

Wasting Food, Wasting Resources

Potential Environmental Savings Through Food Waste Reductions

Arkaitz Usabiaga ,¹ Isabela Butnar,¹ and Philipp Schepelmann²

¹UCL Institute for Sustainable Resources, London, United Kingdom

²Wuppertal Institut für Klima Umwelt Energie GmbH, Wuppertal, Germany

Keywords:

environmental foodprint
environmentally extended
input-output analysis
food waste
industrial ecology
multiregional input-output

 Supporting information is linked to this article on the JIE website

Summary

Food is needed to maintain our physical integrity and therefore meets a most basic human need. The food sector got in the focus of environmental policy, because of its environmental implications and its inefficiency in terms of the amount of food lost along the value chain. The European Commission (EC) flagged the food waste issue a few years ago and adopted since then a series of policies that partially address the problem. Among these, the Resource Efficiency Roadmap set the aspirational goal of reducing the resource inputs in the food chain by 20% and halving the disposal of edible food waste by 2020. Focusing on consumer food waste, we tested what a reduction following the Roadmap's food waste target would imply for four environmental categories in EU28 (European Union 28 Member States): greenhouse gas emissions, land use, blue water consumption, and material use. Compared to the 2011 levels, reaching the target would lead to 2% to 7% reductions of the total footprint depending on the environmental category. This equals a 10% to 11% decrease in inputs in the food value chain (i.e., around half of the resource use reductions targeted). The vast majority of potential gains are related to households, rather than the food-related services. Most likely, the 2020 target will not be met, since there is insufficient action both at Member State and European levels. The Sustainable Development Goals provide a new milestone for reducing edible food waste, but Europe needs to rise up to the challenge of decreasing its per capita food waste generation by 50% by 2030.

Introduction

Food is a key satisfier of one of the most basic human needs, that of subsistence (Max-Neef 1992). Nevertheless, the degree of fulfillment of this need is very uneven around the world. While 805 million people—11% of the world population—were undernourished in 2014 (FAO 2014), one third of food is wasted globally (Gustavsson et al. 2011). This has relevant economic, ethical, social, and environmental implications.

Recently, food has become an issue of European environmental policy making. Its production exerts considerable

pressures on the environment (Tukker and Jansen 2006), while at the same time large amounts of food are thrown away (Monier et al. 2010; Gustavsson et al. 2011). The Resource Efficiency Roadmap adopted by the European Commission (EC) in 2011 (EC 2011) put the problem of food waste on the European Union's (EU) agenda. In that document, the EC set the aspirational goal of reducing resource inputs into the food chain by 20% and halving the disposal of edible food waste by 2020 (EC 2011, 18). Consequently, the 7th Environmental Action Plan (EC 2014a, 38) promised a “comprehensive strategy to combat unnecessary food waste.” The issue also features prominently in

Conflict of interest statement: The authors have no conflict to declare.

Address correspondence to: Arkaitz Usabiaga, UCL Institute for Sustainable Resources, Central House, 14 Upper Woburn Place, London, WC1H 0NN, United Kingdom. *Email:* arkaitz.usabiaga.15@ucl.ac.uk

© 2017 The Authors. *Journal of Industrial Ecology*, published by Wiley Periodicals, Inc., on behalf of Yale University. This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
DOI: 10.1111/jiec.12695

Editor managing review: Arnold Tukker

the recently adopted Circular Economy Action Plan (EC 2015). At the international level, food waste is also receiving close attention. For example, the Sustainable Development Goal 12.3 calls for halving “per capita global food waste at the retail and consumer levels” and reducing “food losses along production and supply chains, including post-harvest losses” by 2030 (UN 2015, 22).

The environmental implications of food systems have been assessed from bottom-up (Jungbluth et al. 2000; Foster et al. 2006; Lukas et al. 2015), top-down (Tukker and Jansen 2006; Schmidt and Merciai 2014; Reynolds et al. 2015), or both (Jungbluth et al. 2011; Virtanen et al. 2011) perspectives. Most assessments of potential environmental savings from better practices focus on dietary changes (Baroni et al. 2007; Marlow et al. 2009; Tukker et al. 2011; Wolf et al. 2011; Vanham et al. 2013; Auestad and Fulgoni 2015). In the last years, more attention has been paid to potential savings attributable to food waste prevention practices. Those who have investigated this issue have mainly focused on potential greenhouse gas (GHG) savings (Audsley et al. 2009; Venkat 2011; Matsuda et al. 2012; Bernstad and Andersson 2015), although a few have also addressed other environmental categories (Chapagain and James 2011; Gentil et al. 2011; Vanham et al. 2015; Reynolds et al. 2016a; Reutter et al. 2017). One of the factors limiting the production of similar studies is insufficient data availability. Recently, the amount of studies quantifying the amount of food wasted at different stages of the food value chain has increased significantly (WRAP 2009; Monier et al. 2010; Gustavsson et al. 2011; Baptista et al. 2012; Hafner et al. 2012; HISPACOOP 2012; Tatlidil et al. 2013; WRAP 2013a, 2013b; Brautigam et al. 2014; Silvennoinen et al. 2014; Reynolds et al. 2016b), although considerable methodological challenges remain, thereby limiting the comparability of the available country estimates (Hanssen et al. 2013).

In this article, we use a top-down approach to quantify the environmental pressures of the EU28 (European Union 28 Member States) food system both from the production and consumption perspectives in the period 1995–2011. Likewise, we combine the results with data on food waste to estimate the scale of potential environmental savings in relation to food waste reduction targets in the EU28. We frame the assessment using the environmental themes covered in the dashboard of indicators proposed in the Resource Efficiency Roadmap (EC 2011)—namely carbon, land, materials, and blue water. Thus, we first describe the methodology and main data sources. Next, we present the main results and discuss the findings. The last section concludes.

Methods

Some Basic Considerations

This article assesses the environmental pressures associated with food production and consumption in the EU28 during the period 1995–2011. The environmental pressure categories include GHG emissions (excluding those from land use and

land-use changes), land use, domestic extraction used (DEU; hereafter referred to as materials), as well as blue water consumption. We offer two complementary views of the system. The first one, the production perspective, accounts for domestic pressures in the production chain of food products. In the second one, the consumption perspective, we allocate the domestic pressures to consumers through the equations presented in the next section. In this article, we use the term foodprint to refer to the cradle-to-gate environmental pressures related to food consumption (i.e., the footprint of food). This should not be mistaken for footprint, which usually covers not only food products, but all the remaining products consumed by final consumers in a country.

