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176. Combined Nutritional and Environmental Life Cycle Assessment of Fruits and Vegetables

Katerina Stylianou[1,*], Peter Fantke[2], Olivier Jolliet[1]
[1] Environmental Health Sciences, School of Public Health, University of Michigan, Ann Arbor, MI, USA
[2] Quantitative Sustainability Assessment Division, Technical University of Denmark, Kgs. Lyngby, DK
[*] Corresponding author: Email: *kstylian@umich.edu*

ABSTRACT

Nutritional health effects from the 'use stage' of the life cycle of food products can be substantial, especially for fruits and vegetables. To assess potential one-serving increases in fruit and vegetable consumption in Europe, we employ the Combined Nutritional and Environmental LCA (CONE-LCA) framework that compares environmental and nutritional effects of foods in a common end-point metric, Disability Adjusted Life Years (DALY). In the assessment, environmental health impact categories include greenhouse gases, particulate matter (PM), and pesticide residues on fruits and vegetables, while for nutrition we consider all health outcomes associated with fruit and vegetable consumption based on epidemiological studies from the global burden of disease (GBD). Findings suggest that one fruit/vegetable serving increase may lead to substantial nutritional health benefits even when considering uncertainty; 35 µDALY/serving$_{fruit}$ benefit compared to a factor 10 lower impact. Replacing detrimental foods, such as trans-fat and red meat, with fruits or vegetables further enhances health benefit. This study illustrates the importance of considering nutritional effects in food-LCA.

Keywords: LCA, fruits, vegetables, nutrition, human health

1. Introduction

Dietary risks are leading the global burden of disease (GBD) with about 12 million annual attributable deaths globally, illustrating the strong relationship between dietary patterns and human health (IHME, 2015). Diet- and food-related life cycle assessments (LCA), up to date, mainly focus on human health impacts associated with environmental emissions. The 'use stage' of food products, although part of a product's life cycle, does not typically consider nutritional effects that occur with consumption and can have substantial effects, positive and/or negative, on human health (Stylianou et al. 2016). Incorporating a nutritional assessment in diet- and food-related LCA would provide a comprehensive and comparable human health effect evaluation of food items and diets that could yield more sustainable dietary decisions.

The nutritional value and beneficial human health effects associated with fruits and vegetables consumption is widely recognized and evident by numerous recommendations urging consumers to increase their fruit and vegetable daily intake (USDHHS and USDA 2015; Nordic Council 2014). However, current conventional fruit and vegetable production methods require the application of pesticides which yields residues that have the potential of inducing human health impacts, a continuous concern requiring a constant monitoring and evaluation. As a result, increased consumption of fruits and vegetables – although considered as a healthier dietary option – could result in higher exposures to a wide variety of pesticides, alongside other environmental heath related impacts associated with corresponding increase in production and distribution. The aim of this study is to assess the overall human health trade-offs between potential environmental and nutritional effects associated with one serving increase of fruits (141 g) and one serving increase of vegetables (123 g) over the average European consumption.

2. Methods

2.1. Framework for comparing environmental and nutritional effects of food

The Combined Nutritional and Environmental Life Cycle Assessment (CONE-LCA) framework evaluates and compares in conjunction environmental and nutritional effects of food items or diets expressed in a common end-point metric, Disability Adjusted Life Years (DALYs) (Stylianou et al. 2016). In this case study, the assessment starts from one serving of fruits and one serving of vegetables as a functional unit (FU) that are associates with environmental health impacts due to life cycle emissions of e.g. greenhouse gases (GHG) and particulate matter (PM) as well as chemical intake from pesticide residues on vegetal food. Nutritional impacts and benefits are assessed in parallel based on published epidemiology data that directly link fruit and vegetable consumption to nutritional health outcomes such as cardiovascular diseases and neoplasms, starting from the GBD. Figure 1 illustrates the general CONE-LCA framework along with the framework used in the case study investigated in this paper (represented in the red dashed box).

