) (FAOSTAT). The annual precipitation in the country is around 80 mm, whereas the evaporation rate is about 2000 mm. This huge gap in the water balance is compensated in agriculture by using groundwater resources, currently under very high pressure and highly vulnerable (Baalousha 2016; Baalousha *et al*. 2018). In 2012 the groundwater extraction rate was about 400Mm^3 yr^{-1}, where between 236 Mm^3 (Darwish *et al*. 2015b) and 250 Mm^3 (Schlumberger Water Services 2009; Baalousha *et al*. 2018) were used for agriculture. This figure is about seven times higher than the natural replenishment rate (about 60 Mm^3) [33]. In order to reduce groundwater extraction some authors have proposed the use of wastewater and low-CO_2 emission technologies to obtain desalted water for crop irrigation (Darwish *et al.* 2015a; Rahman and Zaidi 2018).

In addition, due to the blockade imposed by some neighbouring countries, Qatar is experiencing since mid-2017 an increase in the logistical costs, as food importation has become more expensive (MERatings 2020). As a consequence of this blockade, food has become a sensitive issue and Qatar decided to increase locally produced food and, thus, increasing self-sufficiency (QNFSP 2020), despite of the very challenging pedoclimatic conditions.

In this context it matters to know that Qatar´s C footprint is among the highest in the world, being around 44 tons per capita and year. This figure is about four times Germany´s footprint, twice the footprint of other countries of the Gulf area (Kuwait, Bahrein or UAE) and also twice the world´s average footprint (Alhorr *et al*. 2014). The Paris Agreement, adopted in the Conference of the Parties on its twenty-first session (COP21) (United Nations 2016) encourages all countries to achieve net-zero CO_2 emissions by 2050 and to account for the sources and sinks of the GHG emissions in the context of the Nationally Determined Contributions (NDCs) that have to be communicated every five years (article 4), officially starting in 2020. Therefore, Qatar has now the double challenge of increasing food self-sufficiency under very challenging pedoclimatic conditions while at the same time decreasing the C footprint.

In this context, this study is aimed to: 1) develop a methodology to estimate GHG emissions based on the statistical available data and the official guidelines in order to compare alternatives for a FS transformation which are first, two management system intensities (conventional vs organic) and, second, the territorial scale of the supply chain (regional vs imports-based); 2) to apply the methodology to the conditions of Qatar; and 3) based in the results, to propose specific shifts in the diets in order to decrease GHG emissions while maintaining self-sufficiency goals.

In the following chapter we will introduce the delineation and methodology for the FS and scenario approach as well as data categories, sources and calculations applied for the entire chain assessment, followed by the description of the methodology to estimate the emissions related to the relevant steps of the supply chain. Chapter 3 presents and discusses the results with regard to a shift of production systems and transportation distances, as well as dietary shifts and contextualized the results beyond the system borders. The conclusions highlight the value of our findings and include policy recommendations.

2. Material and methods

2.1 Food systems and scenarios

Two different type of systems were selected for both, plant-based and animal products:

1) Management system intensity (production): conventional vs organic. For the plant-based products GHG emissions were specifically calculated for the different sources (Figure 1a), whereas for animal products emission intensities for each system belong to LCA selected based on a literature review.

2) Territorial scale of the supply chain (distribution): regional vs non-regional (i.e. imports-based). Emissions from packaging and transportation of plant-based and animal products are included here (Figure 1b).

Three type of scenarios were considered for the assessment:

1) Business as Usual (BAU). It defines the current state of the FS. When comparing the production systems BAU is considered to be 100% conventional. When comparing distribution systems, BAU has been calculated according to the imports of the country in 2015 (85% imports).

2) Complete adoption of one of the systems (100% conventional/organic and 100% regional/non-regional).

3) Half adoption of the system (50% conventional + 50% organic and 50% regional 50% non-regional).

2.2 Data management for plant-based products and literature review for animal products.

Figure 2 shows a scheme of the data requirements for the estimation of the GHG footprint. A detailed scheme of the calculation process is shown in figure 3.

a. Consumption and yields

Data on food consumption are official publicly available from the State of Qatar (Planning and Statistics Authority 2013) (table 1). Some products have been excluded from the assessment due to the infeasibility of being produced in the country or lack of data on the production (nuts, tea, coffee, cacao, alcoholic drinks, pork, and oilseeds). The proportion of different consumed red-meat categories has been estimated by using FAO available data from a similar country (UAE). Cereals category includes wheat, barely, maize and other cereals. Vegetables category includes onions, beans, potatoes, sugar beet, tomatoes, cucumbers, cabbages, asparagus, carrots and turnips, cauliflowers and broccoli, pumpkins, eggplants, spinach, lettuce and chicory. Fish was assumed to be entirely farmed fish.

Yields of plant-based products are taken from official statistics from the State of Qatar (Planning and Statistics Authority 2015) (table 1), whereas yields of animal products are taken from the estimations from Zasada *et al*. (2019), since feed requirements of Qatar´s commercial livestock are comparable to the European and US standards .

b. Production

b.1 Plant-based products

Pesticides and inorganic fertilization

Emission factor of pesticides is the value from (Audsley *et al*. 2009), a default value for every country (see 2.5). Specific application rates are taken from FAO (FAOSTAT) (table 2). Emission factor of inorganic fertilizers (production, transportation, storage and transfer) is the one proposed for Asia by Kool *et al*. (2012). Specific application rates for Qatar are not available and, therefore, rates from UAE were taken (FAOSTAT) (table 2).

Organic fertilization

In the study it was assumed that only residues from harvest are applied as organic inputs. Values of nitrogen (N) content in the residues were taken from Esteban *et al*. (2008). When N content was unknown, values from Williams *et al*. (2006) were used. For the calculations of the amount of residues applied, it was assumed that all the residues from harvest would be applied and, for that purpose data on residue-to-product ratio were taken from different studies (Strehler and Stutzle 1987; Rosillo-Calle 2007; Unal and Alibas 2007; Ecofys 2015; FAO, 2018b) (see Supplementary Material, S.1).

b.2 Animal products

Data on emission intensities from livestock production in Qatar are not available *(Clune et al.* 2017). Therefore, a literature review of emission intensities for conventional and organic systems was carried out. The products assessed were milk from cows, beef, poultry, pork, sheep and goat, and fish. Although pork is neither produced nor consumed in Qatar it was also included in the assessment in order to obtain a more complete review on factors to be possibly applied to other study cases in the future. For the literature review only those studies distinguishing between emissions from organic and conventional systems and assessing only the production process (i.e. transportation and packaging not included) were considered. A summary of the average emission intensities for each product is shown in table 3. Complete data are shown in the Supplementary Material (see tables S.2-S.9).

c. Distribution

Transportation

It was assumed that all terrestrial transportation is done by truck (average capacity between 16 and 32 tones), due to the lack of train infrastructures in Qatar. Since the data on imports is from 2013 (Planning and Statistics Authority 2013) (see table S10 in the Supplementary Material), namely before the blockade of 2017, terrestrial transportation was assumed to take place within Qatar and between Qatar and the neighbor countries. For imports from further countries (see 2.5), ship or plane transportation were assumed. Emission factors for the different means of transport are shown in table 4 (Heller 2017; Ecoinvent).

Packaging

Emissions from packaging were estimated from average values from different studies. They were grouped according to the type of commodity (Lindenthal *et al.*, 2010; Sonesson *et al.* 2010; Williams and Wikström 2011; Ziegler *et al.* 2013) (table 5).

2.3 Methodology to estimate CO_2 emissions from the production of plant-based products.

In the following sub-sections calculations of the emissions from the processes shown in the figure 1 are specified.