The subject of the analysis is food supplied for human consumption. As we use it in this article, the term food covers all products that are commonly part of the human diet. This does not only include solid products, but also beverages. For a better overview, we sort the food products in nine groups (see table 1 below and table S1 in the supporting information available on the Journal’s website). Our definition of food consumption excludes edible products that are further processed in the food industry. These are intermediate inputs in the production process of an end product. For instance, this analysis does not consider grapes for wine production to be an end product. By considering the consumption of wine (i.e., the end product), we also cover for the grapes used in its production process.

When setting the boundaries of the system, one should bear in mind that food is not only consumed by final consumers such as households. Although final consumers also comprise governments, nongovernmental organizations, and similar organizations, their relevance in relation to generation of food waste is quite small. Hence, we refer to all final consumer groups as households for better readability. A non-negligible amount of food is consumed in several service industries, such as hospitals, universities, schools, prisons, stadiums, cinemas, restaurants, hotels, and so on. In input-output (I-O) tables, these food purchases take place within those service industries and, ultimately, form part of their value chain. We refer to these sectors as food-related services (see table S2 in the supporting information on the Web).

As for food losses and waste, we follow Parfitt and colleagues (2010), who describe food losses as food wasted in preconsumer stages, while food waste covers food wasted by end consumers. In this assessment, we only address the latter. In line with the previous paragraph, we split up the consumer group into households and bulk consumers (e.g., food-related services). Further, we only assess avoidable and possibly avoidable food waste—in other words, food that was edible at some point—thereby ignoring unavoidable waste such as bones and peelings.

Calculating the Environmental Foodprint in EU28

The EXIOBASE v3.3 multiregional input-output (MRIO) model (Stadler et al. Forthcoming) is the main data source in this calculation. The monetary structure of EXIOBASE represents 200 product groups for 44 countries that account for

Table 1 Product grouping used and examples of representative products

Product group	Examples from the FAO's Food Balance Sheets
Beverages	Wine, Beer, Fermented beverages, Other alcoholic beverages
Cereals (excluding beer)	Barley, Maize, Rye, Oats, Millet
Dairy (including milk)	Butter, Cream, Milk
Fish and fish products	Freshwater fish, Demersal fish, Pelagic fish, Crustaceans, Cephalopods
Meat	Bovine meat, Pig meat, Poultry meat
Other animal products	Eggs, Honey
Other crops	Coffee, Tea (including mate), Cocoa, Spices
Other processed products	Wheat products (e.g., bread, pasta), Rice, Sugar, Vegetable oils
Vegetables, fruit, nuts	Vegetables, Fruits, Nuts

Note: FAO = Food and Agriculture Organization of the United Nations.

more than 90% of the world's gross domestic product (GDP). The remaining countries are grouped in five rest of world regions. Likewise, it contains substantial industry-specific environmental information, including extraction of raw materials, air emissions, water use, and land use. This assessment aggregates the 49 countries and regions to 12 (see table S3 in the supporting information on the Web for the aggregation key used).

In environmentally extended I-O analysis, the formula to calculate the direct and indirect environmental pressures associated with final consumption is well known (Miller and Blair 2009) (equation 1):

$$m = B(I - A)^{-1} y \quad (1)$$

where m denotes the environmental footprint, B the direct environmental pressure intensity, $(I - A)^{-1}$ represents the Leontief inverse, and y the final demand.

Yet, in line with the explanations in the previous section, this formula needs to be adapted to consider the intermediate consumption of food products in food-related services. We do this in several steps. First, we filter the final consumption of countries to remove the nonfood products, which yields the final consumption of food (y_F). With the standard formula of I-O analysis, we can calculate the monetary output required (x') to satisfy the final demand of nonfood products (y')—which include food-related services—as shown below (equations 2 and 3).

$$y' = y - y_F \quad (2)$$

$$x' = (I - A)^{-1} y' \quad (3)$$

The intermediate consumption (z') matrix can be reproduced by multiplying the monetary output (x') by the row- and column-specific input coefficients (a_{ij}). The resulting matrix does not contain any of the inputs required in the value chain of the final demand of food (equation 4).

$$z'_{ij} = x'_j * a_{ij} \quad (4)$$

The second step consists of identifying the food consumed in food-related services. That is defined as follows (equation 5):

$$z_{F,ij} = \frac{x'_j * a_{ij}}{l_{jj}} \quad (5)$$

In this case, row i refers to a food product, column j to food-related services, and l_{jj} is the own use in food-related services as given in the Leontief inverse $(I - A)^{-1}$, that is, the fraction of food-related services required to produce one unit of such services. The sum of each z_{ij} element yields the intermediate food demand vector (z_F). Removing the own use within the food-related services avoids double accounting.

The footprint (m_F) is estimated as in equation (1), but using the sum of the final (y_F) and intermediate (z_F) demand food vectors as reference product (equation 6):

$$m_F = B(I - A)^{-1}(z_F + y_F) \quad (6)$$

The footprint is here given according to the final and intermediate demand of the consumer, but it can also be represented according to the place where the pressures occur. We use that as the equivalent to the production perspective.

Estimating the Potential Environmental Savings from Food Waste Prevention

In order to estimate the potential environmental benefits from reducing avoidable and possibly avoidable food waste from consumers, we have taken product-specific food waste fractions from national studies as references. In spite of the growing number of such studies, there are several limitations that need to be overcome to increase the reliability of, and comparability between, studies. Examples of such limitations include lack of a common methodology, the classification used for waste statistics, which is not clear enough to isolate food waste in certain aggregated categories, and the difficulty of identifying the fraction of food waste included in household waste (Hanssen

