Journal of Cleaner Production 151 (2017) 134–144

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Unheated soil-grown winter vegetables in Austria: Greenhouse gas emissions and socio-economic factors of diffusion potential

Michaela Clarissa Theurl [a, b, *], Stefan Josef Hörtenhuber [a, c], Thomas Lindenthal [a, d], Wolfgang Palme [e]

[a] *Institute of Organic Agriculture (FiBL), Doblhoffgasse 7/10, 1010, Vienna, Austria*
[b] *Institute of Social Ecology (SEC), Alpen-Adria Universitaet Klagenfurt-Wien-Graz, Schottenfeldgasse 29, 1070, Vienna, Austria*
[c] *Department of Sustainable Agricultural Systems, BOKU – University of Natural Resources and Life Sciences, Gregor-Mendel-Straße 33, A-1180, Vienna, Austria*
[d] *Center for Global Change and Sustainability, BOKU – University of Natural Resources and Life Sciences, Borkowskigasse 4, 1190, Vienna, Austria*
[e] *Horticultural College and Research Institute, Schönbrunn, Grünbergstraße 24, 1131, Vienna, Austria*

ARTICLE INFO

Article history:
Received 30 August 2016
Received in revised form
3 March 2017
Accepted 4 March 2017
Available online 9 March 2017

Keywords:
Winter harvest
Low-energy system
Seasonality
Greenhouse gas emissions
Vegetable production
Frost-hardy vegetables

ABSTRACT

The adaption of historic European cultivation techniques for unheated winter vegetable production has gained momentum during the last years in Austria. Studies that evaluate ecological and socio-economic sustainability-factors of these production techniques are scarce. In this study, we analyze the greenhouse gas emissions along vegetable supply chains based on a life cycle approach and investigate factors of the socio-economic system towards future market diffusion of these new-old technologies based on the Sustainability Assessment of Food and Agriculture Systems (SAFA) guidelines of the Food and Agriculture Organization (FAO). Data of the supply-chains of lettuce, spinach, scallions and red radish was collected from field trials in different climatic regions in Austria and compared to existing commercial systems in Austria and Italy. The results show, that unheated winter vegetable production is feasible. Greenhouse gas emissions of unheated vegetables are lower with 0.06–0.12 kg CO_2 equivalent versus 0.61–0.64 kg CO_2 equivalent per kg fresh product crops from heated systems. Due to small packaging units unheated vegetables show maxima of 0.58 kg CO_2 equivalent per kg product. Heated products were outreached by two times when individual shopping trips to the farm were taken into account. Keeping salad frost-free was not found to contribute to a reduction of greenhouse gas emissions compared to conventional systems. The analysis reveals that a diffusion of unheated winter harvest systems depend primarily on 11 interdepending socio-economic factors. An innovative subsidy system and the creation of a positive image of winter harvest from unheated vegetables production together with an increased utilization rate of polytunnel areas and the consultancy for producers and processors are the most influential factors towards a sustainable market diffusion of winter harvest produce.

1. Introduction

The importance of finding new ways to reduce resource inputs and developing new products which will help to support the shift towards a resource efficient and low-carbon economy (European Commission, 2011). Consumers increasingly demand for fresh, high quality vegetables that are seasonally produced by local producers. The commercial vegetable production sector is growing in countries like Austria (+2.6% p.a.) or Denmark (+2–5% p.a; Koch, 2016) and accounts 18% of the total value of agricultural production in Europe (McIntyre, 2014).

In winter months, the demand is met by energy-intensive production systems requiring considerable fossil energy for heated glasshouse technologies and by imported products with long-distance transport that majorly contribute to global warming (Theurl et al., 2014). Alternatively, low-energy demanding winter harvest vegetables without heating and artificial light such as winter purslane (see Fig. 1), might be an innovative way to reduce greenhouse gas (GHG) emissions especially in the light of increasing air temperatures, changing precipitation and a

---

[*] Corresponding author. Institute of Organic Agriculture (FiBL), Doblhoffgasse 7/10, 1010, Vienna, Austria.
E-mail address: michaela.theurl@fibl.org (M.C. Theurl).

http://dx.doi.org/10.1016/j.jclepro.2017.03.016

prolonged growing season in Central Europe (Trnka et al., 2011). Historically, to the end of the 19th century, specialized winter cultivation such as glass-topped and manure heated systems widely prevailed in France and the UK (Coleman, 2009). The term winter harvest was first introduced by Coleman (2009). We hereinafter refer winter harvest vegetables (or produce) to unheated, soil-grown vegetables that are harvested between the beginnings of November to the end of March (Palme, 2016).

While standard literature (e.g. Vogel, 1996) reports maxima values of −5 °C on the resistance of vegetables against cold, Palme and Kupfer (2008) showed that Asian greens are able to withstand temperatures fare below zero, e.g. −14 °C. In Austria, organic producers were the pioneers of implementing and developing winter harvest techniques in order to strengthen direct marketing structures (IFOAM EU Group, 2015). In general, the industrial food systems and especially the vegetable production in Europe is not only characterized by high technical requirements, but also by a sophisticated chronology of post-harvest procedures i.e. packaging and storage and transport supermarket logistics. Especially the distribution of organic vegetables via box schemes is a frequent and important channel for organic growers in Austria (Kummer et al., 2016) is likely related to lower GHG compared to the "last mile" when consumers take the car to purchase their vegetables (Coley et al., 2009).

A large number of studies have already investigated the environmental impacts of commercial lettuce production systems by life cycle assessment (LCA; Fusi et al., 2016; Gunady et al., 2012; Hospido et al., 2009; Romero-Gámez et al., 2014; Tasca et al., 2017). Castoldi et al. (2011) e.g. analyzed soilless baby leaf production and claimed that up to 38% of total energy input is related to the indirect requirement to manufacture the greenhouse structure. Hospido et al. (2009) explored different seasons in the consumption by comparing imported Spanish lettuce and heated lettuce from UK and showed that key GHG emissions arise from long-distance transport and heating. Others claimed that the optimization of nitrogen fertilizer management is of major importance when comparing different production systems of lettuce and escarole in Spain (Romero-Gámez et al., 2014) and that agricultural machinery is a major hotspot of the total carbon footprint (CF; Gunady et al., 2012). A comparison of environmental impacts of organic and conventional lettuce production in Greece showed that GHG emissions were lower in organic lettuce when assessing per areas but higher when related to the yield (Foteinis and Chatzisymeon, 2016) and Italian organic endive production showed no overall favor compared to conventional production (Tasca et al., 2017).

However, none of these studies have been designed to study winter harvest systems by analyzing soil-grown cultivars in unheated polytunnels and open field at temperatures below freezing. Furthermore, studies on Asian greens or baby-leaves are rare. In Austria, organic farmers are increasingly implementing winter harvest techniques for their short chain marketing at farm shops or via box schemes. However, there is still little understanding about these alternative winter production systems and significant data gaps prevail regarding a future potential of such systems in Austria and their contribution to sustainable transformation pathways (Hampl, 2016; Palme and Kupfer, 2015; Theurl and Hörtenhuber, 2016; Wenger and Wenz, 2012). For instance, additional resource input for frost-free heating might be necessary in meeting consumer demand during the peak season around Christmas.

This study explores different forms of innovative winter harvest technologies for different vegetables in contrast to existing industrial vegetable production technologies including the entire supply chain. The aim is to assess GHG emissions and socio-economic aspects of unheated, soil-based winter vegetable production and close the gap in understanding the sustainable diffusion potential of these systems. We followed an integrative approach by utilizing data from field trials and compare it to current systems from the literature. First, we systematically addressed GHG emissions along the supply chain of different crops and analyzed optimization potentials from the agricultural production stage, transport, and packaging. Second, we explored the socio-economic conditions of winter harvest production in Austria in a semi-quantitative system analysis at regional scale and revealed crucial factors of winter harvest systems towards a sustainable market diffusion.