2.3.1 Conventional management

Pesticides

Emissions from the use of pesticides in conventional agriculture were calculated by using the Eq. 1.

$$CO_{2\,pesticides} = EF \times AR \qquad \text{(Eq. 1)}$$

where EF is the emission factor of the pesticide (production, transportation, storage and transfer) (Kg CO_2 Kg pesticide^{-1}) and AR the average pesticide application rate for Qatar (Kg pesticide ha^{-1}).

Inorganic fertilization

Emissions from inorganic fertilization (Eq. 2) come from the production of the specific fertilizer (N, P or K-based) (Eq. 3) (Eq. 4) and the N_2O emissions resulting from the application of the N-fertilizer (Eq. 5) (Kg CO_2-eq ha^{-1}) (IPCC 2006, 2019)

$$CO_{2-\text{eq}\,inorg.\ fert.} = CO_{2\,\text{N,P,K}-fertilizers} + CO_{2-eq}[N_2O]_{N-fertilizer} \qquad \text{(Eq. 2)}$$

$$CO_{2\,\text{N,P,K}-\text{fertilizer}} = CO_{2\,\text{N}-\text{fertilizer}} + CO_{2\,\text{P}-\text{fertilizer}} + CO_{2\,\text{K}-\text{fertilizer}} \qquad \text{(Eq. 3)}$$

Where CO_2 emissions for each fertilizer (Kg CO_2 ha^{-1}) are calculated as follows:

$$CO_{2\ N,P,K-fertilizer} = EF_{N,P,K-fertilizer} \times AR_{N,P,K-fertilizer} \quad \text{(Eq. 4)}$$

where EF is the emission factor of the specific inorganic fertilizer (N, P, K) (production, transportation, storage and transfer) (Kg CO_2 Kg $fertilizer^{-1}$) and AR the application rate of each inorganic fertilizer (Kg fertilizer ha^{-1}).

$$CO_{2-eq}[N_2O]_{N-fertilizer} = AR \times 0.01 \times {}^{44}/_{28} \times 298 \quad \text{(Eq. 5)}$$

where AR is the application rate of the N-fertilizer (Kg fertilizer ha^{-1}), 0.01 is the IPCC emission factor for added nitrogen, 44/28 is the conversion factor to transform to N_2O emissions and 298 is the global warming potential for nitrous oxide.

For both, CO_2-eq from pesticides and inorganic fertilization, results are given per surface unit (hectares). In order to convert them to emissions per capita (Kg CO_2 $capita^{-1}$) the following equation was applied (Eq. 6):

$$CO_{2-eq} = CO_{2-eq\ inorg.\ fert.} \times \frac{1}{Y} \times C \quad \text{(Eq. 6)}$$

where $CO_{2-eq\ inorg.\ fert.}$ are the CO_2 emissions per surface unit (Kg CO_2 ha^{-1}), Y is the yield for the specific product (Kg product ha^{-1}) and C is the consumption per capita of the product (Kg product $capita^{-1}$).

2.3.2 Organic management

Organic fertilization

Application of residues from harvest were considered as organic fertilizer. The calculation of the emissions (Kg CO_2-eq Kg $product^{-1}$) were done as follows (Eq. 7):

$$CO_{2-eq}[N_2O]_{org.\ fert.} = RP \times N \times 0.01 \times {}^{44}/_{28} \times 298 \quad \text{(Eq. 7)}$$

where RP (Kg residue Kg $product^{-1}$) is the residue-to-product ratio, N is the nitrogen content of the residue (Kg N Kg $residue^{-1}$), 0.01 is the IPCC emission factor for added nitrogen, 44/28 is the conversion factor to transform to N_2O emissions and 298 is the global warming potential for nitrous oxide.

2.4 Methodology to estimate CO_2 emissions from the production of animal products

In this case, due to the lack of information on GHG emissions from livestock activities in arid areas (Clune *et al*. 2017) a literature review was carried out (see section 2.2.b.2). In the literature review only those studies developing a LCA of the production phase were considered. GHG emissions from the consumption of animal products (Kg CO_2-eq $capita^{-1}$) were calculated as follows (Eq. 8):

$$CO_{2-eq\ animal} = C \times EF \quad \text{(Eq. 8)}$$

where C is the consumption per capita of the specific product (Kg product capita^{-1}) and EF is the emission factor (i.e. emission intensity) of the production of the animal product (Kg CO_2-eq Kg product^{-1}).

2.5 Methodology to estimate CO_2 emissions from transportation

To calculate emissions from imports a similar methodology to that developed by (Scholz, 2013) was followed (Figure 3). First, the amount of plant-based and animal products of each country of origin was calculated. The proportion of the imported product from each country was estimated by using available data on the amount of dollars spent on importing animal and plant-based products for 2015 (https://wits.worldbank.org/). For that assessment it was assumed that the proportion of dollars used for the imports is equal to the proportion of tons of imported food. This assumption was necessary due to the lack of information on the amount of food imports. The next step is to consider the mean of transport. For plant-based products, it was assumed than all the intracontinental terrestrial transport comes by truck, whereas for intercontinental and transoceanic transport it was assumed that the 50% of plant-based and 80% of animal products come by ship, and the remaining come by plane. This assumption was based on the fact that most crop-based products are perishable and must be transported in just a few days (Scholz 2013; Steadie-Seifi 2017; QNFSP 2020) (Figure 3).

Then, the CO_2 emissions from the transportation of each product were calculated as follows (Kg CO_2 capita^{-1}) (Eq. 9):

$$CO_{2\,transportation} = C \times EF \times D \qquad \text{(Eq. 9)}$$

where C is the consumption of the product per capita (Kg product capita^{-1}), EF is the emission factor of the mean of transport (Kg CO_2 Kg product^{-1} Km^{-1}) and D is the distance (Km) between the country of origin and Qatar.

For calculating the distances by plane Google Maps was used, whereas for calculating the distances by ship the website Sea Distances (https://sea-distances.org/) was used. The most important port of the country was selected as port of origin. In case of different important ports existing in the country, the nearest port to Qatar was selected.

2.6 Methodology to estimate CO_2 emissions from packaging

CO_2 emissions from packaging are linked to the place of production. In this study it was assumed that products coming from local production are not packaged, with the exception of milk, dairy products, eggs and cereals, which were considered to be packaged regardless of the place of production. Thus, CO_2 emissions from packaging (Kg CO_2 capita^{-1}) were calculated as follows (Eq. 10):

$$CO_{2\,packaging} = C \times EF \qquad \text{(Eq. 10)}$$

where C is the consumption of the product per capita (Kg product capita^{-1}) and EF is the emission factor of the packaging of the specific type of product (Kg CO_2 Kg product^{-1}).

3. Results and discussion

3.1.Production

a) Animal products

Emission intensities of meat from ruminants (beef, sheep and goat) account for the highest values (>10 Kg CO_2-eq Kg product^{-1}) mainly due to the enteric fermentation producing methane (CH_4). Intermediate values are found for monogastric animal meat and eggs (3 – 7 Kg CO_2 Kg product^{-1}) and the lowest values for milk from cows (1 Kg CO_2 Kg product^{-1}) (table 3). For monogastric – and also ruminants –emissions come from the CH_4 releases from the stored manure, which also emits nitrous oxide (N_2O) and in a lesser extent to the CO_2 from the fossil fuels and energy usage (UNEP 2013).