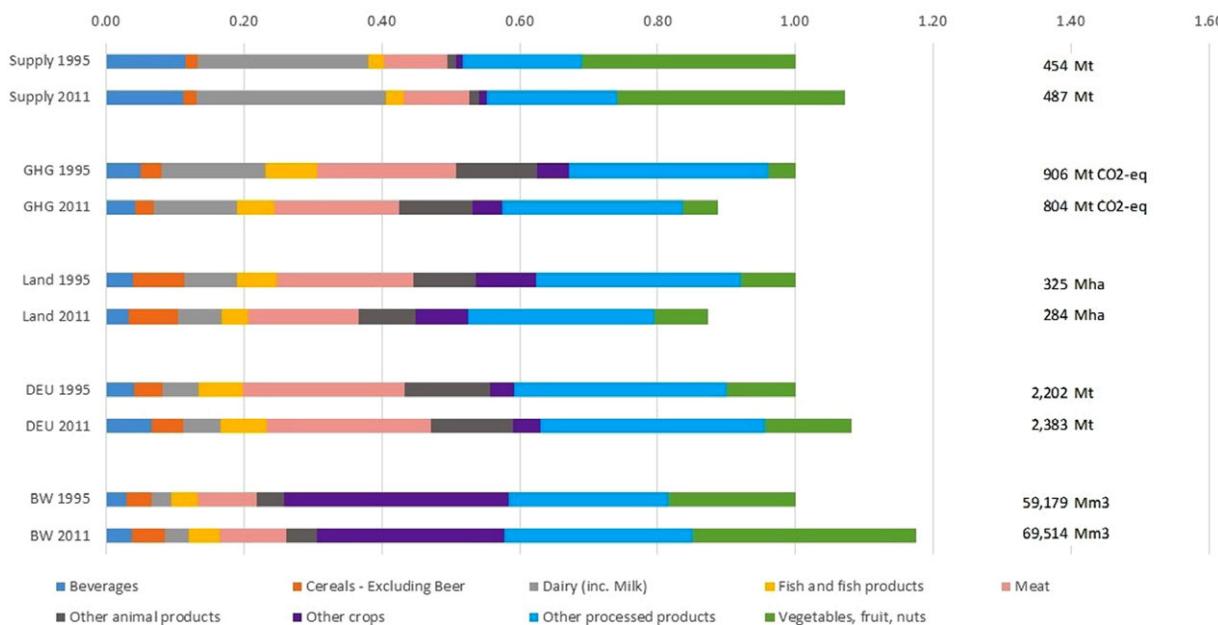


Figure 1 Trends in food supply and environmental footprints in EU28, 1995 and 2011.

Note: BW = blue water consumption; DEU = domestic extraction used; GHG = greenhouse gas; Mha = million hectares; Mm³ = million cubic meters; Mt = million tonnes; MtCO₂-eq = million tonnes of carbon dioxide equivalents. Source: FAO Food Balance Sheets (Supply) and own calculations using EXIOBASE v3.3 (Environmental footprint).

et al. 2013). For these reasons, we have opted for taking the waste fraction figures for the hospitality sector and for households from the Waste & Resources Action Program (WRAP) (2009, 2013b) due to the comprehensiveness of the studies. These data have been adapted to match the product classification used in this article as explained in the Supporting Information on the Web. Given that the values refer to the UK, the results should be interpreted carefully and taken only indicative of the extent of potential savings. This is also the main source for consumer food waste used by the Food and Agriculture Organization of the United Nations (FAO) for European countries (Gustavsson et al. 2013).

The potential savings (m_{sav}) is the result of multiplying the total footprint by total avoidable and possibly avoidable food waste. The latter is the sum of the waste fraction of bulk consumers (w_z) multiplied by the share of bulk food consumption over the total food consumption plus the waste fraction of final consumers (w_y) multiplied by the share of final food consumption over the total food consumption. All these parameters take the form of vectors in which the rows match the product classification used in the MRIO model (equation 7).

$$m_{sav} = m_F \left(w_z * \frac{z_F}{z_F + y_F} + w_y * \frac{y_F}{z_F + y_F} \right) \quad (7)$$

Results

Between 1995 and 2011, the amount of food provided for domestic consumption in the EU28 has grown by 7% (figure 1). Supply is dominated by vegetables and fruits, milk

and dairy products, followed by other processed products such as bread and pasta, beverages, and meat products. Although there have been no major changes in the broad demand structure, there have been shifts within the aggregated product groups. For instance, over the last two decades, pork products still represent around half of meat consumption, but there seems to be a shift from cattle toward poultry products. Similar shifting consumer preferences relate to fruits where oranges and other citrus fruits are gaining market shares from apples and bananas. There are also shifts among vegetable oils where olive and palm oils have increased their relevance at the expense of sunflower seed oil.

The environmental intensity of food consumption is very diverse. Meat products, other animal products, and other processed products have a much higher contribution to the EU28's footprint in relation to their mass. At the opposite end of the spectrum, vegetables, dairy products, and beverages rank much lower in environmental intensity. In absolute terms, the environmental footprints of the EU28 related to GHG emissions and land use have dropped by 11% and 13%, respectively, between 1995 and 2011. In contrast, the material (DEU) and blue water foodprint have risen by 8% and 17%.

From the production perspective, domestic GHG emissions, land use, and material extraction related to the food system have decreased 18%, 11%, and 2%, respectively, between 1995 and 2011. In contrast, domestic blue water consumption has experienced a small increase (9%) in the same period (figure S1 in the supporting information on the Web).

The absolute domestic pressures and the environmental footprints of all environmental pressure categories shows that