2. Material and methods

2.1. Description of the study sites and reference systems

The focus of this study were twelve organic and conventional crops from four crop groups: salads, spinach, scallions and red radish. The database for this study were organic vegetables cultivated in field trials on six organic farms and two experimental stations from October 2014 to April 2015 (Betz et al., 2015 (unpublished); Palme and Theurl, 2016). Conventional crops were modelled based on data taken from the literature (see 2.2; Demerci, 2001; Lindenthal et al., 2010; Statistik Austria, 2014). Data on crop types and cultivation specific data is reported in Table 1. Depending on the farm specific conditions and farmers individual preferences and interests, crops were cultivated in open field (ORG-F) and unheated polytunnels (U-ORG) and all under organic (ORG) farming principles (see Bio Austria, 2016; European Commission, 2008). In order to explore the potential of winter vegetable systems in milder and colder climates, the study sites were located in all four Austrian climatic zones, reaching from alpine, Atlantic middle European to continental-pannonic and continental-illyric (Hiebl et al., 2011, Table 1). All crops analyzed in this study were soil-grown because (i) the Austrian Organic farming association and the EU regulation do not allow the cultivation of vegetables on rock-wool, hydroculture or nutrient film techniques (Bio Austria, 2016; European Commission, 2008) and (ii) salad, spinach, scallion and radish and are traditional soil-grown crops in Austria. We explored baby- and multileaf *Lactuca sativa* var. *crispa*, hereinafter called 'Lollo' and 'Mix' (including *Lactuca sativa* var. *longifolia*) in organic polytunnels. In order to see the significance of additional heating requirements, baby-leaf Lollo was tested in unheated and heated polytunnels, because organic principles allow frost-free heating with renewable energy sources up to 10 °C (Bio Austria, 2012). Under Atlantic middle European climates, we tested the chicory cultivar 'Catalogna' in organic open field and winter purslane or *Claytonia perfoliata*, a species from the family of Montiaceae and with North-America origin in organic polytunnel systems. An addition to the existing product range are scallions (*Allium fistulosum* or *Allium cepa*) that were cultivated in the alpine climate in open fields and unheated polytunnels as well as spinach (*Spinacia oleracea*). Red radish *(Raphanus sativus* var. *sativus)* is traditionally grown in Austria (Statistik Austria, 2014).

Since winter vegetables have not been the main crop in the crop rotation of the participating farmers and thus stand at the end of a common crop rotation, additional fertilizer was not applied to the production area. Organic producers apply compost or manure at least once a year over longer periods of 15–20 years in polytunnels or glasshouses and over 20 years in open fields. Floating row cover was used to protect open field chicory Catalogna and spinach against low-temperatures and damages caused by game (e.g. rabbits, roe deer).

In order to compare the different crop groups, management systems and distribution channels, we identified five classes: (a) Unheated organic Baby-leafs Mix via box scheme with POS at the doorstep of a household and Lollo compared to heated Lollo distributed with no distribution (POS at the farm shop). (b) Customary supermarket logistic for organic and conventional open field Catalogna (CON-F). (c) Unheated organic winter purslane packed in a plastic cup and intermediary path distribution compared to unheated, unpacked organic spinach (no distribution) and conventional heated lettuce (CON-H) distributed via supermarket logistic. Winter purslane was grown and packed at one farm, then transported 200 km to the intermediary producer who distributed the product via the box to the consumer. (d) Organic winter scallions in unheated polytunnels and open field, both considering an individual shopping trip by car to the farm shop. (e) Organic red radish distributed via box scheme to conventional red radish via supermarket logistics. Information on distances is documented in Table 1.

2.2. Calculation of greenhouse gas emissions

By following a LCA approach (ISO, 2006a, 2006b), the calculation of the carbon footprint (CF) considered the following six life cycle stages of twelve crop supply chains, from agricultural production to the POS: (i) area management: agricultural production including upstream inputs to the farm (e.g., fertilizer production, pesticides, upstream transport); (ii) heating in glasshouses; (iii) packaging; (iv) storage; (v) emissions from imports (long-distance transport); (vi) emissions from food distribution (consumer shopping, supermarket logistics, box delivery scheme). The system boundary is shown in Fig. 2 and excludes the household user stage and the waste stage. The functional unit was kg un-/packed fresh product at the POS and the environmental impact category was global warming potential in kg CO_2 equivalents (CO_2e). The global warming potential (GWP) calculation method was used in previous studies and is described elsewhere (Hörtenhuber et al., 2010; Lindenthal et al., 2010; Theurl et al., 2014; Theurl, 2016) but was expanded with a nitrogen (N) model for a detailed calculation of N demand and N_2O (nitrous oxides) emissions from managed soils in the agricultural production stage (see Fig. 2). We analyzed nine organically managed systems based on primary data directly obtained in personal interviews from every farm and experimental side. Details of the inventory analysis in Table 1, e.g. machinery and heating energy use or fertilizer input was collected by questionnaires developed based on experience from previous research (Theurl et al., 2014). Organic yield data was collected from different plots for one reference period, the winter 2014/15, numbers shown in Table 1 are robust averages (see 3.1.1 sensitivity analysis). The background data for the conventional systems were taken from location specific literature (e.g. yield data from Demerci, 2001) and compared to statistical data in accordance to official manuals and fertilizer recommendations (Daxbeck et al., 2011; Demerci, 2001; Feller et al., 2011; Istat, 2015; Lattauschke, 2004; Statistik Austria, 2014). Building infrastructure, such as steel, aluminum or plastic were excluded from the calculations. Process data shown in Fig. 2 were calculated with data sets provided by ecoinvent v2.2, the Austrian version of the GEMIS (Global Emission Model for Integrated Systems) and the KTBL database for machinery and (soil) cultivation (Frischknecht et al., 2005; KTBL, 2015; Umweltbundesamt (UBA), 2014).

The N-model was based on calculating the N-balance and N_2O-emissions following three steps: (i) N uptake by the crops according to Feller et al. (2011) where decelerating soil N-mineralization rates during winter months were assumed to be 2 kg N per ha and week; (ii) N- fertilizer requirement as a function of yield and subtracting soil-N nominal values according to Feller et al. (2011) and BMLFUW (2008); (iii) leaching/run off rates from active fertilization was estimated according to the amount and type of fertilizer, to the type of management (protected or open field) and prevalence of irrigation. We assumed 10% N leaching in case of slowly available N-fertilizer application, i.e. compost or crop residues in organic systems and 23.5% in case of readily available N-fertilizers, i.e. mineral fertilizer in case of conventional red radish. Leaching rates in open field Catalogna was modelled with 35% in case of farm yard application (ORG-F) and 47% when mineral fertilizer (CON-F) based on Leclerc et al. (1995) in accordance with Hartl et al. (2012).

2.3. Semi-quantitative system analysis

We employed a systematic semi-quantitative system analysis to gain insights about socio-economic system characteristics and factors that influence the sustainable market diffusion of the winter harvest systems in Austria. In a system, factors interact with each other and the entire system develops dynamically in a certain direction and sustainable governance is needed to foster or prevent certain developments (Wiek et al., 2008). By identifying a system goal, i.e. a sustainable diffusion of winter harvest systems, we are able to ascertain the most influential factors (Scholz and Tietje, 2002; Wiek et al., 2008).

The analysis is based on the writing teams' long-term experiences and know-how and insights from dialogs with stakeholders of the vegetable sector in Austria e.g. producers, consumers, members of the Austrian chamber of agriculture etc. (BMLFUW, 2016; Palme and Kupfer, 2015; Palme and Theurl, 2016, 2016; Theurl, 2016). We used the Sustainability Assessment of Food and Agriculture Systems (SAFA) guidelines (FAO, 2014) as our underlying conceptual framework to address topics and indicators in defining and assessing the sustainability of winter harvest systems. More than five internal discussion rounds were necessary to perform the qualitative assessment of the following steps. First of all, to analyze the thematic scope of the impact assessment of the socio-economic factors in the winter harvest system, we identified important and relevant SAFA subthemes, e.g. mission statement, value creation, stability of the supply chain etc. (see Table 1).

In Step 1, for the sake of informational value and simplicity, we identified 13 factors that characterize the winter harvest system (see Table 2). According to the SAFA guidelines, the factors are

Fig. 1. Picture (a) unheated plastic tunnel in Austrians alpine region 1.500 m above sea level; (b) winter purslane stand before the first harvest; (c) harvestable Asia salad at baby leaf-stage.

Table 1

Characteristics of the vegetables production systems and input data for the LCA and system analysis. ORG-U = organic produce from unheated polytunnels. ORG-F = organic produce from open fields. CON-H = conventional produce from heated glasshouse. ORG-H = organic produce kept frost-free. *) mark reference systems; POS = point of sale. See text for more details. Comparison a-e) refer to the five system classes analyzed in this study.