The literature review indicates that the emissions per unit of product are similar between the two systems, conventional and organic, although there are differences between the specific products (table 3). For instance, for milk from cows the same emission factor was found (1 Kg CO_2-eq Kg product^{-1}) due to the similar values reported by the authors (Cederberg and Mattsson 2000; Haas *et al*. 2001; Cederberg and Flysjo 2004; Williams *et al*. 2006; Thomassen *et al*. 2008; Hirschfeld *et al*. 2009; Grünberg *et al*. 2010; Lindenthal *et al*. 2010b). Similar findings occur with beef (12-14 Kg CO_2-eq Kg product^{-1}) (Hirschfeld *et al*. 2009). On the other hand, for fish (1.77 vs 0.87 Kg CO_2-eq kg product^{-1}) (Pelletier *et al*. 2009; Ziegler *et al*. 2013; Robb *et al*. 2017), sheep (17.5 vs 10.1 Kg CO_2-eq Kg product^{-1}) (Williams *et al*. 2006) and pork (3.9 vs 3.0 Kg CO_2-eq Kg product^{-1}) (Williams *et al*. 2006; Hirschfeld *et al*. 2009; LCA Food Database) the conventional management has been reported to emit more CO_2 than the organic. Conversely, the organic management account for higher emission intensities for poultry meat (6.7 vs 4.6 Kg CO_2-eq Kg product^{-1}) (Williams *et al*. 2006; Hirschfeld *et al*. 2009) and eggs (7.1 vs 5.6 Kg CO_2-eq Kg product^{-1}) (Williams *et al*. 2006) (table 3).

For fish, more than 90% of the emissions came mainly from the feed. The reduction in the emissions in the organic system to almost half of the conventional is due to the change in the feed formulations (e.g. from fish and animal protein meals to vegetable-based meals) [71]. On the other hand, poultry consumes high value feeds and the nutritional needs are met by arable crops, whereas ruminants are able to digest cellulose and, therefore, can be fed by grass (Williams *et al*. 2006). To produce arable crops in the conventional system, synthetic fertilizers are used and, therefore, more energy (i.e. more CO_2 emissions) is required than in the organic system. However, due to the lower organic bird performance (i.e. lower efficient system because of the higher feeding requirements to produce the same amount of meat) the benefits of this lower energy requirements are over-ridden (Williams *et al*. 2006).

Regarding the differences in the CO_2 emissions between conventional and the organic systems and considering the organic system as baseline (i.e. zero emissions), the emissions per capita from the conventional system - taken as the business as usual scenario – amount 103 Kg CO_2-eq yr^{-1}, where around 85% of the reductions (88 Kg CO_2-eq capita^{-1} yr^{-1}) come from the plant-based products and 15% (15 Kg CO_2-eq capita^{-1} yr^{-1}) from the animal products (table 6 and Figure 4). This was due to the fact that, in average, emission intensities of animal products in organic and conventional systems are very similar (6.34 and 7.32 Kg CO_2-eq Kg product^{-1}, respectively) (table 3), and so are the differences in the CO_2 emissions.

However, in absolute numbers, the consumption of animal products amount the highest total CO_2-eq emissions (738 and 723 KgCO_2-eq capita^{-1}, for the conventional and the organic

systems, respectively) (table 6 and figure 5). This figure is similar to the value found in another study for United Arab Emirates (765 $KgCO_2$ $capita^{-1}$, (nu3 2018)). This fact is explained because the emission factors of animal products are much higher than those of the plant-based, leading to a much lower total CO_2-eq emissions from the latter (9 and 97 $KgCO_2$-eq $capita^{-1}$, for the organic and the conventional systems, respectively) (table 6 and figure 5). Therefore, we found that around 87% of the total GHG emissions come from animal products in the conventional system, whereas this value is even higher, around 98%, in the organic system.

b) Plant-based products

For plant-based products, GHG emissions are markedly higher in the conventional system. The use of inorganic fertilizers plays a key role on the total amount, accounting for more than 95% of the total emissions (figure 6). In the organic system, emissions per unit of product are 2.3, 24, 92 and 7.9 times lower than in the conventional system for dates, fruits, vegetables and cereals, respectively. It is due to the different N content of the residues applied, as well as the different residue-to-product ratio of the specific plant-based products (see table S.1 in the Supplementary Material).

Emissions from inorganic fertilization come from two sources. First, the GHG emitted in the processes before being applied (production, transportation, storage and transfer) (Kool *et al.* 2012), and second the N_2O emissions after their application (IPCC 2006, 2019). In average, around two thirds of the emissions belong to the fertilizer production (1,547 Kg CO_2 ha^{-1}), whereas the other third come from the emissions that occur in the context of application (846 Kg CO_2-eq ha^{-1}) (IPCC 2006, 2019; FAOSTAT). Our results are in line to those shown in the official statistics of FAO, estimating around 0.20 Kg CO_2 Kg $cereal^{-1}$ (world average) (FAOSTAT), whereas in our study the value for conventionally-produced cereals was slightly higher (0.42 Kg CO_2 Kg $cereal^{-1}$).

c) Emissions from irrigation

However, neither in our study nor in other similar studies (e.g. (FAOSTAT)) additional emissions from irrigation (i.e. water desalination) are included. This is due to the lack of accessible and accurate data on water requirements and current sources of water used for irrigating crops in Qatar – or countries under similar pedoclimatic conditions – and emission factors from water desalination. Nevertheless, in order to show an example of how irrigation from desalted water would imply in terms of CO_2 emissions, an estimation of the emissions from irrigation for cereal production in Qatar has been done. Thus, considering an estimated emission factor of 2.04 Kg CO_2 m^{-3} freshwater for desalted water (average value from different desalination processes from Liu *et al.* (2015)) and an estimated required irrigation for cereals in Qatar of 1.52 m^3 Kg $cereal^{-1}$[1], around additional 3.1 $KgCO_2$ would be emitted per kilogram of cereal produced. Furthermore, considering the feed requirements of beef, and poultry meat[2] [76], 21.7 and 6.2 Kg CO_2 per kilogram of beef and poultry from desalted water would be emitted, respectively, if they were produced in Qatar.

[1] Average value of estimated blue water required to produce different types of wheat, maize and barley [114]
[2] Estimations from Brown (2006) of 7kg of grain per kilogram of beef and 2 kg per kilogram of poultry.

Currently agriculture in Qatar relies mainly on groundwater sources [77], extracting around 250 Mm^3 per year, when the sustainable rate would be around only 60 Mm^3 [33] [35], and leading to an impoverishment of the groundwater quality (e.g. increase in the salinity) [77] [78]. Therefore, additional regional production should be based on the use of non-groundwater sources (i.e. at this moment desalted seawater) (Darwish *et al*. 2015a).

Although in this study CO_2 emissions from irrigation are not included in the calculations of the production of regional plant-based products and neither the emissions from feeding the livestock, these estimations could give an idea about the order of magnitude of the additional emissions that regional production would imply. For regional plant-based products, additional emissions from irrigation would be around one order of magnitude higher than those from the production, whereas for animal-based products these could be in the same order of magnitude. However, the energy losses due to the decrease in the energy use efficiency from feeding animals lead, in absolute numbers (i.e. emissions per kilogram of final product), to higher emissions from irrigation from animal-based products.

Nevertheless, there could be lower-emission options to obtain water for irrigation. Among these options the use of wastewater or by-products from wastewater has become one of the most important alternative water sources in the recent years (Darwish *et al*. 2015a, 2015b; Osman *et al.* 2016; Echchelh *et al.* 2020; Kogbara *et al.* 2020). Furthermore, some lower-emission technologies could be applied to the desalination plants like hybrid systems (e.g. solar photovoltaic cells with wind energy, nanofiltration and ultrafiltration for pre-treatment, electrodialysis and reverse osmosis, forward osmosis with nanofiltration) (Rahman and Zaidi 2018; Klaimi *et al.* 2019) or even some future CCU (Carbon Capture and Utilization) technologies to re-use the CO_2 with the brine produced in the plant to produce carbonates after a mineralization process (Dindi et al. 2018; Galvez-Martos *et al.* 2018; Oh *et al*. 2019; Mustafa *et al*. 2020; Yoo *et al.* 2020). Recently, in this line Namany *et al*. (2019) using a holistic energy, water, and food (EWF) Nexus approach in Qatar found that diversifying the energy and water mix by introducing more than 70% of renewable energy technologies and utilizing reverse osmosis would decrease the environmental impact of this process by 60% from these two sectors.

