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LCA FOR AGRICULTURE

# Sustainability assessment of peri-urban organic horticulture — A case study in the United Kingdom

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**Abstract**

**Purpose** There is a growing concern about the resilience and sustainability of horticultural production in the United Kingdom (UK) as a result of high energy costs and insufficient local labour, causing over-reliance on imports. In this study, we present an integrated environmental and economic assessment of organic peri-urban horticulture using primary data from a farm in Sheffield.

**Methods** This study includes a farm-to-gate hybrid life cycle assessment (LCA) using the ReCIPE (H) approach for the functional unit of 1-kg tomatoes produced in an unheated polytunnel without supplementary lighting, and 1 kg of field-grown courgettes. All analyses were conducted in SimaPro software using environmental data from the ecoinvent database. Results were compared with those from a systematic literature review of similar studies.

**Results** We found that the production of organic tomatoes and courgettes resulted in a global warming potential (GWP) of 0.61 kg $CO_2$-eq and 0.11 kg $CO_2$-eq respectively using a process-based LCA approach. Using a hybrid LCA approach, however, yielded a GWP of 3.53 kg $CO_2$-eq and 1.70 kg $CO_2$-eq for the production of organic tomatoes and courgettes respectively. An additional scenario included farmgate-to-warehouse transportation for both domestic and imported produce from Spain, but found that the GWP of tomatoes in the case study was 1.87 times higher than those from Spain. Economic analysis showed that the marginal increase in the prices of tomatoes and courgettes from the case study farm was 4.6 and 5.15 times less than the market prices.

**Conclusion** We conclude that the studied production system is both economically and environmentally sustainable as compared to the existing scenario. Other potential benefits of peri-urban organic horticulture include employment, mental health, community cohesion, which remain to be explored in a future qualitative study. The present study is novel as it appears to be the first application of hybrid LCA to UK horticulture. The findings are highly topical given the recent horticultural supply constraints in the UK.

**Keywords** Hybrid LCA · Food sustainability · Resilience · Affordability

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## 1 Introduction

### 1.1 UK horticultural production and imports

The utilised agricultural area of the UK is around 17.3 million hectares which accounts for more than 70% of the total land in the country (McCalmont et al. 2017). A larger proportion of total land is used for agriculture in the UK than in any country in the European Union (EU). Most of this utilised agricultural land is grassland, with crops, mainly cereals, being grown on only 4.7 million hectares (Richter and Semenov 2005). The land areas used to grow fresh produce for human consumption (horticulture), comprising fruit and vegetable crops, excluding potatoes was 147,976 ha in 2021 of which 112,220 ha were used to grow field vegetables. This area yields about 2.54 million metric tons that meet 57.2% of UK consumption demand, with a retail value of £1.66 billion (DEFRA 2022a). It is important to note here that the yields of protected and field grown crops vary from each other. Here, protected horticulture refers to that which enables "some control of wind-velocity, moisture, temperature, mineral nutrients, light intensity and atmospheric composition" typically in glasshouses or polythene-covering polytunnels (Wittwer and Castilla 1995). Analysis of horticultural statistics (DEFRA 2022a) shows that, between the years 1985 and 2015, protected horticulture achieved an average yield of 267.13 metric tons ha$^{-1}$, with an average value of £965.34/metric ton, but only used a land area of 1491 ha. On the other hand, in the same period, field horticulture achieved average yields of 17.43 metric tons ha$^{-1}$, with an average value of £4911.95/metric ton, and used a land area of 148,335 ha. On a like-for-like basis, between the years 1985 and 2016, the average yield of lettuce in field farming has been 22.95 metric tons/hectare (t/ha) which is significantly ($t = 11.59$, $p < 0.05$) less than 33.53 t/ha achieved for lettuce in protected farming. Similarly, the value of lettuce from field farming (£638.38) has been significantly lower ($t = 4.90$, $p < 0.05$) than that produced from protected horticulture (£1241.90/metric ton) between the aforementioned years. Despite the advantages offered by protected farming, vegetables from this source form only a small proportion of the overall supply mix as shown in Fig. 1 below. The figure also shows that the share of UK vegetable consumption that is home-grown has declined in recent years, increasing reliance on imports, especially from the EU (DEFRA 2021). This makes UK food security vulnerable to existing and potential supply chain disruptions in Europe such as those demonstrated during the Ukraine war (Wang et al. 2022). Also, rising fuel and energy costs mean that the production and transport costs are also increasing for imported produce as exemplified in an increase of 8.2% in fresh vegetable consumer price index between the years 2015 and 2023 (ONS 2023). This issue has become a serious concern lately when bad weather in Spain forced UK supermarkets to ration vegetables (Gross 2023). This makes this study highly topical and relevant to the debate on UK's food system resilience.

Figure 1 also shows the changes in the index of productivity (metric ton/hectare) and value (£/hectare) for field and