	Salads							Spinach	Green onions		Red radish	
	Comparison a)			Comparison b)		Comparison c)			Comparison d)		Comparison e)	
	Baby-leaf Mix ORG-U	Baby-leaf Lollo ORG-U	Baby-leaf Lollo ORG-H*	Chicory Catalogna ORG-F	Chicory Catalogna CON-F*	Winter purslane ORG-U	Lettuce CON-H*	Spinach ORG-U	Scallion ORG-U	Scallion ORG-F	Red radish ORG-U	Red radish CON-H*
System	Polytunnel (unheated)	Polytunnel (unheated)	Heated polytunnel	Open field	Open field	Polytunnel (unheated)	Heated greenhouse	Polytunnel (unheated)	Polytunnel (unheated)	Open field	Polytunnel (unheated)	Heated greenhouse
Management	organic	organic	organic	organic	conv.	organic	conv.	organic	organic	organic	organic	conv.
Climate zone	Atlantic middle European	Continental illyric	Continental illyric	Atlantic middle European	Mediterranean	Atlantic middle European	Continental pannonic	Alpine	Alpine	Alpine	Continental pannonic	Continental pannonic
Previous crops	tomato, egg plants, peppers	tomatoes	peppers	red beet	n.a.	fruit vegetable rarities	tomato, cucumber	tomato	tomato, cucumber, pepper	potatoes	zucchini	tomato, cucumber
Sowing date	03/10/14	25/09/14	25/09/14	14/08/14	n.a.	15/09/14	n.a.	03/09/14	26/08/14	26/08/14	31/10/14	15/12 + 15/01
Planting date	30/10/14	13/10/2014	13/10/2014	09/09/14	n.a.	12/10/14	15/01/+27/02/mean	14/10/14	24/10/14	24/10/14	–	–
Harvest dates	29/01/15–20/03/15	07/11/14–22/12/14	27/12/14	15/12/14–22/12/14	n.a.	20/01/15–10/04/15	03/03/av.-07/05/av.	21/04/15	06/03/15–25/03/15	27/02/15–14/03/14	13/03/15–24/03/15	15/02–29/04
Irrigation	sprinkling	sprinkling	sprinkling	circle sprinkler	circle sprinkler	sprinkling	sprinkling	sprinkling	sprinkling	–	sprinkling	sprinkling
Other inputs	–	–	–	floating row cover	floating row cover	–	–	floating row cover	–	–	–	–
Heating, energy source	–	–	district heat	–	–	–	district heat	–	–	–	–	district heat
Heating requirement (MJ/m^2/season)	–	–	35.31	–	–	–	33.45	–	–	–	–	22.16
Storage (days)	–	–	–	–	–	–	2	–	1	–	–	2
Packaging	loose	loose	loose	loose	loose	100 g plastic cup	–	loose	rubber ring, loose	loose	rubber ring, loose	–
Distribution channel	box scheme	farm shop	farm shop	box scheme	supermarket logistic	inter-mediary	supermarket logistic	farm shop	shopping trip to farm shop	shopping trip to farm shop	box scheme	Super-market
Distance: farm to POS (km)	55	0	0	55	1300 (import) + 600	200 + 55	250	0	10	10	55	250
Yield (kg/ha)	5,755	3,000	6,350	20,000	20,000**	15,000	28,100	7,000	3,583	2,570	6,356	31,000

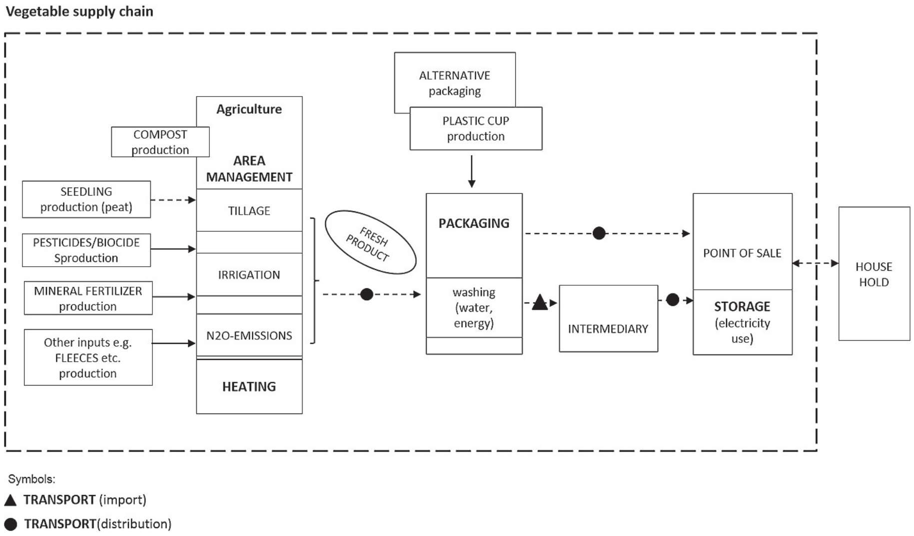

Fig. 2. System boundary and schematic supply chain flow diagram of the production systems analyzed in this study. Solid lines depict upstream transport, whereas dashed arrows represent transport distances that might or might not be included in the carbon footprint calculations in depended from the specific supply chain. See text for detailed information. Capital letters in bold refer to the aggregated life cycle stages.

located along the four dimensions of sustainability: Good Governance, Environmental Integrity, Economic Resilience and Social Wellbeing. While the focus of the system boundary is on local and regional level, some factors indirectly reach national or European level, e.g. regional & seasonal production or image of winter harvest products. We neglected the potential impact of local decisions at a global level (Hubacek et al., 2016). Farm level pertained individual choices of producers, whereas regional level refers to regional

Table 2
Description of system relevant factors at farm and regional level that characterize the Austrian conditions along the four dimensions of sustainability for winter harvest systems according to the SAFA guidelines (FAO, 2014).

#	SAFA Subtheme	System factor	Aim or anticipated effect of the factor towards a sustainable market diffusion of winter harvest systems	Scale
1	Mission Statement	Image of winter harvest products	Aim is the positive public image related to unheated winter harvest production, establishment of e.g. an innovative products brand, raising awareness through advertisement, education, seminars etc. in order to create trust and demand.	regional, national
2	Value Creation	Subsidies	Relates to an initial implementation of subsidies regulations by the Austrian government for producers and processors to foster winter harvesting and leading to displacement effects in the region (e.g. from heated to unheated systems).	regional, national
3	Value Creation	Regional value-added	Aim is an increase of regional added value and reinforcement of deprived regions induced by cultivation of winter harvest products, e.g. employment creation, stable prices.	regional
4	Stability of Supply	Regional & seasonal production	Aim is the increase of seasonal and regionals vegetable production in Austria related to a potential reduction of long-distance imports during winter months in order to increase level national self-sufficiency by increasing domestic unheated winter harvest.	regional
5	Land Degradation	Polytunnel areas in winter under use	Aim is a higher utilization rate of area, especially the use of free, actual unused polytunnel and glasshouse areas of already existing greenhouses during winter months.	regional
6	Capacity Development	Consultancy	Aim is to expand marketing and business consultancy for producers including growing know-how transfer (e.g. on practices and plant diseases) and direct marketing (e.g. farm shops, markets etc.)	farm, regional
7	Greenhouse Gases	Carbon footprints of vegetable production in winter	Aim is to reduce the carbon footprints of unheated winter harvest products, regarding imported produce as well as from heated glasshouses.	farm, regional
8	Soil Quality	Regional environmental impacts	Aim is to minimize regional environmental impacts from vegetable production such as eutrophication of local water bodies, pesticide residues in crops, contaminated soils, humus depletion in the region.	farm, regional
9	Food Quality	Demand: product quality	Increase consumer demand for high quality winter harvest products in terms of appearance, freshness, sanitation, purity. Quality standards and controls are met.	farm, regional
10	Quality of Life	Work satisfaction	Aim is to keep working intensity at level to guarantee profitability (standard working hours) for smaller and medium sized farms.	farm
11	Profitability	Price/farm incomes	Aim is to guarantee profitable yearly crop rotation by expanding the rotation with a winter element for smaller and medium sized farms and guarantee sufficient farm income and stable prices.	farm
12	Energy Use	Resource use	Aim is to reduce/minimize the use of fossil energy carriers in Austrian vegetable production systems at farm level, in other crop elements, e.g. peat, fertilizer input. Not only winter harvest systems, but whole crop rotation.	farm
13	Species Diversity	Agrobiodiversity	Aim is to have a diverse repertoire of cultivars in winter harvest production.	farm

development or (regional) environmental impacts (e.g. risk of eutrophication of surrounding water sheds).