3.2. Distribution and packaging: non-regional vs regional production

The differences in the CO_2 emissions from the packaging between the regional and the non-regional and BAU scenarios are of 25 and 21 Kg CO_2 $capita^{-1}$, respectively (table 7 and figure 7). These values are four times lower than the difference in the CO_2-eq emissions from the production of plant-based products, but in the range of the production of animal products. Despite the emission factors of packaging of animal products are almost double of the plant-based, total emissions from plant-based products are slightly higher due to the higher consumption of the latter (table 5 and figure 7).

Regarding the transportation, the differences in the CO_2 emissions between the regional and the non-regional and BAU scenarios are of 915 and 780 Kg CO_2 $capita^{-1}$, respectively (table 8). That is one order of magnitude higher than the differences found in in the production and packaging. Almost two thirds of the emissions belong to the plant-based products, whereas the other third comes from the transportation of the animal products (table 8 and figure 8). This is due to two facts, i) the higher consumption of plant-based products, and ii) the higher proportion

of perishable products (i.e short shelf life and easily deterioration) in the plant-based products group that must be transported by plane (Steadie-Seifi 2017; QNFSP 2020). In this line, average emissions from transportation of regional products amounted 0.023 $KgCO_2$ Kg product^{-1} for both plant-based and animal products, whereas for imported products emissions are remarkably higher, between 60 and 90 times for plant-based and animal products (1.47 and 1.92 Kg CO_2 kg product^{-1}), respectively (table 8) (see also tables S.11-S.13 in the Supplementary Material). These values are very similar to those calculated in a similar study in Sweden [61], where the average emissions per unit of imported food product were 1.64 Kg CO_2.

In Qatar the majority of the fodder used to feed animals in livestock is imported [38] and part of it comes from the US [90]. Considering the specific emission factor (table 4) and distance by ship, around 0.33 $KgCO_2$ per kilogram of transported product would be emitted. That means, for feeding regional livestock in Qatar emissions from the transportation of the feed would be around 2.31 and 0.66 Kg CO_2 kg^{-1} for beef and poultry meat produced in Qatar, respectively. However, if the meat was not produced in Qatar but directly in the US and then imported to Qatar the emissions from transportation would be reduced to 0.33 Kg CO_2 kg product^{-1}, in the case that they were transported by ship.

However, fodder production in Qatar could be increased and CO_2 emissions from irrigation decreased by implementing TSE (Treated Sewage Effluent) facilities. In this line, Qatar has increased green fodder cultivated areas by combining groundwater and TSE more than three times in eleven years (2001-2012) reaching 5,183 ha, whereas the area irrigated with only TSE sources was around 1,520 ha in the year 2012 (Osman *et al*. 2016). This increase in the use of TSE technologies would decrease the emissions associated to the regional food production, making the imports less sustainable in terms of GHG emissions and preserving groundwater sources (Osman *et al*. 2016; QNFSP 2020).

3.3. Decreasing CO_2 footprint by shifting diets in Qatar

a) Animal-based diets

Due to the water scarcity, very high insolation and poor soils that characterize arid areas only very specific products can be produced regionally in a traditional way (e.g. dates[91] or camels [92]), although in the recent years new organic farms practicing greenhouse production have appeared. In general, organic livestock farming is carried out extensively, based on grazing (permanent grasslands, natural pastures, specific rotations…) and, therefore, in Qatar only conventional livestock farming can be implemented, as it can be carried out indoors by maintaining specific climatic conditions and by feeding the livestock with imports [93]. However, this leads to a high increase in the CO_2 footprint compared to the animal products produced in temperate areas. In this sense, it is very important to highlight that, due to the lack of studies and data, the emission intensities from livestock come from LCA estimations from temperate areas and, therefore, they do not take into account the specificities of the livestock farming in Qatar (e.g. extra water and energy consumption) [93]. For example, according to our results (tables 6 and 7) the consumption of 1 kg of imported conventional beef in Qatar would imply the emission of 13.87 Kg CO_2 (13.43, 0,15 and 0.29 Kg CO_2-eq kg product^{-1} from production, packaging and transportation, respectively) (97% from production) if it is frozen meat transported from Australia by ship, or 28.48 Kg CO_2 (13.43, 0,15 and 14.90 Kg CO_2-eq kg product^{-1} from production, packaging and transportation, respectively) (47% from production) in case it is fresh meat imported from Australia by plane. These results suggest that

495 even though the additional emissions from commercial livestock farming in Qatar are not
496 known, emissions from transportation and packaging would be negligible compared to those
497 from the production in the total balance when transporting by ship (i.e frozen meat or fresh
498 meat from nearby countries).

499 An exception would be the traditional regional livestock. Traditional livestock species (e.g.
500 camels, goats) which are used to the extreme conditions of Qatar could be fed by indigenous
501 palatable plants and palatable halophytes, which consume less freshwater and, therefore, could
502 be used as fodder. These species could substitute the current exotic plants used for feeding the
503 livestock (e.g. rhode-grass (*Chloris gavana*) and alfalfa (*Medicago sativa*)), which can consume
504 up to 48,000 m^3 ha^{-1} yr^{-1} of water [92].

505 However, what is clear from our results is that decreasing the level of meat from ruminants
506 could be an effective strategy to decrease the GHG emissions. Emissions from transportation
507 and packaging remain similar but emissions from conventional production are three times lower
508 for poultry meat, meaning a decrease in 8.83 Kg CO_2-eq Kg $product^{-1}$ (from 13.43 to 4.6 Kg
509 CO_2-eq kg $product^{-1}$). Considering the actual consumption of beef in Qatar, the shift from beef
510 to poultry meat would lead to a decrease of about 74 Kg CO_2-eq per capita and year. This
511 relatively high reduction in the GHG emissions from the shift from ruminants to monogastrics
512 is in line with other studies showing differences between three times (Aan Den Toorn *et al.*
513 2017) until one order of magnitude [95], and suggesting that up to 65% of the world´s GHG
514 from livestock would come from cattle (Kevany *et al.* 2018).

515

516 b) Plant-based diets

517 In our scenarios, we selected organic fruit and horticulture farming also due to the fact that they
518 use organic inputs (residues from harvest, manure, pruning debris, sewage sludge, compost…)
519 as fertilizers. However, they do not necessarily require soil, but they can be grown by using
520 soil-free substrates and water or can be combined with aquaculture (i.e. aquaponics) [96]. In
521 our study, emissions from the use of inorganic fertilizers and pesticides in the production of
522 conventional vegetables averaged 0.12 Kg CO_2-eq Kg $product^{-1}$ (Figure 6). Considering an
523 emission factor from packaging of 0.06 Kg CO_2 Kg $product^{-1}$ (table 5) and same emission factor
524 for transportation than in the previous example for meat (table 4), emissions from packaging
525 and transportation would be higher than those from the production. Moreover, since the
526 emissions from inorganic fertilizers and pesticides are relatively high compared to those from
527 the organic system (Figure 6), and considering the emissions from transportation and
528 packaging, regional and organic farming might be considered as mitigating options.

529 Another mitigating option also suggested by many authors since the last decade (e.g. Steinfeld
530 *et al.* 2006; Bajželj *et al.* 2014; Hedenus *et al.* 2014; Joyce *et al.* 2014; Tilman and Clark
531 2014; Springmann *et al.* 2016; Kevany *et al.* 2018) is decreasing the level of meat and dairy
532 consumption and, thus, increasing plant-based products consumption (i.e adopting vegetarian
533 or vegan diets). According to our results reducing the consumption of animal products to half
534 of the current level and substituting them with plant-based products would save around 368
535 $KgCO_2$ $capita^{-1}$[3]. In this line, Joyce *et al.* (2014) in a literature review found that shifting to non-

[3] Estimated emissions of plant-based products are not a LCA, since emissions from tillage operations are not included in the calculations. However, according to our estimations, around 1,547 Kg CO_2 ha^{-1} would be emitted

meat diets could save up to half of the total diet-associated emissions compared to an average diet.