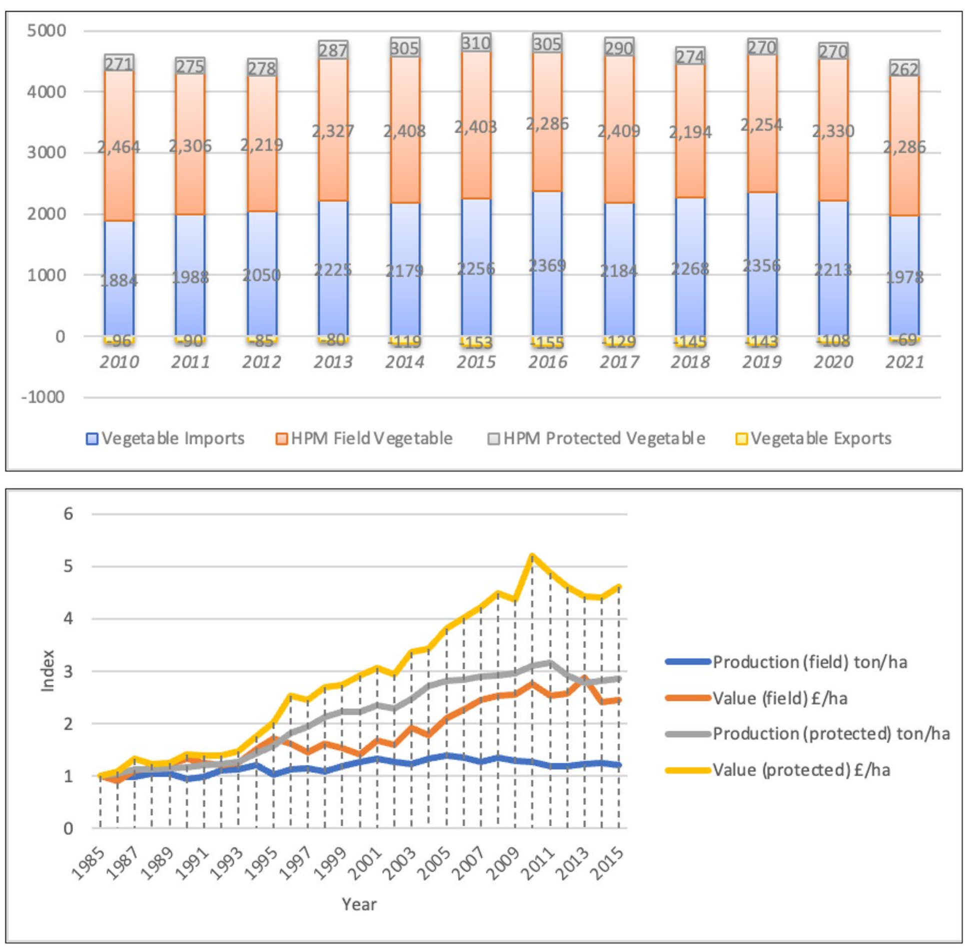



**Fig. 1** (Above) UK vegetable supply by source (000 metric tons). HPM stands for Home-Produced Marketed (DEFRA 2022a). (Below) change in productivity and value of field grown and protected vegetables in the UK (DEFRA 2022a). Index is the proportional value relative to baseline year (1985)

protected vegetables grown in the UK. The index has been created by normalizing the values for all years with respect to the first year in the chart i.e. 1985. This corresponds to values of 14.83 metric ton/hectare and £278.56/hectare for field vegetables. For protected vegetables, these values were 126.23 metric ton/hectare and £91,962.33/hectare in 1985. While the productivity of the field vegetables has plateaued and remains close to 1, the productivity of protected vegetables increased by around three times between 1985 and 2015. Similarly, the market value of both field and protected vegetables has been increasing which is a reflection of the escalation of labour, input, transport and retail costs. However, the rate of increase in the value of protected vegetables increased fivefold as opposed to that for field vegetables which increased 2.5 times approximately in the evaluated period.

### 1.2 Environmental emissions of horticulture

Both conventional and protected horticultural systems can have significant environmental impacts. For instance, 32.8% of England's field vegetable production is conducted on Fenland peat soils, which comprise around half of grade 1 agricultural land in England (NFU 2020). Typical crops grown directly on Fenland peats include lettuce and celery (IUCN 2020). For UK overall, only 7% of peatlands are used for crop production but they also emit 32% of the total peatland GHG emissions (Evans et al. 2017). Similarly, environmental impacts are also caused by peat extraction as growing media/substrate for amateur gardening as well as professional use for crops such as mushrooms and blueberries. In high-input protected horticulture, crops are typically grown in glasshouses, in artificial rooting substrates, with supplementary heating and lighting, with highly controlled irrigation and liquid fertilization (fertigation). Studies have shown high-input protected horticulture to be more productive yet more environmentally intensive than open field horticulture (Maureira et al. 2022). As such, quite often, it becomes a question of trade-offs between choosing either of the two systems. However, with increasing costs of energy, the sustainability of high-input protected horticulture is increasingly questionable. Table 1 given below displays the emissions of courgettes and tomatoes grown in field and protected environments. The inclusion criteria for studies reported in Table 1 included those conducted in Europe (and Morocco due to UK imports) or the USA as listed in Web of Science, reporting LCA results expressed in units of kg $CO_2$-eq per unit area or weight with a cradle-to-farmgate system boundary only. This is because transport distance, packaging and processing types vary from one case to another. Similarly, monetary functional units are susceptible to change due to inflation. In some cases, such data was extracted from supplementary materials of the journal articles. Similarly, where only charts were made available for results, values were extracted where possible. Some studies reported different sub-configurations of production systems (e.g. heating methods), and in such cases, ranges for the yield and emission values have been presented. We have highlighted tomatoes and courgette in Table 1 as tomatoes are the highest value imported horticultural product in the UK, mainly originating from Spain and the Netherlands (DEFRA 2022a). Similarly, most courgettes sold in the UK are imported from Spain and Morocco. Both of these countries are water scarce, and existing water supplies are threatened further due to climate change (Hess and Sutcliffe 2018; Taheripour et al. 2020). Moreover, while there are significant environmental impacts associated with long transportation distances, use of energy for heating greenhouses may also play a significant role in the overall impacts (Theurl et al. 2014).