In Step 2, we categorized the 13 factors to subthemes and decided that the two factors subsidies and regional value-added are both equal important for the analysis towards a sustainable market diffusion and therefore belong to subtheme value creation.

In Step 3, we determined an aim for each factor that described the direction to where the factor could optimally develop according to the SAFAs sustainability objectives. A description of the 13 factors of the winter harvest system and their individual aim is summarized in Table 2. For instance, the factor image of winter harvest products is classified by the SAFA subtheme missions statement with the objective that "[…] all areas of sustainability [are made] clear to the public, to all personnel and other stakeholders through publishing a mission statement or other similar declaration (such as a code of conduct or vision statement) that is binding for management and employees or members" (FAO, 2014) and prevails at all scales.

In Step 4, we defined the parameters of the system goal, which is to reach a sustainable diffusion of winter harvest systems in Austria ensuing from the current situation in which mostly organic pioneers grow winter harvest products. The goal is described along the 13 factors (see Table 3): positive image creation (↑), increased regional value added (↑), increased seasonal and regional production quantity (↑), efficient use of existing polytunnels areas (↑), the diverse (agrobiodiversity) and a higher product quality (↑), increased farm income and work satisfaction (↑), whereas to reduce CFs and other environmental impacts as well as resource use.

In Step 5, we evaluated the interaction of the factor within the system. The impact of the potential achievement of one factor's aim over another was evaluated by a direct linear cause-effect relationship. The intensity of the relationship between the two factors reached from 0, i.e. no or ambiguous impact to +2, strong direct impact. The impact matrix shown as Table 5, is the results of seven internal discussions workshops (see section 3.2). In cases where no clear consensus was found in the discussion groups a sensitivity analysis was performed to analyze the impact of different impact intensities on the system (see 2.3.1 sensitivity analysis).

In Step 6, building upon the impact matrix developed in Step 5, we performed the quantitative system analysis with the software Systaim SystemQ (Scholz and Tietje, 2002; Tietje, 2013). By using the software, the direct as well as indirect feedback loops between the factors were evaluated. The results of such an analysis quantified the contribution (or effectiveness) of each factor to achieve a sustainable market diffusion of winter harvest systems.

Table 3

Overall sustainability goal. Arrows indicate a) ascending and b) descending, double arrows indicate no trend of the individual system factor's aim. Please see Table 2 for the aim description.

System factor	Goal
Image of winter harvest products	↑
Subsidies	↕
Regional value-added	↑
Regional & seasonal production (quantity)	↑
Polytunnel areas in winter under use (utilization rate)	↑
Consultancy	↕
Carbon footprints of vegetable production in winter (reduction)	↑
Regional environmental impacts (reduction)	↑
Demand: product quality	↑
Work satisfaction	↑
Price/farm incomes	↑
Resource use (reduction)	↑
Agrobiodiversity	↑

2.4. Sensitivity analysis

The sensitivity analysis had a twofold purpose. First we tested the impact of yield and leaching factor variation for the CF of the area management, which refers to the agricultural production stage excluding the heating energy demand. We used the lowest and highest yield data provided by the producers or given in the literature (Betz et al., 2015 (unpublished); Demerci, 2001). For each crop, we calculated a variant assuming no leaching (0%) and another in which we assumed a doubling of the leaching factor used in the baseline. Second, we performed a sensitivity analysis of the factors from the semi-quantitative system analysis for cases were no consensus about the explicit relation between two system factors was found (Table 5). In total, we calculated eleven variants of the baseline calculation in order to show the minimum and maximum values of a system factor's effective contribution achieving the overall sustainability goal defined in Table 3. Given the case of a range e.g. 0 to 1 (see Table 5), the baseline calculation relates to the first value, whereas the sensitivity analysis refers to the second value.

3. Results

3.1. Carbon emissions along the supply chains

At a first glance, the results presented in Fig. 3 showed that CFs of vegetables from winter harvest systems were not per se lower compared to heated conventional systems when evaluating the whole supply chain. The total CFs of the twelve crops were very heterogeneous ranging from 0.103 kg CO_2e for organic loose spinach to 3.085 kg CO_2e for frost-free kept fresh baby-leaf Lollo. The CFs of the organic baby leafs Mix and Lollo with 0.165 kg CO2e or 0.111 kg CO_2e were on average 95% lower compared to the frost-free kept fresh organic Lollo. 36% or 0.060 kg CO_2e of the baby leaf Mix arose from box scheme distribution transport. Energy for keeping the Lollo frost-free was a 98% hotspot of the CF of Lollo (2.99 kg CO_2e per kg produce; yellow bar in Fig. 3a). The total CF of organic and conventional Catalogna in open field cultivation was 0.137 and 0.307 kg CO_2e per kg packed salad. While the GWP of the organic area management was 41% (or 0.049 kg CO_2e) lower, the overall difference was −55% due to the difference in distribution transport, because the conventional Catalogna was additionally imported from Italy (dark blue bar in Fig. 3b) which accounted for 0.108 kg CO_2e per kg product. Emissions from supermarket logistic distribution within Austria were 0.060 kg CO_2e per kg product in both variants. The results presented in Fig. 3c showed, that organic winter purslane with 0.584 kg CO_2e nearly outweighed the CF from heated conventional glasshouse lettuce with 0.653 kg CO_2e per kg product. Emissions from the plastic flow-pack were 0.453 kg CO_2e per kg winter purslane (purple bar in Fig. 3c) and heating emission were 0.493 kg CO_2e per kg lettuce (yellow bar in Fig. 3c). Unpacked spinach showed 83% lower emissions than winter purslane and conventional lettuce. The comparison between organic scallions in unheated polytunnels and open field, both sold in a farm shop to where consumers went by car, revealed no difference on their overall CF. Hotspot emissions from the 10 km shopping trip were 1.170 kg CO_2e per kg scallions (cyan bar in Fig. 3d) and contributed 90–91% to the total CF with was 1.281 kg CO_2e in the polytunnel and 1.301 kg CO_2e in open field. A small difference of 14% was found in the GWP of the area management of scallions. The CF of unheated organic red radish was 0.120 kg CO_2e per kg product to which 50% was box scheme distribution transport (see Fig. 3e). Heated radish had almost a 6 times higher CF mainly due to emissions from heating (0.580 kg CO_2e) than organic radish. Supermarket logistic showed 2.5 times lower transport emissions (0.024 kg CO_2e) for

Table 4

Sensitivity analysis of yield level and nitrogen leaching factors effecting the CFs of the agricultural production stage without considering heating, packaging, storage and transport. ORG-U = organic produce from unheated polytunnels. ORG-F = organic produce from open fields. CON-H = conventional produce from heated glasshouse. ORG-H = organic produce kept frost-free. *) mark reference systems. ** Since the baseline leaching factors was 0.47, we assumed 53% increase for the sensitivity analysis.

	Variation of yield in %	Agricultural production stage [kg CO2e/kg fresh product]	Variation of leaching factors in %	Agricultural production stage [kg CO2e/kg fresh product]
Baby-leaf Mix ORG-U	+67/−24	0.105 (0.074–0.129)	0/+100	105 (104–106)
Baby-leaf Lollo ORG-U	±17	0.111 (0.099–0.127)	0/+100	0.111 (0.110–0.111)
Baby-leaf Lollo ORG-H*	±6	0.070 (0.068–0.072)	0/+100	0.070 (0.068–0.072
Winter purslane ORG-U	±67	0.078 (0.058–0.177)	0/+100	0.078 (0.075–0.82)
Spinach ORG-U	±14	0.103 (0.094–0.115)	0/+100	0.103 (0.101–0.109)
Lettuce CON-H*	+25/−10	0.126 (0.118–0.131)	0/+100	0.126 (0.116–0.125)
Chicory Catalogna ORG-F	+75/−20	0.056 (0.032–0.070)	0/+100	0.056 (0.048–0.064)
Chicory Catalogna CON-F*	-+50/−37	0.120 (0.080–0.189)	0/+53**	0.120 (0.100–0.130)
Scallion ORG-U	+44/−37	0.111 (0.084–0.169)	0/+100	0.111 (0.111–0.111)
Scallion ORG-F	+148/−74	0.124 (0.057–0.449)	0/+100	0.124 (0.124–0.124)
Red radish ORG-U	+74/−48	0.056 (0.039–0.093)	0/+100	0.056 (0.056–0.057)
Red radish CON-H*	+11/−13	0.060 (0.054–0.069)	0/+100	0.060 (0.055–0.066)

conventional radish than for box scheme distribution with 0.060 kg CO_2e per kg product. A small difference was recognized between the organic and conventional area management (−7%) in the red radish comparison.