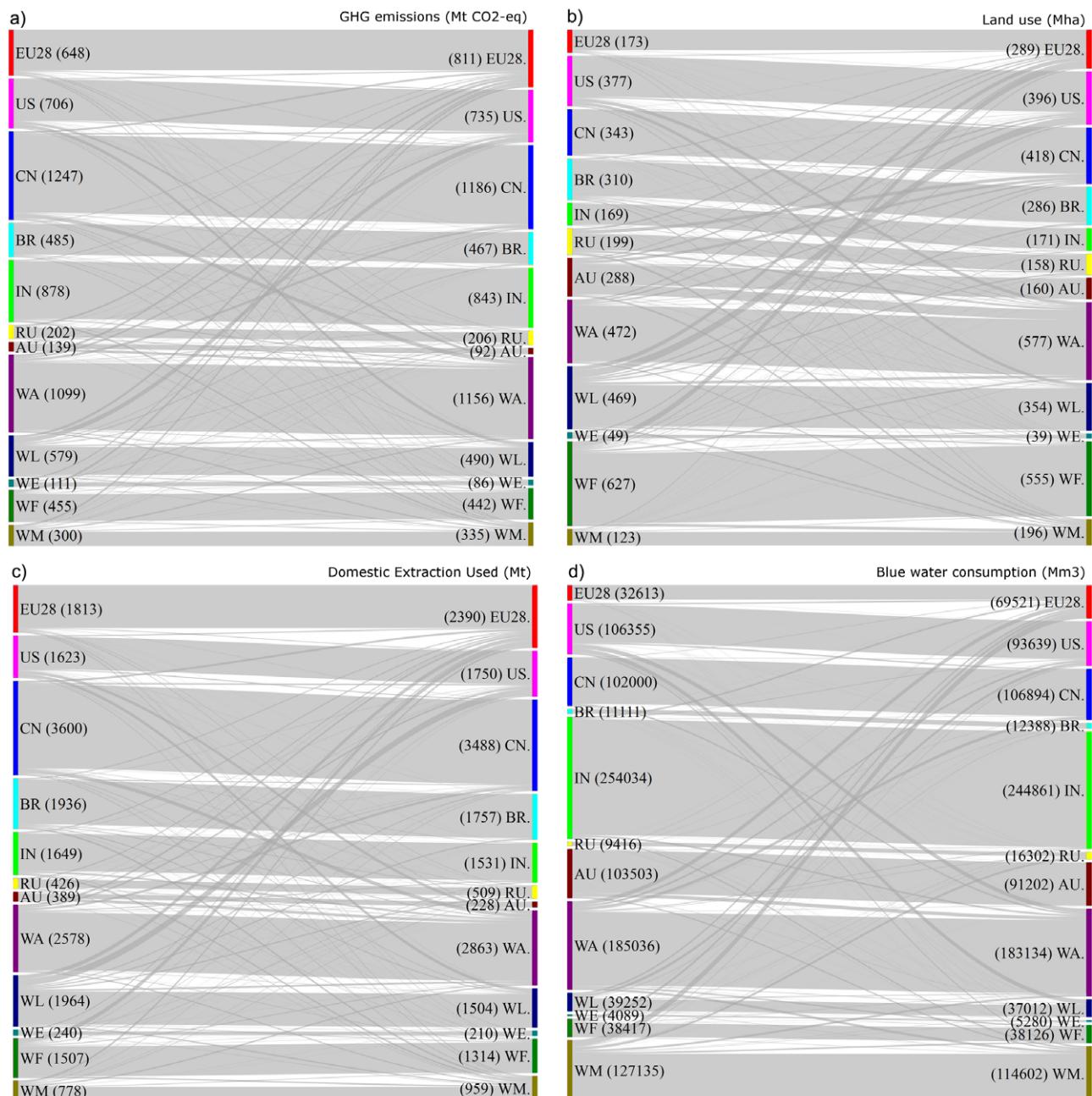


Figure 2 Origin and destination of environmental pressures related to food, 2011: (a) GHG emissions; (b) land use; (c) domestic extraction used; (d) blue water consumption.

Note: EU28 = European Union 28 Member States; US = United States; WA = Rest of the world Asia and Pacific; WL = Rest of the world America; WE = Rest of the world Europe; WF = Rest of the world Africa; WM = Rest of the world Middle East. Source: own calculations using EXIOBASE v3.3. GHG = greenhouse gas; Mha = million hectares; Mm³ = million cubic meters; Mt = million tonnes; MtCO₂-eq = million tonnes of carbon dioxide equivalents.

the EU28 is a net exporter of pressures (figure 2). The ratio of consumption-based against production-based pressures is higher in the case of blue water consumption (2.13) and lower for GHG emissions (1.25). Depending on the pressure category there are different regions affected. When looking at net pressures shifted elsewhere by the EU28, the Asia and Pacific region—excluding the Middle East—ranks first in GHG emission and blue

water consumption. America appears first in land and materials. Africa also ranks high in terms of land and materials, while imports from the Middle East embody high quantities of water. Environmental pressures shifted to other European countries are relatively small compared to the other world regions.

Given the magnitude of the environmental pressures of the European food system, measures to improve the efficiency of

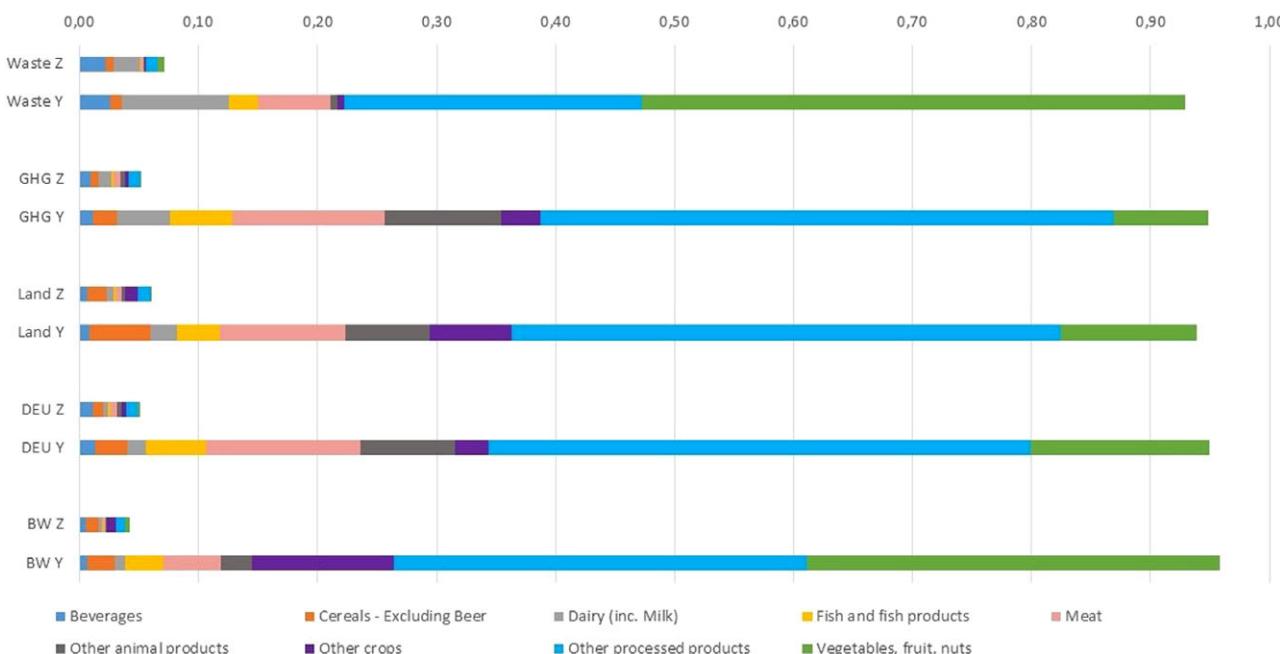


Figure 3 Composition of avoidable and possibly avoidable consumer food waste and related environmental pressures, 2011.

Note: The Z suffix in the legend refers to bulk consumers (food-related services), while the Y suffix to final consumers (mainly households). BW = blue water consumption; DEU = domestic extraction used; GHG = greenhouse gas. Source: own calculations using EXIOBASE v3.3 and WRAP (2009, 2013b).

the value chain, including the reduction of waste, offers a huge potential to reduce environmental pressures. Theoretically, around 20% of the European environmental footprint could be reduced by completely eliminating avoidable and possibly avoidable consumer food waste (figure S2 in the supporting information on the Web). Relative to the total footprint, the potential savings range between 3% for GHG emissions and 15% for blue water consumption. According to our estimates, more than 90% of the potential environmental benefits are attributable to eliminating the fraction of household food waste that has been edible at some point as shown in figure 3.