3.4.Gaps, future researches, and synergies and trade-offs with other ecosystem services

a) Lack of studies in Qatar and countries under similar pedoclimatic conditions

The complete lack of studies in Qatar assessing emission factors and intensities in agriculture and livestock (Clune *et al*. 2017) led us to consider many assumptions. Emission intensities of animal products are taken from studies carried out in temperate areas, with very different conditions than those existing in Qatar, where water and energy requirements are typically much higher. For agriculture, UAE´s application rate of inorganic fertilization has been taken (FAOSTAT), whereas the emission factor from its production was taken from Asia´s default value from Kool *et al*. (2012). Similarly, the application rate of pesticides was taken from FAO Statistics for Qatar (FAOSTAT) and the emission factor from the production of pesticides was a default value from Audsley *et al.* (2009).

Furthermore, due to the lack of studies on organic farming in arid areas SOC sequestration has not been considered in the study. Vicente-Vicente *et al*. (2016) found in a meta-analysis in Mediterranean woody crops that the application of organic amendments could sequester up to 5 t C ha^{-1} yr^{-1} (18 t CO_2 ha^{-1} yr^{-1}). Our study has considered only as fertilizer the application of residues from harvest in the organic farming, thus excluding the application of other organic amendments (compost, manure, sewage sludge…), since their type, application rate and N dynamics depend highly on the specific local conditions (e.g. nearby livestock farms, nearby industries generating organic byproducts…) (Masunga *et al.* 2016; Vicente-Vicente *et al*. 2016; Charles *et al.* 2017; He *et al*. 2020) and these data are not available in Qatar. Therefore, the reduction in the emissions in organic agriculture compare to the conventional system shown in this assessment must be taken as estimations since eventually depend on the balance between the N_2O emissions and SOC after the application of the organic inputs.

b) System boundaries

The assessment, especially for the plant-based products, has been developed in order to compare systems (organic vs conventional and regional vs non-regional). When comparing organic vs conventional agricultural systems, only those practices that are different between the two systems have been considered. However, when comparing regional vs non-regional products, local specificities were not considered due to the many different origins of the imports and the complexity of the systems in each country. The result is that the CO_2 footprint from irrigation (i.e. seawater desalination) in Qatar has not been included when calculating emissions from regional products. In the same way, for livestock regionally produced in Qatar, additional emissions from importing the fodder or those from maintaining the climatic conditions in indoor facilities were not taken into account. Nevertheless, as we are aware of those processes, specific sections and estimations have been included in the study in order to figure out the order of magnitude of them (e.g. section 3.1.c).

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from the use of inorganic fertilizers, whereas from tillage activities emissions would be between 7 – 56 Kg CO_2 ha^{-1} [115] and, thus, can be negligible for the overall calculation.

c) Synergies and trade-offs with other ecosystem services

Assessing the effect of different FS in terms of GHG emissions means assessing only one regulating ecosystem service [106]. However, fostering one specific FS also affects other ecosystem services beyond GHG emissions. For instance, organic farming improves soil supporting services, like SOC content (e.g.Aguilera *et al*. 2013) and, thus, it affects positively some soil fertility properties (e.g. microbial activity, soil porosity and water retention). Furthermore, organic farming might affect positively other regulating ecosystem services (e.g. pollination, biological control, biodiversity), whereas there might be some trade-offs especially with provisioning ecosystem services (e.g. food production) (Boone *et al*. 2019; Zhong *et al.* 2020). On the other hand, traditional regional production fosters cultural and aesthetic ecosystem services like local economy, traditions and quality of the landscape (Barrena *et al*. 2014; Nahuelhual *et al.* 2014; Assandri *et al*. 2018).

However, fostering intensive commercial regional livestock (e.g. cows) increases country´s food production, but they might emit more GHG than the imported meat or milk because the climatic conditions of the country do not allow low-CO_2 emissions intensive livestock. As a matter of fact, the great majority of the fodder in Qatar is not produced in the country but in far-distant countries "including the USA and other northern and southern hemisphere countries" [90], thus consuming land and resources in other countries and emitting extra GHG emissions. Therefore, new frames considering externalities beyond the country borders, like telecoupling (Liu *et al*. 2013), should be considered when assessing the impacts of a FS on ecosystem services, as the current FS cannot be isolated within the country, but they depend on international food chains. Thus, we found a clear trade-off between increasing country´s food production of non-traditional animal products and GHG emissions in Qatar. This trade-off could be mitigated through the increase in the production of traditional animal products (e.g. camels, goats, sheep) that can be fed with local plant species in an extensive way [92].

4. Conclusions and recommendations for policymakers

In our study the ambition was to introduce and apply a methodology for a databased assessment of the potential for GHG emission savings associated with the transformation of the food system towards a more sustainable (organic) production system or a distance-related shortening of supply chains. With the emerging experiences regarding food chain resilience along the COVID-19 crisis the regionalization of global food chains became a broadly considered issue. In this course also the transformation towards more climate neutral and sustainable systems is addressed. Our study presents first assessments of a possible transformation scenarios resulting from a post-crisis situation, following the embargo situation in Qatar. We have purposely adapted our approach to the particularly conditions (e.g. pedoclimatic) of this country. Although the results and conclusions are to be valued specifically under these conditions, our methodological approach should also be useful for other case studies.

Achieving a GHG-neutral food system is not feasible, since every activity has an impact on GHG emissions. Even the SOC sequestration, which is the main sink of CO_2 in the food system has a limit and is reversible. Therefore, comparing food production systems and commodities in terms of GHG emissions could be a suitable methodology when assessing the suitability of the different systems in the decision-making processes. Regarding animal products, the

majority of the emissions come from the production, with the exception of the products coming by air freight, where transportation could contribute up to half of the total emissions. Due to the climatic conditions in Qatar, which make production of animal products more costly in terms of energy and water consumption than in other climates, imports by ship or truck would emit less GHG than regional production. Furthermore, the production of plant-based products would emit around one order of magnitude less GHG than animal products. However, in order to keep the emissions under a relatively low level, vegetables production in Qatar should be done in an efficient way and by using lower- or non-CO_2 emission technologies (e.g renewable energies, precision and smart farming, re-use of organic by-products, use of wastewater…) and by implementing emerging food-system innovations like combining the production of plant-based products with fish farming (i.e. aquaponics systems).

On the other hand, the trade-offs between the local production of non-traditional animal products and GHG emissions might be unavoidable at the short-term, due to the unstable international food supply chains, mainly due to the current blockade that is affecting Qatar since 2017 by some surrounding countries of the Gulf Region and more recently to the COVID-19 crisis.

Therefore, we suggest a dietary change, which should be boosted by local authorities. According to our results and other current literature, implementing the production and fostering the consumption of traditional animal products is highly recommendable. Primarily however, the reduction of the consumption of animal products in favor of the plant-based, would lead to an important decrease in the GHG emissions. In addition, implementing efficient and likewise sustainable innovations for indoor food production should be prioritized.

Declarations

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Author contributions

Conceptualization J.L.V.V and A.P; Data curation J.L.V.V; Formal analysis J.L.V.V and A.P; Funding acquisition A.P; Investigation J.L.V.V and A.P; Methodology J.L.V.V; Project administration A.P; Resources A.P; Software J.L.V.V; Supervision A.P; Validation J.L.V.V; Visualization J.L.V.V; Roles/Writing - original draft J.L.V.V and A.P; Writing - review & editing J.L.V.V and A.P.