3.1.1. *Agricultural production stage: sensitivity analysis*

A sensitivity analysis was carried out on two aspects, i) yield variation and ii) nitrogen leaching factors. Results in Table 4 showed that while yields strongly influenced the amount of GHG emissions, doubling the baseline leaching factor of each crop had a negligible influence on the CF of the agricultural production stage (without heating). The CFs of vegetables from winter harvest systems ranged from +47/-37% of the original value on average. Yield variations therefore are relatively high, remarkably in case of organic open field scallions, for which yield maxima were 1.5 times higher and yield minima were 74% lower that the baseline and thus CF -54/+262%. The agricultural production stage was found to have 0.446 kg CO_2e/kg scallions for the minimum yield variant. The results showed, that the variation of the leaching factors had far less influence on the baseline results. Since the baseline leaching factors was 0.47 for Italian Catalogna, we assumed +53% for the maxima value of the sensitivity analysis.

3.2. *Regional conditions for sustainable winter harvest diffusion*

The analysis of winter harvest systems in Austria resulted in the identification of 13 major factors. The relationships between the factors was evaluated by direct linear response relation. The impact of one system factor on each of the 12 other factors within system is shown in the impact matrix as Table 5. For instance, the more publically positive image of winter harvest products was accomplished, the higher was the quantity of regional and seasonal winter harvest systems. The result was a strong proportional impact as indicated by 2 (see Table 5). This evaluation also showed, that factors have an impact on, i.e. influencing many other factors, e.g. consultancy had a medium to strong impact on 10 other factors. Demand for high quality product and subsidies had an impact on more than 8 other factors. Controversially, factors such as regional value-added, regional environmental impacts or CF of winter vegetable produce, explicitly affect only one other factor directly. Moreover, the analysis revealed factors that are only influenced by few or no other factor, e.g. demand for high quality products and subsidies. Some factors, e.g. the image of winter harvest products, was influenced by the majority of 10 other system factors.

In order to reach a sustainable market diffusion, 3 to 5 factors were simultaneously important and not one factor alone. The magnitude to which each system factor was responsible to achieve the goal of a sustainable diffusion is shown in Fig. 4. The two most effective factors were subsidies (13%) and the image of winter harvest products (12%). The factors polytunnel areas in winter under use, consultancy, demand for high quality produce and regional and seasonal production contribute equally with 10% to the achievement of the overall goal. A result of 9 to 5% effectiveness was achieved by the farm level factors, price/farm income, work satisfaction, agrobiodiversity and resource use as well as the CFs along the supply chain. At the lower end and thus considered as not very effective were value added from winter harvest produce in the region and other environmental regional impacts (see Fig. 4). The

Table 5

Impact matrix: results of the relation between the 13 system factors, i.g. the impact of each factor on the other 12 factors. 0 indicates no or an ambiguous impact, 1 a medium impact and 2 indicates a strong impact. 0–1, 1–0, 1–2 or 2–1 indicate ranges; the baseline was calculated with the first value, whereas the sensitivity analysis with the second value (see Fig. 4).

#	System factor	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Image of winter harvest products	x	0–1	2	2	1	0	0	1	0	0	0–1	1	2
2	Subsidies	0	x	2	2	1	0–1	1	1	1	2	2	0–1	0
3	Regional & seasonal production	2	0	x	0–1	1	2	0	0	1	1	1	0	0
4	Polytunnel areas in winter under use	1	0	2	x	1	1	0	0	0	1	2	0	0
5	Consultancy	0	0	1–2	1	x	1	1	1	1	1	1	1–2	1–2
6	Regional value-added	1–2	0–1	0	0	0	x	0	0	0	0	0	0	0
7	Regional environmental impacts (reduction)	1	0–1	0	0	0	0	x	0	0	0	0	0	0
8	Agrobiodiversity	2	0	0–1	0	1	0	0–1	x	0	0	0	1–0	0
9	Resource use (reduction)	2–1	0	0	0	0	0	1	0	x	2	1	0–1	0
10	Carbon footprints of winter vegetable produce (reduction)	2	0–1	0	0	0	0	0	0	0	x	0	0–1	0
11	Price/farm incomes	1	0	1–2	1	1	1–2	0	0–1	0	0	x	2	0
12	Work satisfaction	1	0	1	1	0	0	0	1	0	0	1	x	0
13	Demand: product quality	2–1	0–1	2–1	1	1–0	0–1	1	1	1	1	1	0–1	x

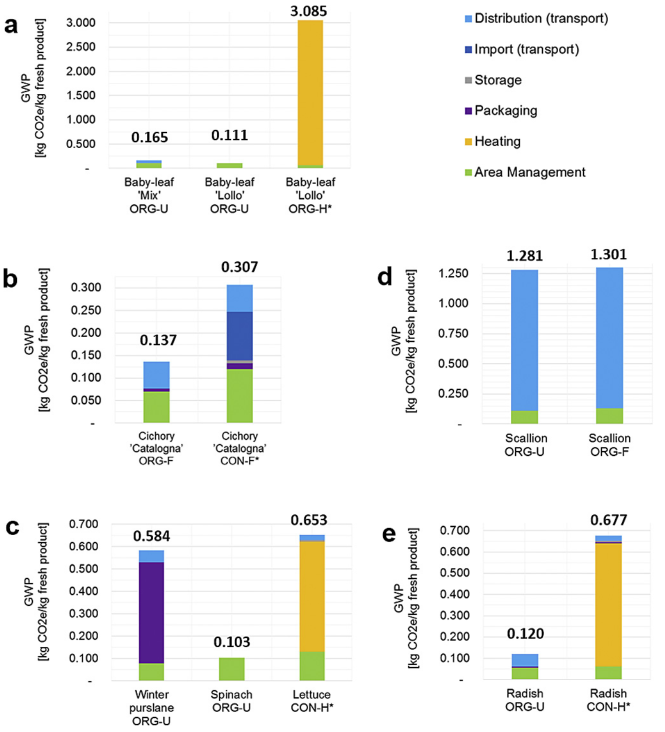

Fig. 3. Carbon footprints of winter harvest products compared to a reference systems (a) unheated and frost-free kept organic Baby-leafs (b) organic and conventional open field Catalogna (c) unheated organic purslane, spinach compared to conventional heated lettuce (d) organic winter scallions in unheated polytunnels and open field (e) organic and conventional red radish. ORG-U = organic produce from unheated polytunnels. ORG-F = organic produce from open fields. CON-H = conventional produce from heated glasshouse. ORG-H = organic produce kept frost-free. *) mark reference systems.

results of the sensitivity analysis shown in Fig. 3 revealed that in general baseline values were closer to the minimum value but the overall picture remained robust. Two factors were underestimated in the baseline and increased their effectiveness in the sensitivity analyses: consultancy and price/farm incomes reached value of 13% and 11%.

4. Discussion

4.1. Agricultural performance and feasibility

The field trials demonstrated that unheated winter cultivation was feasible in all climate regions in Austria. Lowest temperatures of −17 °C were measured in open field Catalogna in Atlantic middle European climate: The winter 2014/15 was mild compared to the long-term average and in polytunnels, lowest temperature observed were −5 °C in red radish and −8 °C in winter purslane cultivation. Depending on the performance of previous crops (mostly fruit vegetables) in the polytunnels, the planting time started sooner (mid of October) or later (end of October). The recorded yield per hectare in this study (see Table 1) might thus be blurred. Organic baby-leaf Lollo had one, while winter purslane had three cuttings, but data was in line with numbers reported for Northern Italian soil-grown lamb's lettuce (Fusi et al., 2016). The lowest level at 2,570 kg open field scallions per hectare was recorded in the alpine climate zone. Scallions in polytunnels suffered from Botrytis infection due to high humidity and cloudy weather in the alpine regions and yield performances where quite low with 3,583 kg fresh product per hectare. Yield maxima was recorded from healthy plots at 6,380 kg scallions per hectare.