Table 1 shows that the yield and impacts from the production of tomato and courgette varied spatially from one country or region to another. For instance, the yields and impacts from non-organic tomato production were generally higher in Northern European countries (France, Netherlands, Sweden and Norway). This is because most of the production in the studies included from these countries involved heating. Such impacts were the lowest in Southern Europe (Spain and Italy) and periphery countries (Morocco). Other factors include the crop variety, kind of production (organic vs non-organic) and the variation in inputs (e.g. heated vs non-heated greenhouse). For instance, the yield of (non-organic) cherry tomatoes was generally lower but impact generally higher than that for other varieties. Finally, yield from field production was lower than that from protected horticulture. Additional variations exist with respect to the choice of the functional unit and the LCA methodology used. Some of the hidden differences pertain to the assumptions made while defining the system boundaries and calculating the useful life of the inputs (Notarnicola et al. 2017). To mitigate some of the issues inherent in process LCAs, studies increasingly use novel methods such as hybrid LCA. However, existing literature on hybrid LCA of crop production is still quite scarce. As explained in Section 2, we aim to fill these gaps by using hybrid LCA as well as process-based LCA to evaluate the environmental impacts of different crops.

### 1.3 The case for urban food growing

Vegetables are an important part of healthy diets; their affordability and availability are critical for food security. As explained above, vegetable supply in the UK relies mainly on imports from European countries, many of which are suffering from the impacts of climate change impacting the demand and availability of irrigation water supplies, and crops being increasingly exposed to extreme summer heat

**Table 1** Yields and emissions of vegetables across field and protected horticulture (cradle-to-farmgate), colour coded for regional perspective

| No. | Location | Vegetable (variety) | Substrate in protected | Organic | Heating | Yield in field | Yield in protected | Emission field (kg $CO_{2\text{-eq}}$) | Emission protected (kg $CO_{2\text{-eq}}$) | LCA method | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Albania | Tomato | - | No | No | | 95 t/ha | | 2660.4 per hectare | ReCiPe2016 | Canaj et al. (2020) |
| 2 | Hungary | Tomato | Rockwool | No | Yes | | 48 kg/$m^2$ | | 780–2000 per metric ton | CML 2001 | Torrellas et al. (2012) |
| 3 | Sweden | Tomato | - | Yes | Yes | | 35 kg/$m^2$ | | 366.39/metric ton | ReCiPe2016 H | Bosona and Gebresenbet (2018) |
| 4 | Norway | Tomato | | No | Yes | | 126.6–129.7 kg/$m^2$ | | 5.70–7.28 per kg | ReCiPe 2016 H | Naseer et al. (2022) |
| 5 | Netherlands | Tomato | Rockwool | No | Yes | | 56.5 kg/$m^2$ | | 440–5000 per metric ton | CML 2001 | Torrellas et al. (2012) |
| 6 | France | Tomato | Rockwool | No | Yes | | 450 t/ha | | 2.02 per kg | IPCC 20 years | Boulard et al. (2011) |
| 7 | Italy | Tomato (cherry) | - | No | No | | 96.3 metric ton/ha | | 1245.9/metric ton | CML 2001 | Cellura et al. (2012) |
| 8 | Italy | Tomato (cherry) | Peat moss | No | No | | | | 17.55–23.3 per $m^2$ | | de Albuquerque Landi et al. (2022) |
| 9 | Leon, Spain | Tomato (cherry) | Coconut husk | Yes | No | | 11 kg/$m^2$ | | 0.14 per kg | CML-IA | Urbano et al. (2022) |
| 10 | Spain | Tomato (cherry) | Perlite | No | - | 6.23 kg/$m^2$ | 8.83 kg/$m^2$ | 216 per metric ton | 617 per metric ton | ReCiPe | Romero-Gámez et al. (2017) |
| 11 | Spain | Tomato | Perlite | No | No | | 16.5 kg/$m^2$ | | 250 per metric ton | CML 2001 | Torrellas et al. (2012) |
| 12 | Almeria, Spain | Tomato (classic) | Perlite | No | No | | 16.5 kg/$m^2$ | | 250 per metric ton | CML2001 | Neira et al. (2018) |
| 13 | Catalonia, Spain | Tomato | | No | No | 127 metric ton/ha | 166 metric ton/ha | 152.6 per ton | 155.5 per metric ton | CML2001 | Martínez-Blanco et al. (2011) |
| 14 | Spain | Tomato | | No | No | | 16.5 kg/$m^2$ | | .022-.024 per kg | ReCiPe H | Sanyé-Mengual et al. (2015) |
| 15 | Almeria, Spain | Tomato | | No | Both | | 93–153 metric ton/ha | | 0.39–1.33 per kg | | Neira et al. (2018) |
| 16 | Morocco | Tomato | Soil | No | No | | 208 t/ha | | 0.215 per kg | ReCiPe H | Payen et al. (2015) |
| 17 | California, USA | Tomato | Vermiculite: peat moss | No | | 123 metric ton/ha | | 0.027 per kg | | IPCC-100 years | Winans et al. (2020) |
| 18 | Southern Italy | Courgette | - | No | No | | | 0.77–0.78 per kg | | ReCiPe 2016 | Canaj et al. (2021) |

**Table 1** (continued)

| No. | Location | Vegetable (variety) | Substrate in protected | Organic | Heating | Yield in field | Yield in protected | Emission field (kg $CO_{2\text{-eq}}$) | Emission protected (kg $CO_{2\text{-eq}}$) | LCA method | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | Spain | Courgette | | | | | | 0.23 per kg | | ReCiPe | Frankowska et al. (2019) |
| 20 | Austria | Courgette | | Yes | | | | 0.1 per kg | | IPCC (2007) | Lindenthal et al. (2009) |

(Scheelbeek et al. 2020). This puts into question the resilience of vegetable supply for the UK households. Unless more efficient, secure and affordable means of local production are ensured, UK vegetable supply will remain vulnerable to the threats of climate change such as water shortages (Hess and Sutcliffe 2018).