660

661 **Conflicts of interest**

662 The authors declare no conflicts of interest

663

664 **Availability of data and material**

665 The relevant results are shown in the manuscript, whereas other supporting data are shown in
666 the Supplementary Material.

667

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Figures

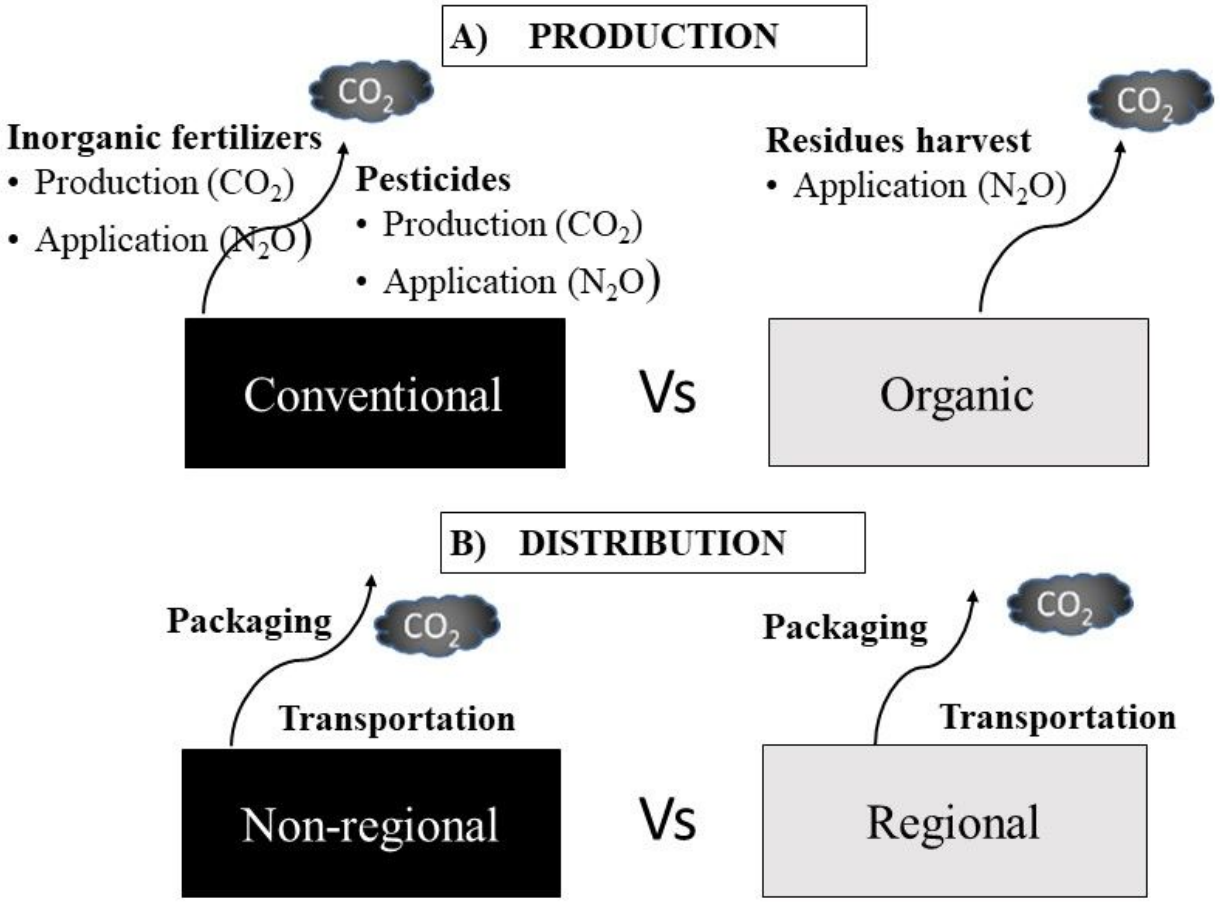


Figure 1

Two different type of systems were selected for both, plant-based and animal products

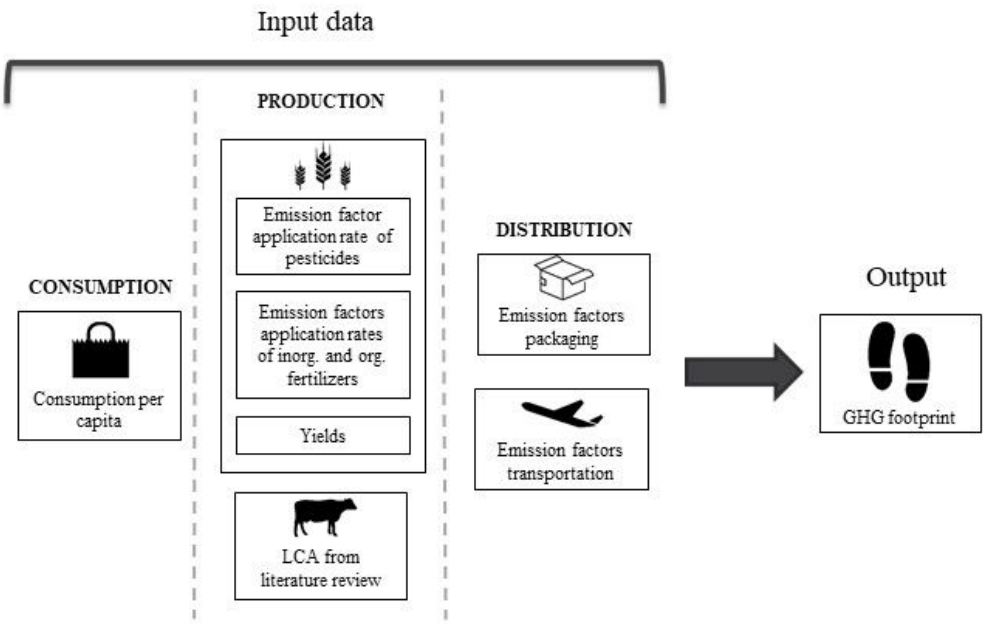


Figure 2

A scheme of the data requirements for the estimation of the GHG footprint.