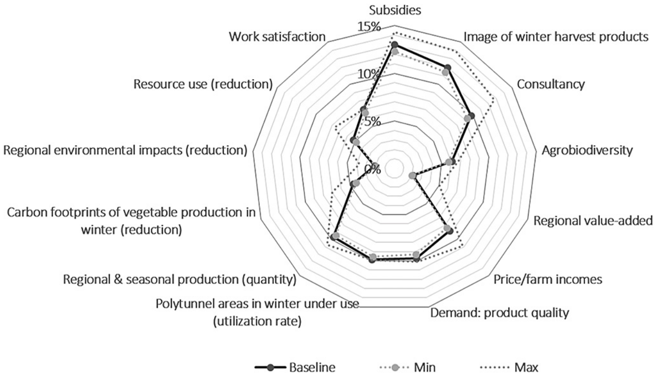

Fig. 4. Contribution (effectiveness) of the system factors to achieve the sustainability goal of the winter harvest system calculated with Systaim SystemQ (Scholz and Tietje, 2002; Tietje, 2013). Minimum and maximum values represent the results from the sensitivity analysis.

Although in general organic yields are assumed to be lower (Seufert et al., 2012), we found that the average yield was 20,000 kg per hectare for organic Catalogna and thus similar to data found from Italian statistics. In winter harvest systems, yield maxima per hectare were 35,000 kg Catalogna (ORG-F) and 25,000 kg winter purslane (ORG-U). However, the floating row cover provoked problems with snow pressure and yield records were at the lower level of the potential yield range at 16,000 kg per hectare. Strikingly, in contrast to conventional yields, red radish from organic production was nearly 5 times lower. One major reason were temperature vast below 0 °C in the organic system and heated conventional radish systems relied on mineral fertilizer input as well the production window was different since it was harvested until the end of April. Although, selectively use of highly soluble organic nitrogen fertilizers such as vinasse is common in intensive organic vegetable production (Theurl et al., 2014), it was not evident in the winter harvest systems of this study. Conversely, protected conventional systems are much more intensive and use mineral fertilizers and pesticides (Romero-Gámez et al., 2014; Tasca et al., 2017). The heterogeneous yields between the variants influenced the CF per kg produce massively.

4.2. Evaluation of distributions channels and packaging

Although it seems intuitively plausible that local food distribution requires less transport because fewer ton kilometers have to be travelled due to shorter distance, this study showed that this holds not true in general and confirms results from previous studies (Sim et al., 2007). Especially when individual shopping trips by consumers to the farm shop were considered, results showed the amount of GHGs achieve levels of vegetables from heated glasshouses, e.g. this was seen when comparing organic winter scallions with heated tomatoes (Theurl et al., 2014). Additional GHG emissions between 0.040 and 0.120 kg CO_2e per kg produce could be caused by supermarket shopping (in towns) by car (Lughofer, 2010), e.g. in context with purchasing of imported Italian Catalogna, which was not analyzed in this study. Besides, lettuce from protected UK production have higher CFs (Hospido et al., 2009). Results from our study revealed, 90–91% of total emissions of organic scallions in this specific, alternative form of distribution are from shopping trips to the farm shop, in contrast to 60–90% from heating energy in the case of the heated crops. Apart from farm shop distribution, the results showed that supermarket logistic and box scheme transport contributed much less to total CFs. In terms of absolute GHG emissions per kg product, different distribution channels are listed in ascending order as follows: supermarket logistics (not considering the distance between supermarket and household), box scheme, imports (long-distance transport via supermarket logistics) and individual shopping trips by car to the farm shop. Interestingly, distribution via intermediaries did not show a huge effect to the total CF. While relative contribution was 10% from distribution transport to intermediary in the case of winter purslane, box scheme distribution contributed 44% of the total CF of fresh Catalogna (ORG-F).

In addition, packaging was a major hotspot of vegetable products (Fusi et al., 2016), especially when produce was distributed via supermarket logistics it is binding for organic produce due to tight tracking and certification schemes. Most significant was the share of packaging of winter purslane with 0.45 kg CO_2e (77%) in comparison to only 0.01 kg CO_2e (5%) for bagged Catalogna. Interestingly, processed tomatoes were found to have 0.45 kg CO_2e from tin packaging (Theurl et al., 2014). Responsible for the significant high emission is the small packaging unit of 100 g flow-packed winter purslane. Although a larger packaging unit would reduce GHG emissions, the alternative for leaf-salads so far is the use of consumers own reusable boxes at POS in farm stores or simply use a plastic bag (Fusi et al., 2016).

4.3. Towards market diffusion in Austria

In the light of sustainable development, this study derived three system factors that behave as steering instruments and upon which measures can be derived: subsidies, image of winter harvest products and consultancy. The results revealed the implementation of a subsidy system as high priority. Potential measures of a subsidies system could include financial subsidies of unheated winter harvest systems, promotion of newcomers, tax incentives for existing producers, implementation of a joint branding in the region or public procurement (Morgan, 2008). The second most important factors was the building of a positive public image of winter harvest products. Activities in this area can be awareness campaigns and advertisement, educational measures e.g. via consumer communication, advertisement, workshops in schools, adult evening classes etc. (Eigenbrod and Gruda, 2015). Moreover, the winter harvest system diffusion could be steered with improved consultancy measures for producers and processing companies. Expansion of advisory services relates not only to an improved transfer of growing-know-how, e.g. on practices and dealing with crop diseases, but also to business consultancy regarding direct marketing channels. Funding of field days or demonstration farm for instance presents a synergy between increasing the image of winter harvest produce and the consultancy of farmers (FAO, 2016). Winter harvest reveals the potential to allow farmers with short chain marketing to close winter gaps and meet consumer demand. The winter assortment in box scheme marketing as well as at the local market stays fresh and diversified during the winter period. The stabilization of existing and implementation of new marketing opportunities, e.g. via local community supported agriculture, accompanied by the chamber of agriculture and members of the farmers associations for both, conventional and organic producers can therefore be considered as important activities especially for city region food systems (Walthall, 2016).

Although the CF provides a good overview of the environmental impacts along the supply chain of a product, results from the system analysis revealed that a reduction of the CF had only a relatively small effect on the sustainable diffusion. This can be explained by the fact, that besides to the image of winter harvest produce there was only little direct interaction with the other socio-economic factors of the system. However, this study proves that the insights gained from such environmental calculations are important in the preparation of decision making, i.e. the subsidy system and consultancy activities (Peters, 2010).

With respect to prices - important to guarantee a sufficient farm income - results showed that high prices had a medium effect towards the achievement of the overall system aim. We considered this result as inconclusive, because prices are not influentially effecting the overall system goal, but at the same time, depend on free market conditions. The sensitivity analysis showed however, that prices/farm might be considered as a major driver towards diffusion, probably especially in the mid or long term. Nevertheless, high prices per se seem not to be a significant factor in purchasing decisions (Starr et al., 2003). Austrian wholesale prices for organic winter harvest salads are 14 € per kg (Achleitner, 2017) and high class gastronomy even pays prices of 20–22 € per kg for locally and organically produced seasonal winter harvest produce (Brodnjak, 2017). As customary supermarket distribution was not feasible in all cases, most farmers relied on farm shops. At the moment, there seems to be a marketing advantage for direct marketing farmers who are able to communicate the seasonal quality of their produce directly to the consumers, which is often considered a characteristic of local food systems (IFOAM EU Group, 2015; Mount, 2012).

5. Conclusions

This study explored the commercial adequacy of unheated soil-grown organic winter cultivation techniques in polytunnels and open field in Austria. Results from field trials in Austria, which here are not reported in detail, revealed that winter cultivation was feasible in all climatic regions. Winter harvest of vegetables that withstood polytunnels indoor temperatures of −8 °C and open-field maximum of −17 °C was possible. By taking an integrative perspective along the supply-chain we found that organic winter harvest products showed huge GHG emission reduction potentials compared to traditional heated systems. Keeping polytunnels frost-free with energy from renewable sources was however not found to be a promising option for a contribution to GHG-reduction since CFs exceeded all other crops by at least two times. A central result was that small plastic packaging units contribute equally to total CF than tin packaging of processed tomatoes. Further research is needed, especially because decent tracking and certification for organic produce requires appropriate and economically attractive alternatives also regarding consumer acceptance e.g. larger packaging units.