The small area of land currently used for protected horticulture, and the high yields obtained compared to field-growing, indicates that a substantial amount of horticultural production could be conducted closer to urban centres where population demand for fresh produce is largest, and there is the greatest potential availability of labour to grow and harvest crops. One potential model for addressing these issues is to develop peri-urban low-input horticulture based on organic production methods outdoors and in unheated polytunnels, without supplementary lighting, or heating. This model has been successfully developed by Sheffield Organic Growers and Regather Farm which have repurposed three adjacent arable fields in the Moss Valley in Sheffield for organic horticultural production, certified by the Soil Association, growing vegetables and fruit outdoors and in polytunnels. The food is delivered to specialist independent retailers less than 5 km away in the city and delivered directly to consumers via vegetable box schemes. These production systems have the advantages of reduced capital investment and running costs compared to glasshouses with environmental controls (especially heating and lighting as indicated in Table 1). By bringing horticultural production close to urban populations that can supply labour to grow, harvest and sell produce directly to local consumers, the supply chain is kept short, transport-associated emissions may be reduced and environmental, social and health benefits may be obtained. In this study, we considered tomato production in unheated, unlit, polytunnels and courgette production in open-field cultivation (after germination and seedling establishment in an unheated, unlit polytunnel). Polytunnels are steel-framed tunnel structures covered with polyethylene sheets and used commonly by gardeners and farmers to grow vegetables. To reiterate, these crops are relevant as most of the tomatoes (~86%) and courgettes (~81%) consumed in the UK are imported (Frankowska et al. 2019) as shown in Fig. 2 below.

## 2 Methods

This study used life cycle assessment (LCA) to understand the environmental impact assessment of tomatoes in a polytunnel and courgettes in an open field at Regather Farm. Primary data for the life cycle inventory (LCI) was obtained from Regather Farm through a questionnaire survey. The polytunnel was assumed to have a life of 20 years for most construction materials except HDPE

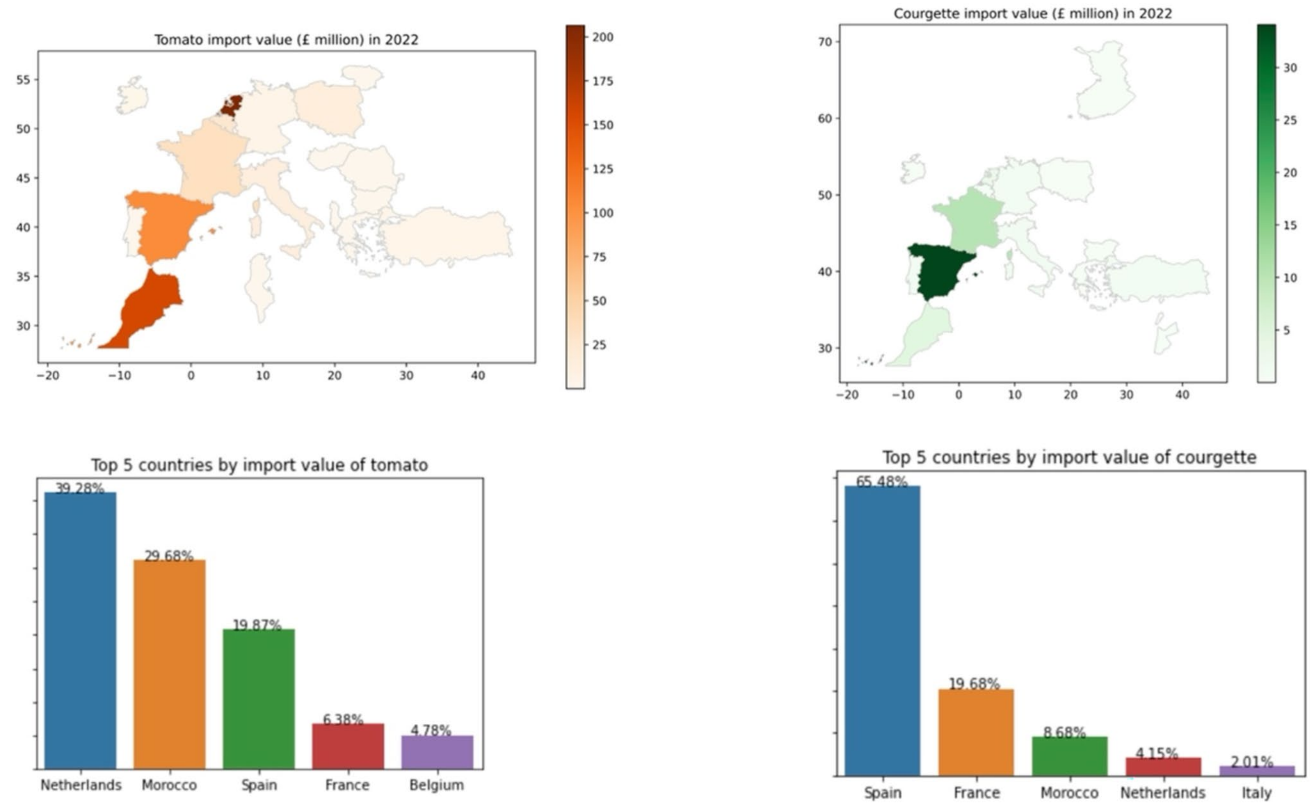



**Fig. 2** Map and bar graph displaying main countries of import for tomato and courgette. Data extracted from (HM Revenue & Customs 2023)