Regarding the contribution of individual product groups, figure 4 shows the hotspots of avoidable and possibly avoidable consumer food waste. For different product groups, the Y axis indicates the potential savings that could be obtained by reducing household food waste to zero. The environmental pressure differs depending on the environmental pressure category as shown in figure 4. For readability, the points in figure 4 represent a mean value of all four environmental pressure categories to give an overall impression of the environmental relevance. The X axis shows the fraction of food wasted. Other processed products offer considerable opportunities to reduce the pressures associated with consumer food waste. This category comprises, among others, wheat-based products, such as bread, pastries, or cakes, that are thrown away when not consumed shortly after having been baked. Thus, this type of product is not only thrown away in high proportions by consumers and vendors alike, but, at the same time, also represents the products whose contribution to total food waste is highest. Vegetables and fruits

rank second in relevance. In this case, more than one quarter of the acquired product is discarded. This waste fraction represents more than one third of the potential savings in freshwater consumption and more than 10% in material and land use. Waste of meat products is also relevant mainly due to its high environmental pressure-to-mass ratio. GHG emissions, the use of (pasture) land, and materials are the main environmental categories that would benefit from decreasing the fraction of this product (see figure S3-6 in the supporting information on the Web for more details).

At least in the short- to mid-term perspective, a complete reduction of avoidable and possibly avoidable consumer food waste seems unattainable. For this reason, we focus on the potential gains from achieving the food waste reduction target formulated in the Resource Efficiency Roadmap, which calls for halving the disposal of edible food waste by 2020. As explained earlier, we only consider consumer food waste. In the absence of reasonable projections for 2020, we use 2011 data to give an indication of the magnitude of the potential yearly benefits. The blue bars in figure 5 indicate the scale of the savings (as percentage of the EU28 footprint) if the EU would succeed in cutting the waste of each of the foodstuffs by 50%. The orange bars represent the same savings, but as percentage of the EU28's total environmental footprint instead of only the footprint. The error bars in the figure indicate the variability of the environmental savings. The upper end of the bar shows the potential benefits of achieving the target of halving food waste by addressing the most environmentally intensive products first (i.e., those that have high pressure-to-mass ratios), while the

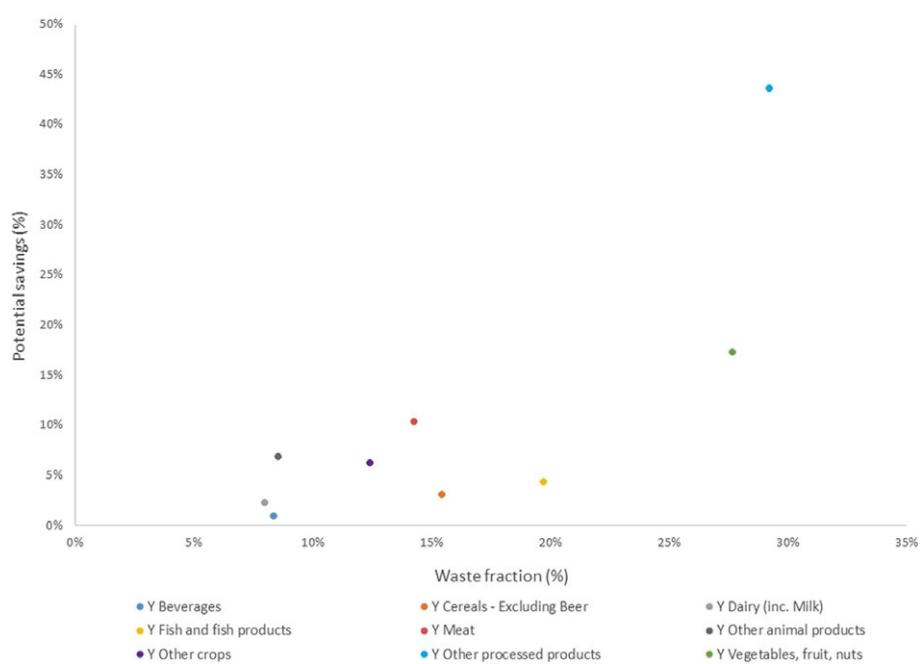


Figure 4 Environmental relevance and fraction of avoidable and possibly avoidable food wasted by households per product type, 2011.
 Note: The Y prefix in the legend refers to final consumers (mainly households). Source: own calculations using EXIOBASE v3.3 and WRAP (2009, 2013b).

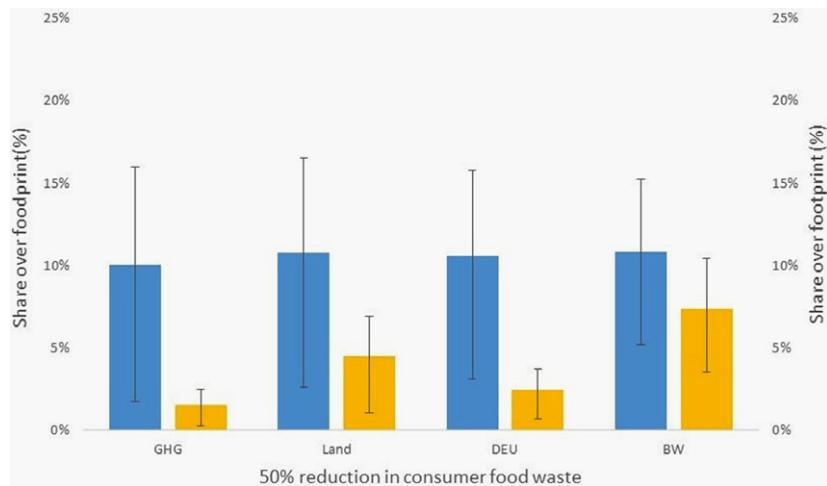


Figure 5 Potential yearly environmental savings from halving avoidable and possibly avoidable consumer food waste quantity, 2011.
 Note: the blue bars show the potential savings as percentage of the EU28's footprint, while the orange bars take the footprint as reference. The error bars indicate the variability of the savings depending on which product's waste is reduced to reach the target. BW = blue water consumption; DEU = domestic extraction used; GHG = greenhouse gas. Source: own calculations using EXIOBASE v3.3 and WRAP (2009, 2013b).

lower part of the bar indicates the benefits of halving avoidable and possibly avoidable food waste by focusing on the least intensive products first.

Discussion

This article has associated the food consumed by Europeans with considerable environmental pressures across different

pressure categories both in the domestic territory as well as abroad. Our results show that European food consumption increases GHG emissions and material use primarily in Asia and the Pacific region. It contributes to the scarcity of blue water mainly in the Middle East. Primarily in America and Africa, European food consumption has an impact on land use. Although not addressed here, the direct and indirect environmental consequences associated with the food system go beyond these areas

and include biodiversity loss mainly as a result of land use and land-use changes (Newbold et al. 2015), soil erosion (Verheijen et al. 2009), and many other (UNEP 2016). The trade-induced shift of environmental pressures also has major social and political impacts, for example, the export of blue water from the Middle East into the EU contributes to social tension and political instability of the region (Kliot 1994). Likewise, using land for African exports to Europe can get in conflict with the local food production.