In addition, these innovative low-energy winter harvest systems could contribute closing the supply gap in winter months and provide an alternative in countries that rely on imported vegetables from the Southern parts of Europe. Results of field trials showed that yields of winter harvest vegetables could be improved and more research would help to identifying e.g. optimal air ventilation techniques to reduce air moisture within the polytunnels and preventing diseases such as Botrytis or powdery mildew infestation.

The system analysis revealed that a sustainable market diffusion of winter harvest products required an innovative subsidy systems as well the creation of an increased positive image of winter harvest produce through marketing, educational measures or the implementation of a specific brand in order to increase the utilization rate of existing (vacant) polytunnel areas in winter months and the seasonal and regional production quantity. Nevertheless, more research is needed to quantify economic profitability including social factors worker‘s satisfaction and understand consumer-farmer relationship in more detail. The outstanding role of protected cultivation under organic principles need further investigation especially with regard to soil fertility and crop rotations in polytunnels and the use of eco-friendly materials as substitutes for peat.

Acknowledgements

The research for this article was funded by the Austrian Rural Development Program, measure 124a under 33 the project cooperation “Winterernte: Saisonaler, Energie-extensiver und innovativer Gemüsebau”. We acknowledge support from ERC Starting Grant 2010-263522 LUISE. This research was partly funded by 1 the Austrian Science Funds (FWF), project number P29130-G27. We thank the collaborating farmers, Matthias Stolze and the three anonymous reviewers for their valuable comments on the text.

References

Achleitner, G., 12.1.2017. Japanese greens, Price per Kilogram, exquisite gastronomy delivery. Interview with an organic producers.

Betz, A.-M., Lengauer, D., Palme, W., Stopper, E., Theurl, M.C., 2015. Endbericht des Projektes Winterernte: Saisonaler, Energie-extensiver und innovativer Gemüseanbau im Rahmen der LE-Maßnahme „Kooperationsvorhaben M124a“ (Unpublished).

Bio Austria, 2016. Produktionsrichtlinien für die biologische Landwirtschaft in Österreich, Fassung Jänner 2016.

Bio Austria, 2012. BIO AUSTRIA Regulations for Organic Farming in Austria.

BMLFUW, 2008. Richtlinien für die sachgerechte Düngung im Garten- und Feldgemüsebau, 3. Auflage. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.

BMLFUW, 2016. Grüner Bericht 2016. Bericht über die Situation der österreichischen Land- und Forstwirtschaft im Jahr 2015 (Report about the Situation of Austria’s Agriculture and Forestry) (No. 57. Auflage). Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.

Brodnjak, R., 25.1.2017. Japanese greens, Price per Kilogram, exquisite gastronomy delivery. Interview with an organic producers.

Castoldi, N., Bechini, L., Ferrante, A., 2011. Fossil energy usage for the production of baby leaves. Energy 36, 86–93. http://dx.doi.org/10.1016/j.energy.2010.11.004.

Coleman, E., 2009. The Winter Harvest Handbook. Year-round Vegetable Production Using Deep-organic Techniques and Unheated Greenhouses. Chelsea Green Publ. (White River Junction, Vt).

Coley, D., Howard, M., Winter, M., 2009. Local food, food miles and carbon emissions: a comparison of farm shop and mass distribution approaches. Food Policy 34, 150–155. http://dx.doi.org/10.1016/j.foodpol.2008.11.001.

Daxbeck, H., David, P., Holler, C., Strelec, M., Moudry, J., 2011. Möglichkeiten von Großküchen zur Reduktion ihrer CO2-Emissionen (Maßnahmen, Rahmenbedingungen und Grenzen). Projekt SUKI. Handbuch Vers. 1.0. Ressourcen Management Agentur (RMA), Vienna.

Demerci, M., 2001. Ermittlung der Deckungsbeiträge für die wichtigsten Gemüsekulturen im Gewächshaus in Österreich. Universität für Bodenkultur, Institut für Obst-und Gartenbau, Wien.

Eigenbrod, C., Gruda, N., 2015. Urban vegetable for food security in cities. A Rev. Agron. sustain. Dev. 35, 483–498. http://dx.doi.org/10.1007/s13593-014-0273-y.

European Commission, 2008. Commission Regulation (EC) No 889/2008 of 5 September 2008 Laying Down Detailed Rules for the Implementation of Council Regulation (EC) No 834/2007 on Organic Production and Labelling of Organic Products with Regard to Organic Production, Labelling and Control.

European Commission, 2011. Roadmap to a Resource Efficient Europe: Communication from the Commission to the European Parliament. The Council, The European Economic And Social Committee And The Committee Of The Regions 571 Final.

FAO, 2014. The Sustainability Assessment of Food and Agriculture Systems (SAFA) Guidelines - Version 3.0. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

FAO, 2016. Conducting Farm-based Trainings on How to Enhance On-farm Ecosystem Services Inspiring the Farm Community to Adopt New Practices. Food and Agriculture Organization of the United Nations, Rome.

Feller, C., Fink, M., Laber, H., Maync, A., Paschold, P., Scharf, H.C., Schlaghecken, J., Strohmeyer, K., Weier, U., Ziegler, J., 2011. Düngung im Freilandgemüsebau. In: Fink, M. (Ed.), Schriftenreihe des Leibniz-Instituts für Gemüse- und Zierpflanzenbau (IGZ), 3. Auflage, Heft 4. ed. Großbeeren.

Foteinis, S., Chatzisymeon, E., 2016. Life cycle assessment of organic versus conventional agriculture. A case study of lettuce cultivation in Greece. J. Clean. Prod. 112 (Part 4), 2462–2471. http://dx.doi.org/10.1016/j.jclepro.2015.09.075.

Frischknecht, R., Jungbluth, N., Althaus, H.-J., Doka, G., Dones, R., Heck, T., Hellweg, S., Hischier, R., Nemecek, T., Rebitzer, G., Spielmann, M., 2005. The ecoinvent database: overview and methodological framework (7 pp). Int. J. Life Cycle Assess. 10, 3–9. http://dx.doi.org/10.1065/lca2004.10.181.1.

Fusi, A., Castellani, V., Bacenetti, J., Cocetta, G., Fiala, M., Guidetti, R., 2016. The environmental impact of the production of fresh cut salad: a case study in Italy. Int. J. Life Cycle Assess. 21, 162–175. http://dx.doi.org/10.1007/s11367-015-1019-z.

Gunady, M.G.A., Biswas, W., Solah, V.A., James, A.P., 2012. Evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces (Lactuca sativa), and button mushrooms (Agaricus bisporus) in Western Australia using life cycle assessment (LCA). J. Clean. Prod. 28, 81–87. http://dx.doi.org/10.1016/j.jclepro.2011.12.031.

Hampl, S., 2016. Möglichkeiten der Ertrags und Qualitätssicherung bei alternativem Wintergemüse. Diplomarbeit/Masterarbeit - Abteilung Gartenbau, BOKU-Universität für Bodenkultur, Wien.

Hartl, W., Erhart, E., Feichtinger, F., 2012. Humusaufbau auf Ackerfl ächen im Zusammenhang mit Klima-, 'Boden- und Gewässerschutz. Presented at the 3. Umweltökologisches Symposium 2012, Lehr- und Forschungszentrum für Landwirtschaft Raumberg-Gumpenstein, Raumberg-Gumpenstein, pp. 39–44.

Hiebl, J., Reisenhofer, S., Auer, I., Böhm, R., Schöner, W., 2011. Multi-methodical realisation of Austrian climate maps for 1971–2000. Adv. Sci. Res. 6, 19–26. http://dx.doi.org/10.5194/asr-6-19-2011.

Hörtenhuber, S., Lindenthal, T., Amon, B., Markut, T., Kirner, L., Zollitsch, W., 2010. Greenhouse gas emissions from selected Austrian dairy production systems—model calculations considering the effects of land use change. Renew. Agric. Food Syst. 25, 316–329. http://dx.doi.org/10.1017/S1742170510000025.

Hospido, A., Milà i Canals, L., McLaren, S., Truninger, M., Edwards-Jones, G., Clift, R., 2009. The role of seasonality in lettuce consumption: a case study of environmental and social aspects. Int. J. Life Cycle Assess. 14, 381–391. http://dx.doi.org/10.1007/s11367-009-0091-7.