sheet which was assumed to have a life of 5 years. The functional unit was 1 kg of crop (tomato or courgette), and the system boundary included all activities up to the farmgate. Manufacturing and transportation of raw materials was not included in the study due to the unavailability of such data. However, information about the structure and components of the polytunnels was collected among other inputs. For courgette, the LCI included consideration of the time in the polytunnel for germination and early establishment before planting outdoors. All analysis was carried out in SimaPro software using the ecoinvent database 3.8. The ReCIPE Hierarchical (H) approach was used for the analysis with results explained in the form of 18 standard indicators (midpoint). The midpoint level relates strongly to environmental flows and has inherently low uncertainty associated with it and therefore was used for the environmental impact assessment in this research. The hierarchical approach was used as it is the most commonly used approach found in the authors' literature review (Table 1). The ReCIPE method was used to have the results in a greater number of categories as compared to those obtained from, say, IPCC or CML. Additionally, a large number of studies have used this methodology in the past which makes it easier to compare the results. This can also be seen in Table 1 where a majority of the studies report results using the ReCIPE methodology.

Additionally, a hybrid LCA approach was also used in this study which integrates the process LCA technique and environmental input–output (EIO) LCA model. The hybrid LCA methodology integrates the bottom-up, process LCA technique and the top-down, environmental input–output (EIO) LCA model. This provides a robust, systematically complete system boundary which accounts for the entire supply chain and avoids double counting (Ibn-Mohammed et al. 2016). Some studies suggest that hybrid LCAs may run the risk of overestimation (Yang et al. 2017) although this has been disputed by subsequent studies (Pomponi and Lenzen 2018). Overall, hybrid LCA is a useful technique which can, at least, be used to understand the scale of the potential impacts.

This model has previously been used in studies such as those evaluating wind power and biofuel in the UK (Acquaye et al. 2012; Wiedmann et al. 2011). However, to date a hybrid LCA technique does not appear to have been used to assess environmental impacts of organic crop production in the UK. The LCIA results correspond to the values in the year 2020 and all costs have been accounted for by taking into consideration the average lifetime values of the inputs. However, the economic results present the values both before and after the impact of the COVID pandemic i.e. for years 2018 as well as 2021/2022.

## 3 Results

### 3.1 Environmental impact assessment

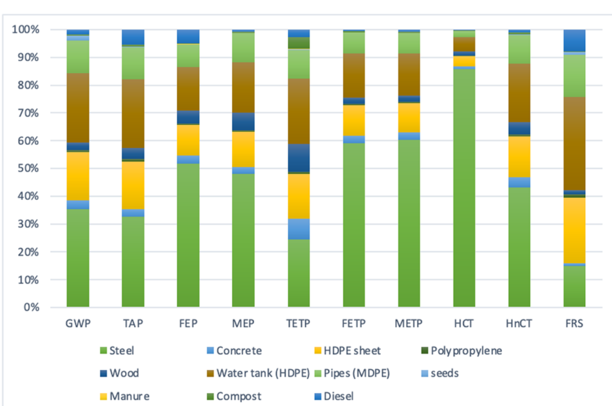
The average yields for tomato and courgette at the Regather peri-urban farm in Sheffield were 1.72 kg/m$^2$ and 2.0 kg/m$^2$ respectively. The results of the process-based LCA are shown in Fig. 3 below in the form of eight different LCIA categories. These results are also provided in the forms of Tables A4 and A5 in the Supplementary file. These categories are Global Warming Potential (GWP), Terrestrial Acidification Potential (TAP), Freshwater Eutrophication Potential (FEP), Marine Eutrophication Potential (MEP), Terrestrial Ecotoxicity Potential (TETP), Freshwater Ecotoxicity Potential (FETP) Marine Ecotoxicity Potential (METP), Human Carcinogenic Toxicity (HCT), Human non-Carcinogenic Toxicity (HnCT) and Fossil Resource Scarcity (FRS). These categories were chosen as they are comparable with those reported using other methods e.g. CML (Cavalett et al. 2013). Table A6 in the Supplementary file presents the results for cumulative energy demand (CED) which is different from the indicators reported by the ReCIPE method but reported for greater detail.

The elementary flows for tomato production consisted of those involving the building/housing of the polytunnel. This included steel, concrete for the structure of the polytunnel, HDPE for polytunnel covering and wood used in doors and window frames. Additional ancillary flows pertained to inputs used to facilitate the production and included HDPE used in water tank, diesel used to pump water to the tank and MDPE pipes used to transfer water from the tank to the polytunnel. Direct inputs for growing the tomatoes included seeds, manure, compost and groundwater. Since impacts related to water use have been incorporated in the additional ancillary flows, it has not been reported as an input in the tables below.

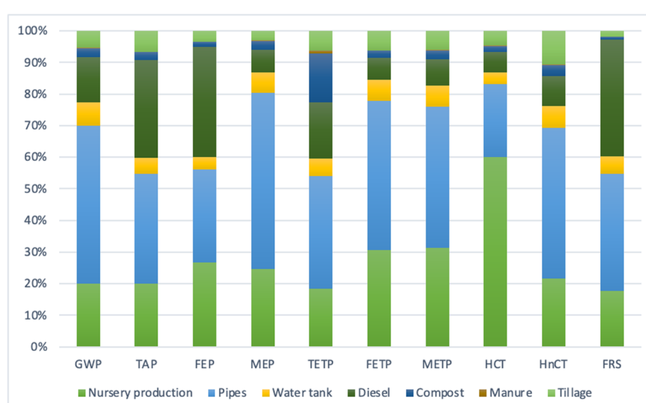
The elementary flows for nursery production of courgette plants were the same as those for tomato production albeit in considerably reduced quantities (see Supplementary file). Additional inputs included HDPE used in water tank, diesel used to pump water to the tank and MDPE pipes used to transfer water from the tank to the field. Direct inputs for growing the courgettes included ground tillage, planting of courgette plants and the use of manure and compost.