At the same time, the food system is highly inefficient, for a lot of edible food is lost along the value chain. The problem is likely to increase in the coming years unless political measures are adopted (EC 2014b).

According to our estimates, consumers throw away almost one fifth of the edible food they acquire (i.e., excluding bones, egg shells, and the like), which represents between 3% and 15% of the EU28's footprint depending on the environmental pressure category. In our analysis, we find that reducing the waste of meat products could have relevant environmental benefits due to its environmental intensity per mass unit, while other processed products, such as bread, pasta, etc., and fruits and vegetables, would bring considerable benefits due to the quantities wasted. When looking at the actors involved, households account for more than 90% of the potential savings.

Although the magnitude of the potential environmental benefits and the potential positive social and geopolitical impacts should sufficiently justify ambitious food waste prevention policies, so far, only a handful of EU Member States have implemented targeted food waste prevention initiatives. Most of these strategies either lack quantifiable results or they are on such a small scale that no significant impacts can be expected at the macro level (EC 2014b). So far, the EC is acting as an enabling agent that supports the Member States (EC 2014b), for example, by contributing to the establishment of a common methodology to quantify food waste (EC 2015). Nonetheless, the EC has not yet adopted the food waste prevention strategy promised in the latest Environmental Action Plan (EC 2014a). From an economic point of view, food waste reductions could yield net monetary gains, since the cost of prevention would be outweighed by the savings in waste management and environmental externalities (EC 2014b). How these gains are reinvested in the economy could also have relevant environmental implications if they lead to a rebound effect (Salemdeeb et al. 2017).

Only a few Member States have adopted quantitative food waste reduction targets, all of which are nonbinding (EC 2014b). At the EU level, the commitment to meet the reduction target from the Sustainable Development Goals by 2030, and the aspirational goals of the Resource Efficiency Roadmap (reducing the resource inputs in the food chain by 20% and halving the disposal of edible food waste by 2020) still stand. As shown in this paper, halving avoidable and possibly avoidable consumer food waste would result in a 2% to 7% yearly reduction of the environmental footprint of the EU28, depending on the pressure category. At the same time, meeting the 50% reduction target for avoidable and possibly avoidable

consumer food waste would lead to an 11% decrease in land, material, and blue water inputs along the food and drinks value chain, thereby contributing strongly toward the second target of the Resource Efficiency Roadmap (reduction of resource inputs by 20%). The reduction potential depends on the food product-specific environmental pressure, which can vary considerably. Thus, the composition of the food waste avoided will determine the extent to which environmental pressures are reduced.

The results we present here provide an overview on the system that delivers the food consumed by Europeans and the level of inefficiency of that system in terms of food waste by consumers. In this vein, the MRIO model used seems to be accurate enough to show major trends, although the results at the individual product level are more uncertain (Stadler et al. this issue). The results are also influenced by the inherent limitations of monetary MRIO models, for example, relatively low-resolution compared to life cycle assessment databases. Likewise, the homogeneous price assumption can lead to misallocation of environmental pressures between the final consumption of countries with different prices for the same food commodities. When it comes to food acquisition data, differences between EXIOBASE and Food Balance Sheets are to be expected, not least because in the latter the amount of food available for human consumption is commonly calculated as a residual of the other components of the domestic supply. Although the effects at the macro level do not seem to be very relevant, important yearly changes are sometimes visible at the product level. In this context, it should be highlighted the disagreement between the Food Balance Sheets and other data sources on food consumption. This issue has been documented by several authors (Rodrigues et al. 2007; Vandevijvere et al. 2013). The hybridization of life cycle and I-O databases could be used to provide more accurate results at the product level. Such a combination of methods could also be used to include the waste management stages of food, which are allocated to the waste sector in I-O models and omitted from this assessment.

The uncertainty at the product level increases due to the different classifications in the databases used, which limits the accuracy of bridge tables used to reconcile data from different sources. For instance, sugars and sweeteners, vegetable oils, and wheat products are an important energy source in the European diet. While these are represented in individual groups in the Food Balance Sheets and EXIOBASE, this is not the case for studies addressing consumer food waste. In the latter case, an important share of sugars and sweeteners is embodied in confectionery, juices and refreshments, bakery products, dairy products, etc. Likewise, part of vegetable oils remains in fried food products. Further, wheat products, such as bread, pastries, pasta, or wheat-based cereals, are included in the same aggregated category in the Food Balance Sheets, which makes it difficult to assign waste factors to each of these items. The same applies to plate scraps reported in food waste studies, which do not have a one-to-one equivalent in the other classifications.

It should also be noted that the food waste factors used refer to the UK and will hence most likely differ in other EU countries. This also adds uncertainty to the results. Therefore, they only indicate the scale of the environmental problems and potential benefits of appropriate policies in the EU28. In absence of better food waste data, the FAO has also used UK data as a proxy for Europe (Gustavsson et al. 2013), which increases the acceptability of the assumption.

Conclusions

In this paper, we have quantified the environmental pressures in four categories (GHG emissions, land use, material use, and blue water consumption) associated with food consumption in the EU28 both from the production as well as from the consumption perspectives for the period 1995–2011. Likewise, we provide insights on the environmental savings that could be achieved by complying with the aspirational targets calling for halving (avoidable and possibly avoidable consumer) food waste by the end of this decade.

Our results support the need to speed up the adoption of measures to combat food waste in the EU28, especially focusing on household waste. The level of policy intervention since the EC flagged the problem in 2010 (Monier et al. 2010) is not sufficient to reverse trends both at the EU and Member State level. Considering the limited progress to this day and the expected evolution of food waste in the absence of additional measures (EC 2014b), there is no indication that the Resource Efficiency Roadmap's target of halving food waste by 2020 will become more than a political aspiration. Unless new targets are adopted as contemplated in the Commission's impact assessment (EC 2014b), the next milestone is defined by the Sustainable Development Goals (SDG) to reduce per-capita food waste generation by 50% by 2030. It remains to be seen whether the EU will rise to the challenge.

Against this background, we illustrated the use of the EXIOBASE database for characterizing the food system at the macro level from an environmental standpoint, and for quantifying a wide range of domestic and global environmental pressures and potential benefits arising from food waste reduction policies. The usefulness of this type of database for evidence-based policy making in the short- to mid-term perspective will depend on advances happening in both official institutions and the research community. Regarding the former, an institutionalization process is already taking place to some extent. In this line, Eurostat is generating MRIO tables for EU28 countries and the Organization for Economic Cooperation and Development (OECD) produced a global MRIO model. Yet, the low resolution of official databases is still a limiting factor. Likewise, more resources are needed for the compilation of comparable food waste statistics. The manual recently published by the FUSIONS project (Tostivint et al. 2016) and the ongoing efforts at Eurostat are encouraging steps in the right direction. In the research community, collaborative virtual laboratories (e.g., Lenzen et al. 2014) promise a highly automated and flexible process to build and enhance the geographical and product

resolution of MRIO tables, potentially extending the amount of policy-relevant research questions that can be addressed with this type of databases.