Hubacek, K., Feng, K., Chen, B., Kagawa, S., 2016. Linking local consumption to global impacts. J. Ind. Ecol. 20, 382–386. http://dx.doi.org/10.1111/jiec.12463.

IFOAM EU Group, 2015. Organic Cooperative Approaches to Rural Development. A Manual for Stakeholders. International Foundation for Organic Agriculture Europe, Brussels.

ISO, 2006a. ISO 14040, Environmental Management — Life Cycle Assessment: Principles and Framework.

ISO, 2006b. ISO 14044, Environmental Management — Life Cycle Assessment: Requirements and Guidelines.

Istat, 2015. http://agri.istat.it/sag_is_pdwout/jsp/NewDownload.jsp. (Accessed 5 April 2016).

Koch, M., 2016. Marktentwicklungen für Obst und Gemüse in Europa.

KTBL, 2015. Online Tool. http://daten.ktbl.de/dieselbedarf/main.html.

Kummer, S., Hirner, P., Milestad, R., 2016. How growth of a local organic box scheme influenced supplying farmers. Acta Fytotech. Zootech. 18, 83–85.

Lattauschke, G., 2004. Anbau von Gewächshausgemüse. Hinweis zum umweltgerechten Anbau. Managementunterlage. Sächsische Landesanstalt für Landwirtschaft.

Leclerc, B., Georges, P., Cauwel, B., Lairon, D., 1995. A five year study on nitrate leaching under crops fertilised with mineral and organic fertilisers in lysimeters. Biol. Agric. Hortic. 11, 301–308. http://dx.doi.org/10.1080/01448765.1995.9754714.

Lindenthal, T., Markut, T., Hörtenhuber, S., Theurl, M., Rudolph, G., 2010. Greenhouse Gas Emissions of Organic and Conventional Foodstuffs in Austria, in: Notarnicola, B., Settanni, E., Tassielli, G., Giungato, P., Università degli Studi di Bari Aldo Moro (Eds.), Lcafood 2010: VII International Conference on Life Assessment in the Agri-Food Sector ;; Bari, Italy, September 22-24 2010 ; Proceedings, Vol. 1. Presented at the VII. International conference on life cycle assessment in the agri-food sector (LCA Food), Bari, pp. 319–324.

Lughofer, E., 2010. Treibhausgas-Emissionen bei unterschiedlichen Vermarktungsformen von Gemüse-eine Fallstudie unter Berücksichtigung des Einkaufsverkehrs.

McIntyre, A., 2014. Report on the Future of Europe’s Horticulture Sector — Strategies for Growth. (2103/2100(INI)). Committee on Agriculture and Rural Development.

Morgan, K., 2008. Greening the Realm: sustainable food chains and the public plate. Reg. Stud. 42, 1237–1250. http://dx.doi.org/10.1080/00343400802195154.

Mount, P., 2012. Growing local food: scale and local food systems governance. Agric. Hum. Values 29, 107–121. http://dx.doi.org/10.1007/s10460-011-9331-0.

Palme, W., 2016. Frisches Gemüse im Winter ernten, 1. ed. Löwnzahn, Innsbruck.

Palme, W., Kupfer, J., 2008. All-Season Low-Energy-Production of Special Greens. Presented at the COST “Organic Greenhouse Horticulture”.

Palme, W., Kupfer, J., 2015. Winterernte: die Produktion von Wintersalaten und —kräutern im ungeheizten Folientunnel, in: „Eiweißpflanzen - Strategien Und Chancen Für Landwirtschaft Und Industrie”. Presented at the 70. ALVA Jahrestagung, Graz, pp. 148–150.

Palme, W., Theurl, M.C., 2016. Vielfalt im Winter. Bio Austria Fachzeitschrift für Landwirtschaft und Ökologie, pp. 40–45.

Peters, G.P., 2010. Carbon footprints and embodied carbon at multiple scales. Curr. Opin. Environ. Sustain. 2, 245–250. http://dx.doi.org/10.1016/j.cosust.2010.05.004.

Romero-Gámez, M., Audsley, E., Suárez-Rey, E.M., 2014. Life cycle assessment of cultivating lettuce and escarole in Spain. J. Clean. Prod. 73, 193–203. http://dx.doi.org/10.1016/j.jclepro.2013.10.053.

Scholz, R.W., Tietje, O., 2002. Embedded Case Study Methods: Integrating Quantitative and Qualitative Knowledge. Sage Publications, Thousand Oaks, Calif.

Seufert, V., Ramankutty, N., Foley, J.A., 2012. Comparing the yields of organic and conventional agriculture. Nature 485, 229–232. http://dx.doi.org/10.1038/nature11069.

Sim, S., Barry, M., Clift, R., Cowell, S.J., 2007. The relative importance of transport in determining an appropriate sustainability strategy for food sourcing. Int. J. Life Cycle Assess. 12, 422–431. http://dx.doi.org/10.1065/lca2006.07.259.

Starr, A., Card, A., Benepe, C., Auld, G., Lamm, D., Smith, K., Wilken, K., 2003. Sustaining local agriculture Barriers and opportunities to direct marketing between farms and restaurants in Colorado. Agric. Hum. Values 20, 301–321.

http://dx.doi.org/10.1023/A:1026169122326.

Statistik Austria, 2014. Gemüseernte 2014. Endgültige Ergebnisse, Wien.

Tasca, A.L., Nessi, S., Rigamonti, L., 1 January 2017. Environmental sustainability of agri-food supply chains: an LCA comparison between two alternative forms of production and distribution of endive in northern Italy. J. Clean. Prod. 140 (Part 2), 725–741. http://dx.doi.org/10.1016/j.jclepro.2016.06.170.

Theurl, M.C., 2016. Local food systems and their climate impacts: a life cycle perspective. In: Niewöhner, J., Bruns, A., Hostert, P., Krueger, T., Nielsen, Ø.J., Haberl, H., Lauk, C., Lutz, J., Müller, D. (Eds.), Land Use Competition: Ecological, Economic and Social Perspectives. Springer International Publishing, Cham, pp. 295–309.

Theurl, M.C., Hörtenhuber, S.J., 2016. Ökobilanz von österreichischem Wintergemüse. Comparison of low-energy production systems in Austria. In: Eiweißpflanzen - Strategien Und Chancen Für Landwirtschaft Und Industrie, pp. 170–172.

Theurl, M.C., Haberl, H., Erb, K.-H., Lindenthal, T., 2014. Contrasted greenhouse gas emissions from local versus long-range tomato production. Agron. Sustain. Dev. 34, 593–602. http://dx.doi.org/10.1007/s13593-013-0171-8.

Tietje, O., 2013. Systemanalyse. Qualitative Modellierung des Dynamik eines komplexen Systems (Zürich).

Trnka, M., Eitzinger, J., Semerádová, D., Hlavinka, P., Balek, J., Dubrovský, M., Kubu, G., Štěpánek, P., Thaler, S., Možný, M., Žalud, Z., 2011. Expected changes in agroclimatic conditions in Central Europe. Clim. Change 108, 261–289. http://dx.doi.org/10.1007/s10584-011-0025-9.

Umweltbundesamt (UBA), 2014. GEMIS Österreich.

Vogel, G., 1996. Handbuch des speziellen Gemüsebaus. Ulmer Verlag, Suttgart (Hohenheim).

Walthall, B., 2016. Strengthening city region food systems: synergies between multifunctional peri-urban agriculture and short food supply chains: a local case study in berlin, Germany. In: Niewöhner, J., Bruns, A., Hostert, P., Krueger, T., Nielsen, J.Ø., Haberl, H., Lauk, C., Lutz, J., Müller, D. (Eds.), Land Use Competition: Ecological, Economic and Social Perspectives. Springer International Publishing, Cham, pp. 263–277. http://dx.doi.org/10.1007/978-3-319-33628-2_16.

Wenger, M., Wenz, J., 2012. Die Überwinterung von Gartensalat (Lactuca sativa L.) im Freiland [Overwintering of lettuce (Lactuca sativa L.) outdoors].

Wiek, A., Lang, D.J., Siegrist, M., 2008. Qualitative system analysis as a means for sustainable governance of emerging technologies: the case of nanotechnology. J. Clean. Prod. 16, 988–999. http://dx.doi.org/10.1016/j.jclepro.2007.04.009.