Figure 3 shows that for most of the categories, tomato production in the polytunnel had greater impacts than those for courgette production in the open field. The primary reason behind this is traced back to the impacts of steel and HDPE used in the polytunnel construction. This can be seen clearly in Tables A4 and A5 in the Supplementary file which shows the relative contribution of different inputs to the impact categories. It can be seen that in the case of courgette production, most of the impacts originated from the operation phase which was mainly due to embodied impacts in the use of MDPE pipes for watering. Similarly, as shown in Table A6 in the Supplementary file, the overall CED for courgette production was less than that for tomato production which was primarily due to a greater magnitude of inputs such as HDPE sheets and MDPE pipes.

Taking GWP as an example, 95.99% of the impacts came from the infrastructure and ancillary equipment used in growing tomatoes. Of the remaining 4.10%, most of the impacts came from the use of diesel to pump water. Thus, having a more sustainable housing can reduce the overall impacts associated with organic tomato production. This




Relative contribution of inputs to impacts from tomato production




Relative contribution of inputs to impacts from courgette production

**Fig. 3** Relative contribution of inputs to impacts from tomato and courgette production

**Table 2** Endpoint indicators for tomato and courgette production per functional unit

| Impact category | Unit | Tomato | | Courgette | |
|---|---|---|---|---|---|
| | | Per kg | Per hectare | Per kg | Per hectare |
| Human health | DALY | 1.59E−06 | 2.75E−02 | 4.71E−07 | 9.42E−03 |
| Ecosystems | species·year | 4.01E−09 | 6.92E−05 | 1.83E−09 | 3.66E−05 |
| Resources | USD2013 | 1.15E−01 | 1.99E+03 | 4.37E−02 | 8.74E+02 |

could include, for instance, the use of recycled and/or refurbished materials for the polytunnel. Similarly, instead of MDPE, pipes made of a more sustainable material could reduce the impacts significantly.

For courgette production, most of the GWP (49.98%) emanated from the use of MDPE pipes, with nursery production and diesel use contributing as the second (19.96%) and the third (14.31%) largest sources of this impact respectively. Once again, the use of more sustainable pipe material and the use of solar PV as an energy source could potentially reduce the long-term impacts.

LCIA using endpoint indicators was also carried out, and the results are shown in Table 2 using units per the functional unit (i.e. 1 kg of product) as well as on a per hectare basis. This has been done for ease of comparison with other studies. Using the World Health Organisation's 'Disability-Adjusted Life Year' (DALY) index, the impact on human health can be calculated for tomato and courgette production as $1.59 \times 10^{-6}$ DALYs and $4.71 \times 10^{-7}$ DALYs respectively. In comparison, a process-based LCA study conducted in Australia showed DALYs of $2.91 \times 10^{-3}$ per kg of tomato in a low-tech (seasonal and unheated) greenhouse and transportation to the market (Page et al. 2012). This higher value is potentially due to the impact of fertilisers and other chemicals in the production of conventional (not organic) tomatoes. A study in Canada on organic tomatoes in greenhouse (with climate control) shows the results to be in the range of $1.21 \times 10^{-6}$ to $3.79 \times 10^{-6}$ DALY per kg of tomatoes produced (Maham et al. 2020). This is higher than the results in our study if the same functional unit (i.e. kg or metric ton) is used for comparison which, in other words, indicates human health disbenefit avoidance (or DALY avoidance) in the present study. Similarly, the field production of courgettes in Italy was estimated to result in human health impacts of $1.29 \times 10^{-6}$ to $1.49 \times 10^{-6}$ DALYs per kg (Canaj et al. 2021). The impacts on ecosystems and resources have been calculated as 6.92E−05 species-year and USD 1.99E+03 respectively for tomato and 3.66E−05 species-year and USD 8.74E+02 respectively for courgette on a per hectare basis. In other studies, for instance, these impacts were 5.33 E−04 species-year/ha and USD1.94E+03/ha for tomato production in Spain based on the use of inorganic fertilisers (Antón et al. 2014). Similarly, a study in Lushnja District, Albania, found these impacts to be 9.60 E−05 species-year/ha and USD2.23E+02/ha for tomato production (Canaj et al. 2020).

As discussed above, the impacts from process-based LCA are not as complete as that from a hybrid LCA which is a combination of both process based and input-output-based LCAs. The results of the hybrid LCA are given in Table 3 which also presents the consolidated results for process-based LCA by combining the impacts for both building and operations. It must be noted here that only one impact category (i.e. GWP) has been presented due to the absence of other indicators in environmental satellite accounts in the input–output tables (Carson 1995). In addition, two transport scenarios have also been presented comparing transport by light vehicle from the farm to the Coop and import from Spain (road and sea). Details

**Table 3** Comparison of process and hybrid LCA results for GWP (kg $CO_2$-eq)

| **Crop type** | **Production** | | **Transport** | | **Total** | **Reference** |
|---|---|---|---|---|---|---|
| | **Process-based LCA** | **Hybrid LCA** | **From Regather farm to Regather Coop, Sheffield** | **From Almeria, Spain, to Sheffield, UK** | **Process based LCA + transport** | |
| Organic cherry tomato (Regather) | 6.10E−01 | 3.53E00 | 9.24E−03 | | 6.19E−01 | This study |
| Organic courgette (Regather) | 1.10E−01 | 1.70E00 | 9.24E−03 | | 1.19E−01 | This study |
| Organic cherry tomato (Spain) | 1.39E−01 | | | 1.91E−01 | 3.30E−01 | Urbano et al. (2022) and this study |
| Organic courgette (Assumed to be sourced from Spain) | 1.00E−01 | | | 1.91E−01 | 2.91E−01 | Lindenthal et al. (2009) and this study |

regarding transportation modes and distances assumed for the analysis are presented in the Appendix.