Acknowledgments

A previous version of this paper was presented at the 5th permanent workshop of the Hispanic-American Input-Output Society (SHAIO) (Bilbao, 29–30.09.2016). We thank two anonymous reviewers for insightful comments on the paper.

Funding Information

The research presented in this article was funded by the European Commission under the FP7 project DESIRE (Developing a System of Indicators for a Resource Efficient Europe).

References

Audsley, E., M. Brander, J. Chatterton, D. Murphy-Bokern, C. Webster, and A. Williams. 2009. *How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050*. Surrey, UK: W. W. Fund-UK.

Auestad, N. and V. L. Fulgoni, 3rd. 2015. What current literature tells us about sustainable diets: Emerging research linking dietary patterns, environmental sustainability, and economics. *Advances in Nutrition* 6(1): 19–36.

Baptista, P., I. Campos, I. Pires, and S. G. Vaz. 2012. *Do Campo ao Garfo. Desperdício Alimentar em Portugal* [From Field to Fork. Food Waste in Portugal]. Lisbon: CESTRAS.

Baroni, L., L. Cenci, M. Tettamanti, and M. Berati. 2007. Evaluating the environmental impact of various dietary patterns combined with different food production systems. *European Journal of Clinical Nutrition* 61(2): 279–286.

Bernstad, A. and T. Andersson. 2015. Food waste minimization from a life-cycle perspective. *Journal of Environmental Management* 147: 219–226.

Brautigam, K. R., J. Jorissen, and C. Priefer. 2014. The extent of food waste generation across EU-27: Different calculation methods and the reliability of their results. *Waste Management & Research* 32(8): 683–694.

Chapagain, A. and K. James. 2011. *The water and carbon footprint of household food and drink waste in the UK*. Banbury, UK: Waste & Resources Action Programme and World Wildlife Fund-UK.

EC (European Commission). 2011. *Roadmap to a Resource Efficient Europe*. COM(2011) 571 final. Brussels: European Commission.

EC (European Commission). 2014a. *General Union Environment Action Programme to 2020: Living well, within the limits of our planet*. Brussels: European Commission.

EC (European Commission). 2014b. *Impact Assessment on Measures Addressing Food Waste to Complete SWD (2014) 207 regarding the Review of EU Waste Management Targets*. Brussels: European Commission.

EC (European Commission). 2015. *Closing the loop—An EU action plan for the Circular Economy*. COM(2015) 614 final. Brussels: European Commission.

FAO (Food and Agriculture Organization of the United Nations). 2014. *Food and Nutrition in Numbers 2014*. Rome: Food and Agriculture Organization of the United Nations.

Foster, C., K. Green, M. Bleda, P. Dewick, B. Evans, A. Flynn, and J. Mylan. 2006. *Environmental impacts of food production and consumption*. London: Department for Environment, Food and Rural Affairs.

Gentil, E. C., D. Gallo, and T. H. Christensen. 2011. Environmental evaluation of municipal waste prevention. *Waste Management* 31(12): 2371–2379.

Gustavsson, J., C. Cederberg, U. Sonesson, and A. Emanuelsson. 2013. The methodology of the FAO study: “Global Food Losses and Food Waste—Extent, causes and prevention”—FAO, 2011. No. 857. Göteborg, Sweden: S. I. f. F. a. Biotechnology. SIK report.

Gustavsson, J., C. Cederberg, U. Sonesson, R. V. Otterdijk, and A. Meybeck. 2011. *Global food losses and food waste—Extent, causes and prevention*. Rome: Food and Agriculture Organization of the United Nations.

Hafner, G., J. Barabosz, F. Schneider, S. Lebersorger, S. Scherhauer, H. Schuller, and D. Leverenz. 2012. *Ermittlung der weggeworfenen Lebensmittelmengen und Vorschläge zur Verminderung der Wegwerf率 bei Lebensmitteln in Deutschland-Kurzfassung* [Determination of discarded food and proposals for a minimization of food wastage in Germany]. Stuttgart, Germany: Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz.

Hanssen, O. J., Å. Stenmarck, P. Dekhtyar, C. O'Connor, and K. Östergren. 2013. Review of EUROSTAT's reporting method and statistics. Fredrikstad, Norway: FUSIONS project.

HISPACOOP. 2012. Estudio sobre el desperdicio de alimentos en los hogares [Study on food waste in households]. Madrid: Confederación Española de Cooperativas de Consumidores y Usuarios.

Jungbluth, N., O. Tierje, and R. W. Scholz. 2000. Food purchases: Impacts from the consumers' point of view investigated with a modular LCA. *The International Journal of Life Cycle Assessment* 5(3): 134–142.

Jungbluth, N., M. Stucki, and M. Leuenberger. 2011. *Environmental impacts of Swiss consumption and production. A combination of input-output analysis with life cycle assessment*. Bern, Switzerland: Federal Office for the Environment.

Kliot, N. 1994. *Water resources and conflict in the Middle East*. London; New York: Routledge.

Lenzen, M., A. Geschke, T. Wiedmann, J. Lane, N. Anderson, T. Baynes, J. Boland, et al. 2014. Compiling and using input-output frameworks through collaborative virtual laboratories. *Science of the Total Environment* 485–486: 241–251.

Lukas, M., H. Rohn, M. Lettenmeier, C. Liedtke, and K. Wiesen. 2015. The nutritional footprint—Integrated methodology using environmental and health indicators to indicate potential for absolute reduction of natural resource use in the field of food and nutrition. *Journal of Cleaner Production* 132: 161–170.

Marlow, H. J., W. K. Hayes, S. Soret, R. L. Carter, E. R. Schwab, and J. Sabaté. 2009. Diet and the environment: Does what you eat matter? *The American Journal of Clinical Nutrition* 89(5): 1699S–1703S.

Matsuda, T., J. Yano, Y. Hirai, and S.-I. Sakai. 2012. Life-cycle greenhouse gas inventory analysis of household waste management and food waste reduction activities in Kyoto, Japan. *The International Journal of Life Cycle Assessment* 17(6): 743–752.

Max-Neef, M. 1992. Development and human needs. In *Real-life economics: Understanding wealth creation*, edited by P. Ekins and M. Max-Neef. London; New York: Routledge.

Miller, R. E. and P. D. Blair. 2009. Input-output analysis: Foundations and extensions. Cambridge, UK: Cambridge University Press.