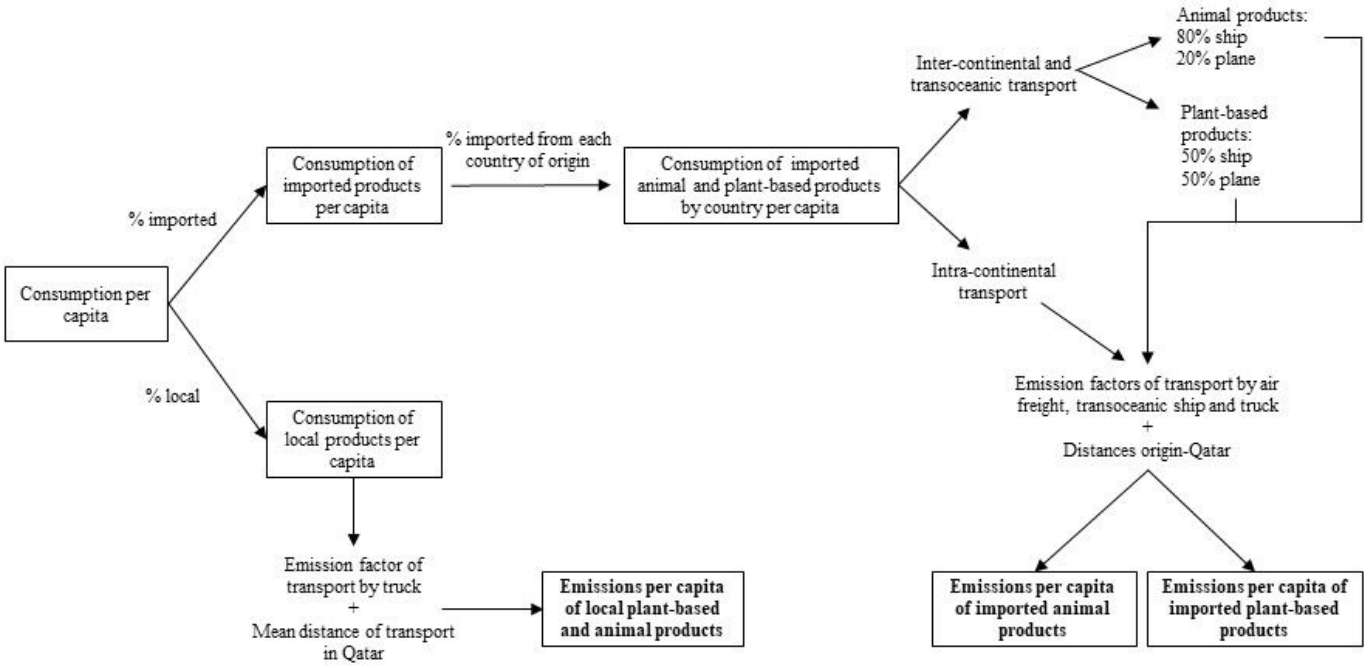
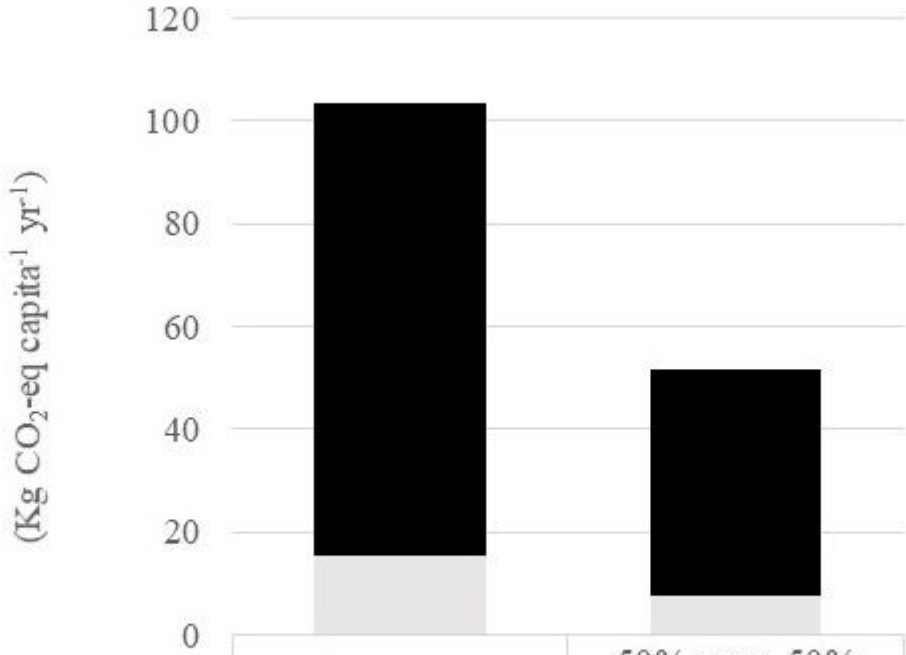


Figure 3

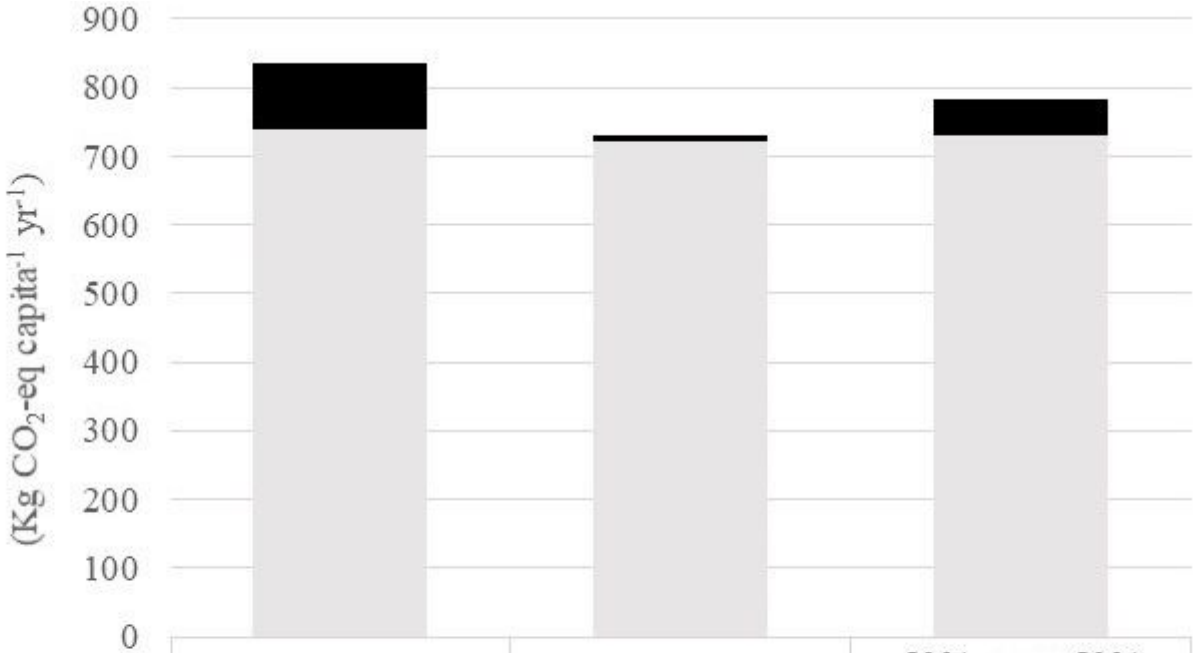
A detailed scheme of the calculation process



	100% conv.	50% conv. 50% org.
plant-based products	87.97	43.98
Animal products	15.49	7.75

Figure 4

The plant-based products and the animal products



	100% conv.	100% org.	50% conv. 50% org.
Plant-based products	96.54	8.57	52.55
Animal products	738.13	722.63	730.38