The inclusion of upstream impacts in the hybrid LCA for the exemplar organic produce at Regather Farm increases the GWP by more than an order of magnitude compared to the process-based LCA. These differences can be attributed to the fact that the hybrid LCA combines the impacts from both upstream and downstream economic activities. This expansion of system boundary, as pointed out by some studies, serves to reduce truncation errors (Salemdeeb et al. 2018). Overall, the findings from this study can be benchmarked against the typical GWP of conventional glasshouse cultivation of tomato in the UK, or imported from the EU, and for courgettes also either grown in the UK, or imported. Since over 80% of tomatoes and courgettes consumed in the UK are imported (Frankowska et al. 2019), the GWP values of the imported produce is arguably the most critical comparison with respect to progressing towards reducing net emissions.

## 3.2 Economic impact assessment

The average tomato and courgette demand in Sheffield were estimated using the values for the Yorkshire and Humber region reported in the UK's family food survey (DEFRA 2018). Figure 4 below shows the time series values of weekly expenditure for purchasing 1 kg of tomato and courgette from the year 2001 to 2021 on a per capita basis, as per the latest available data. It must be noted that data for courgettes was unavailable unless combined with that of fresh marrow, aubergine, pumpkin and other vegetables (henceforth called the courgette group). As such, the time series indicates the direction of change in prices more than the magnitude thereof for courgettes. The values were calculated based on data for fresh and tinned/frozen items consumed in both household consumption and eating out.

Figure 4 shows that while the cost of the courgette group remained relatively stable, that for tomatoes rose sharply between the years 2001 and 2021, representing an increase of 10.56% after adjusting for inflation. This rise was driven by an increase in cost of tomatoes (26.03%) while weekly household consumption (kg) increased by 14% (DEFRA 2018). Adjusted for inflation, the weekly household expenditure (£s) on the courgette group fell by 25.17% between the years 2001 and 2021 while consumption (kg) rose by 114.42%. However, the overall cost (£/kg) of the courgette group increased by 60.46% during this period, after adjusting for inflation. The average household cost of tomatoes and courgette group during this period come out as £1.88 $kg^{-1}$ and £2.43 $kg^{-1}$ respectively. However, these costs correspond to mainstream varieties and include imports.

Government statistics show that the average weekly wholesale prices for home-grown cherry tomatoes and courgettes stand at £5.93 $kg^{-1}$ and £4.24/kg respectively in 2022, compared to £3.63/kg and £3.15/kg in 2018 (DEFRA 2022b). In comparison, the average price of 1 kg of cherry tomatoes and courgettes offered by Regather for the year 2018 were £4.0 and £1.80 respectively and rose marginally to £4.50 and £2.0 respectively for the year 2022. For 2018, while these crops were not grown directly at Regather, it still serves to indicate a slower increase in prices of tomatoes and courgettes offered by Regather. Furthermore, it is important to note here that the vegetables offered by Regather are organic which are usually priced higher than conventional production. Data from the Organic Certification organization in the UK (November 2022) shows that currently the median prices are £6.68 (wholesale) and £10.46 (retail) for 1 kg of organic cherry tomatoes and £2.17 (wholesale) and £4.28 (retail) for 1 kg of organic courgettes (Soil Association

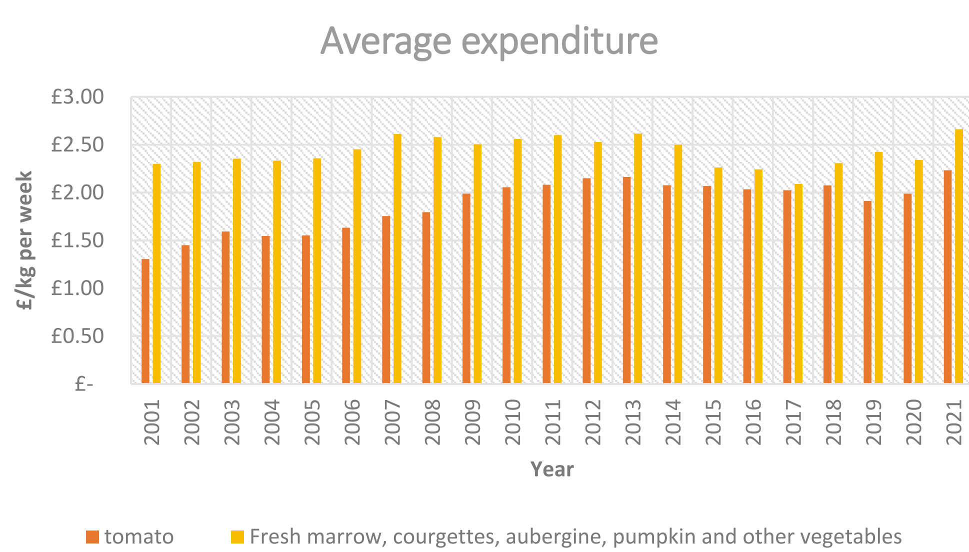



**Fig. 4** Average weekly expenditure per household on tomatoes and courgettes (not adjusted for inflation) (DEFRA 2018)

2022). Clearly, Regather has been producing and selling courgettes at prices lower than the national averages, thus making them more affordable for the local community.

