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

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A R T I C L E I N F O

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

A B S T R A C T

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

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http://dx.doi.org/10.1016/j.jclepro.2017.03.016
0959-6526/

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