Monier, V., S. Mudgal, V. Escalon, C. O'Connor, T. Gibon, G. Anderson, H. Montoux, et al. 2010. *Preparatory Study on Food Waste across EU-27*. Final report to the European Commission's DG Environment. Paris: BIO Intelligence Service.

Newbold, T., L. N. Hudson, S. L. L. Hill, S. Contu, I. Lysenko, R. A. Senior, L. Borger, et al. 2015. Global effects of land use on local terrestrial biodiversity. *Nature* 520(7545): 45–50.

Parfitt, J., M. Barthel, and S. Macnaughton. 2010. Food waste within food supply chains: Quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 365(1554): 3065–3081.

Reutter, B., P. Lant, C. Reynolds, and J. Lane. 2017. Food waste consequences: Environmentally extended input-output as a framework for analysis. *Journal of Cleaner Production* 153: 506–514.

Reynolds, C., M. Mirosa, and B. Clothier. 2016a. New Zealand's food waste: Estimating the tonnes, value, calories and resources wasted. *Agriculture* 6(1): 9.

Reynolds, C., A. Geschke, J. Piantadosi, and J. Boland. 2016b. Estimating industrial solid waste and municipal solid waste data at high resolution using economic accounts: An input-output approach with Australian case study. *Journal of Material Cycles and Waste Management* 18(4): 677–686.

Reynolds, C., J. Piantadosi, J. D. Buckley, P. Weinstein, and J. Boland. 2015. Evaluation of the environmental impact of weekly food consumption in different socio-economic households in Australia using environmentally extended input-output analysis. *Ecological Economics* 111: 58–64.

Rodrigues, S. S. P., C. Lopes, A. Naska, A. Trichopoulou, and M. D. V. de Almeida. 2007. Comparison of national food supply, household food availability and individual food consumption data in Portugal. *Journal of Public Health* 15(6): 447.

Salemdeeb, R., D. Font Vivanco, A. Al-Tabbaa, and E. K. H. J. zu Ermgassen. 2017. A holistic approach to the environmental evaluation of food waste prevention. *Waste Management* 59: 442–450.

Schmidt, J. H. and S. Merciai. 2014. Life cycle assessment of the global food consumption. In Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8–10 October, San Francisco, CA, USA.

Silvennoinen, K., J.-M. Katajajuuri, H. Hartikainen, L. Heikkilä, and A. Reinikainen. 2014. Food waste volume and composition in Finnish households. *British Food Journal* 116(6): 1058–1068.

Stadler, K., R. Wood, T. Bulavskaya, C.-J. Södersten, M. Simas, S. Schmidt, A. Usobiaga, et al. Forthcoming. Developing a time series of detailed environmentally extended multi-regional input-output tables. *Journal of Industrial Ecology*.

Tatlıdil, F. F., İ. Dellal, and Z. Bayramoğlu. 2013. *Food losses and waste in Turkey*. Rome: Food and Agriculture Organization of the United Nations.

Tostivint, C., K. Östergren, T. Quested, H. Soethoudt, Å. Stenmarck, E. Svanæs, and C. O'Connor. 2016. Food waste quantification manual to monitor food waste amounts and progression. D1.7. Fredrikstad, Norway: FUSIONS project.

Tukker, A. and B. Jansen. 2006. Environmental impacts of products: A detailed review of studies. *Journal of Industrial Ecology* 10(3): 159–182.

Tukker, A., R. A. Goldbohm, A. de Koning, M. Verheijden, R. Kleijn, O. Wolf, I. Pérez-Domínguez, and J. M. Rueda-Cantuche. 2011. Environmental impacts of changes to healthier diets in Europe. *Ecological Economics* 70(10): 1776–1788.

UN (United Nations). 2015. Transforming our world: The 2030 Agenda for Sustainable Development United Nations General Assembly. Resolution adopted by the General Assembly. New York: United Nations.

UNEP (United Nations Environment Program). 2016. *Food Systems and Natural Resources*. A Report of the Working Group on Food Systems of the International Resource Panel. Westhoek, H, Ingram J., Van Berkum, S., Özay, L., and Hager M. Nairobi, Kenya: United Nations Environment Program.

Vandevijvere, S., C. Monteiro, S. M. Krebs-Smith, A. Lee, B. Swinburn, B. Kelly, B. Neal, W. Snowdon, G. Sacks, and Informas. 2013. Monitoring and benchmarking population diet quality globally: A step-wise approach. *Obesity Reviews* 14(s1): 135–149.

Vanham, D., A. Y. Hoekstra, and G. Bidoglio. 2013. Potential water saving through changes in European diets. *Environment International* 61: 45–56.

Vanham, D., F. Bouraoui, A. Leip, B. Grizzetti, and G. Bidoglio. 2015. Lost water and nitrogen resources due to EU consumer food waste. *Environmental Research Letters* 10(8): 084008.

Venkat, K. 2011. The climate change and economic impacts of food waste in the United States. *The International Journal on Food System Dynamics* 2(4): 431–446.

Verheijen, F. G. A., R. J. A. Jones, R. J. Rickson, and C. J. Smith. 2009. Tolerable versus actual soil erosion rates in Europe. *Earth-Science Reviews* 94(1–4): 23–38.

Virtanen, Y., S. Kurppa, M. Saarinen, J.-M. Katajajuuri, K. Usva, I. Mäenpää, J. Mäkelä, J. Grönroos, and A. Nissinen. 2011. Carbon footprint of food—Approaches from national input-output statistics and a LCA of a food portion. *Journal of Cleaner Production* 19(16): 1849–1856.

Wolf, O., I. Pérez-Domínguez, J. M. Rueda-Cantuche, A. Tukker, R. Kleijn, A. de Koning, S. Bausch-Goldbohm, and M. Verheijden. 2011. Do healthy diets in Europe matter to the environment? A quantitative analysis. *Journal of Policy Modeling* 33(1): 8–28.

WRAP (Waste & Resources Action Program). 2009. *Household food and drink waste in the UK*. Banbury, UK: Waste & Resources Action Program.

WRAP (Waste & Resources Action Program). 2013a. *Household food and drink waste in the United Kingdom 2012*. Banbury, UK: Waste & Resources Action Program.

WRAP (Waste & Resources Action Program). 2013b. *Waste in the UK hospitality and food service sector—Full technical report*. Banbury, UK: Waste & Resources Action Program.

Supporting Information

Supporting information is linked to this article on the *JIE* website:

Supporting Information S1: This supporting information includes a table showing correspondence between the products in the Food Balance Sheets, EXIOBASE and the grouping used in this article; and a table showing correspondence between food-related services and other services, and EXIOBASE products. It also includes information about processing food waste data in food-related services and final consumers. Last, it includes additional results information.