## 4 Discussion

In this article, we aimed to understand the potential of peri-urban farms in meeting the nutritional needs for urban populations in the UK in a way that is both environmentally and economically sustainable (Benis and Ferrão 2017). We used a case study of peri-urban horticulture in the UK to explore if it can ensure agricultural production which is both cleaner and relatively affordable. The results show that the farm has relatively better environmental and economic impacts as compared to existing scenarios as outlined in Table 2 and Section 3.2. Specifically, this includes overall impacts from courgette production and the selling price of both tomatoes and courgettes. The environmental impacts from tomato production were, however, higher from Regather as compared to those from Spain even after including the scenario involving transportation. However, most of these impacts from the polytunnel can be reduced through the use of recycled or alternate materials. As such, it is similar to the examples of the Michigan Urban Farming Initiative (MUFI) (https://www.miufi.org/projects) and the Evergreen Cooperative Initiative (ECI) (Howard et al. 2010; Vaseau-Sleiman 2018), which not only look to bring food production within the city, but also add value by incorporating socio-economic interventions. Overall, retailing organic produce at lower-than-market value through delivered box schemes enables both greater uptake of their products by lower-income households and reduced emissions through their bicycle facilitated delivery service.

This study demonstrates the positive impacts of cleaner production represented by unheated, unlit polytunnel horticulture, and complements previous studies that argue in its favour (Schmutz et al. 2010). Previous studies show that field-grown organic horticulture would require 30% of the global urban land area to meet actual urban vegetable consumption (Martellozzo et al. 2014). Similarly, a 100% shift to organic food production in the UK would actually lead to increased GHG emissions from increased overseas land use (Smith et al. 2019). However, as shown in Fig. 1b and Table 1, unheated, unlit polytunnels remove this constraint by allowing for greater productivity, at least seasonally. This paper aimed at evaluating whether local peri-urban horticulture has the potential to offer vegetables which are 'cleaner' and more affordable than imports. Such systems also have additional benefits of protecting workers and crops from inclement weather. Finally, a large-scale adoption of low-input polytunnel horticulture could replace much of the field-growing in the Fens which, as discussed in Section 1, have significant environmental impacts and are unsustainable due to peat wastage. In the case of conventional intensive horticulture (as in Fens), the goals of resilience and sustainability are often at odds with each other. For instance, a rise in food demand would place a stress on the environment and on the other hand conservation of habitats and natural resources may adversely affect food production (Cui et al. 2016). In order to balance these competing interests, a holistic policy should be created that is able to achieve both goals simultaneously in a mutually inclusive manner. Apart from shifting some of the supply-side burden to peri-urban farming, demand-side policies focusing on consumer behaviour also need to be considered (Schanes et al. 2018). To put things in context, every year UK generates 15 million metric tons of food waste resulting in a significant environmental footprint (Downing et al. 2015). Around 70% of this food waste is avoidable, and in an era of rising food inflation in UK, food waste prevention and reuse (e.g. by composting) can help alleviate some of the concerns regarding food system resilience. On average, preventing food waste can result in savings of £780 per household each year (Palmer 2022). Recent food waste prevention initiatives have included food sharing through online information sharing. Restaurants and households now distribute leftovers at low or reduced costs through the use of mobile apps (Vo-Thanh et al. 2021). A rising amount of such food is also going to the food banks. For food waste disposal, composting, incineration, and anaerobic digestion are some of the popular recycling methods used in the UK. Hybrid LCA studies have discovered composting to be the most environment friendly of these options in the scenario of a decarbonised UK national grid (Salemdeeb et al. 2018). Another way of ensuring urban food system resilience and sustainability simultaneously is through a change in consumer habits. Transition from a meat-rich diet to a plant-based diet can reduce individual environmental footprints (Chai et al. 2019). The UK has seen a rise in trends towards vegetarian and vegan diets in recent years (Sexton et al. 2022). Since fewer resources are needed to produce vegetables than animal-based foods, this trend can lead to lower cost, healthy and sustainable diets.

## 5 Conclusions

This study aimed to assess the economic and environmental impacts of an example peri-urban organic horticulture model farm in the UK through primary data collection. The results show that the overall impacts are fairly less negative as compared to alternative scenarios as indicated in Table 2 and Section 3.2. This study goes beyond the conventional LCA practices by adopting a hybrid-LCA approach to account also for upstream environmental impacts. To the best knowledge of the authors, it is the first study using this approach in an agricultural context in the UK. This study concludes that given rising costs of energy and other resource inputs associated with conventional agriculture, the organic vegetable production system using unheated polytunnels without supplementary lighting at the case-study farm represents a clean and affordable source of seasonal vegetable supply for the local community. Importantly, this system is not able to deliver out-of-season courgettes and tomatoes, but the Regather farm does supply produce all-year round using seasonal field and polytunnel-produced crops. Future research can assess the feasibility of such farms at national scale to buttress UK's food security while meeting climate change goals simultaneously. The LCA employed in this paper focused on a cradle-to-gate system boundary, and future studies can consider a wider perspective to include post-farmgate impacts. LCA of other peri-urban farms can help develop an index for benchmarking and comparison purposes. Future studies can also compare the results of this study with those of conventional farms in the UK as well as imports.

One of the limitations of this paper include the fact that the cost of setting up and running expenses and labour of the peri-urban farm were not considered in the analysis. Similarly, the farm currently produces organic products which retail at prices lower than national averages. However, a vast majority of consumers purchase conventional food products as costs may discourage healthy eating concerns. Another limitation is that the food grown in polytunnels and field-based horticulture is seasonal and prone to weather impacts. Despite these limitations, this study represents a useful contribution in the current debate on UK food system sustainability and resilience. We hope that the use of hybrid LCA in this study will encourage further adoption and use of this technique for more holistic assessments.

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**Data availability** All data and calculations can be made available to the interested audience upon reasonable request.

## Declarations

**Conflict of interest** The authors declare no competing interests.



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