Figure 5

The conventional and the organic systems

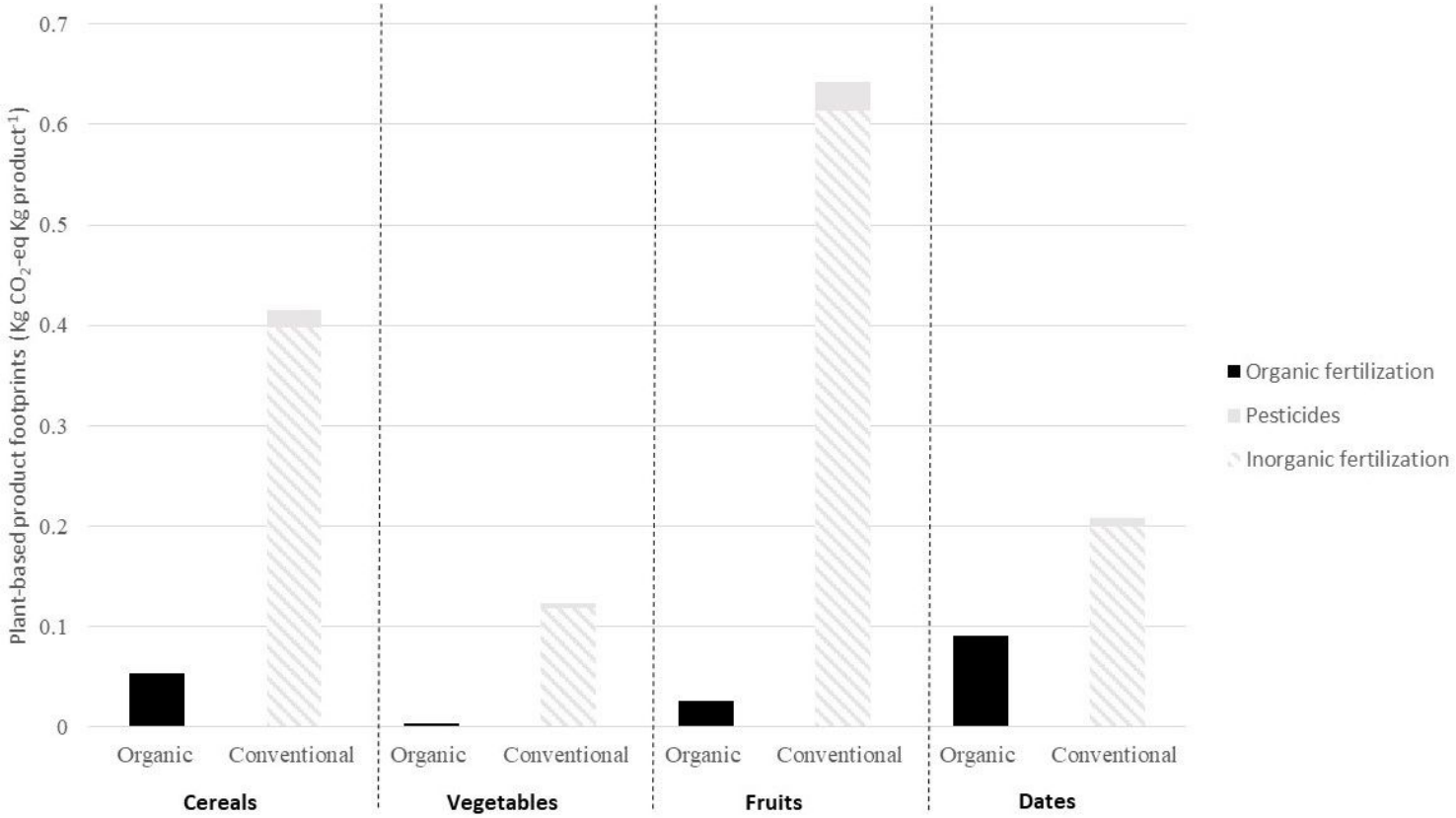
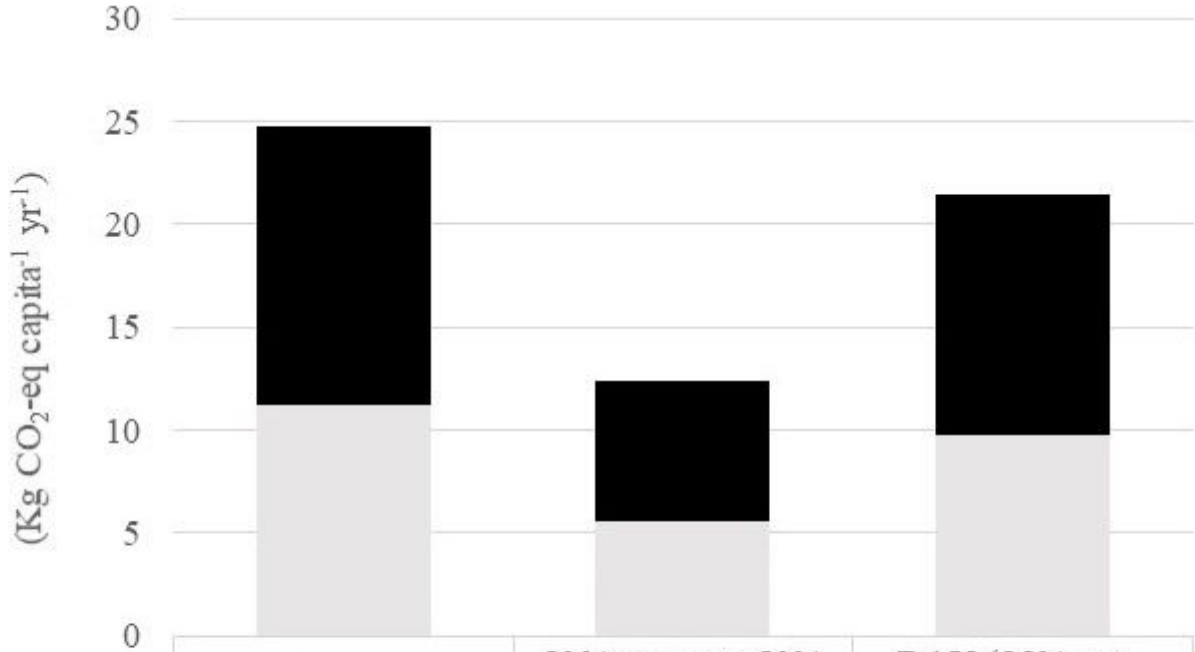


Figure 6

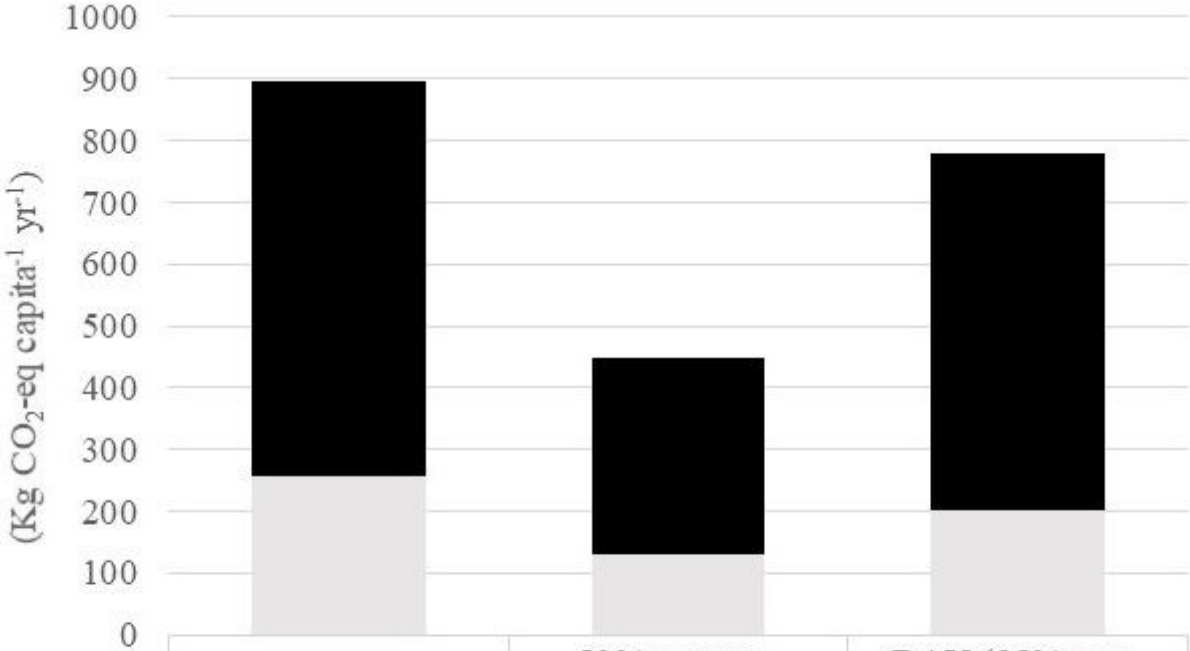
Plant-based products, GHG emissions are markedly higher in the conventional system



	100% non-reg.	50% non-reg. 50% reg.	BAU (85% non-reg.)
Plant-based products	13.59	6.80	11.63
Animal products	11.17	5.59	9.79

Figure 7

The plant-based products and the animal products



	100% non-reg.	50% non-reg. 50% reg.	BAU (85% non-reg.)
Plant-based products	640.05	320.03	578.74
Animal products	257.18	128.59	201.15

Figure 8

The plant-based products and the animal products

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarymaterial.pdf
- Tables.pdf