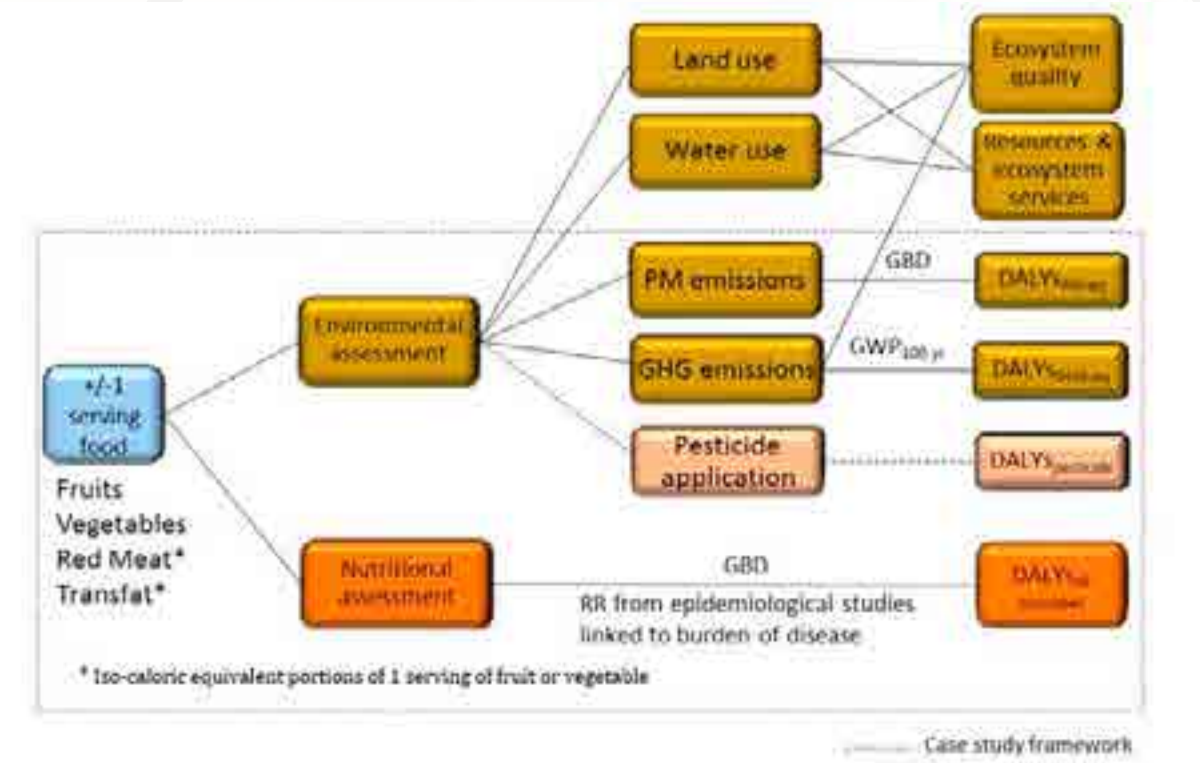

Figure 1. Graphical representation of the CONE-LCA framework. The dashed box denotes the scope of the presented case study

2.2. Case study: fruits and vegetables consumption in Europe

2.2.1. Dietary scenarios

The European Food Safety Authority (EFSA) Comprehensive European Food Consumption Database (EFSA, 2015) reports the average adult European diet. According to the latest data the current population-weighted European daily diet is consisted on average from 195 g of total fruits (fresh and processed) and 218 g of total vegetables (fresh and processed). These intakes correspond to a 1.2 and 1.8 servings of fruits and vegetables daily intake, respectively, which are below the dietary recommendation guidelines (USDHHS and USDA 2015; Nordic Council 2014).

To assess a potential dietary shift towards dietary guidelines, we investigate the case of one serving increase of fruits (141 g) and one serving increase of vegetables (123 g) over the average European consumption and evaluate the corresponding health effects. To consider for more realistic dietary scenario assessment, in addition to the increase in fruit or vegetable consumption, we also evaluate two substitution scenarios based on a default iso-caloric equivalent basis as a first proxy of a) trans-fat and b) red meat, two high burden dietary risk factors in the GBD (IHME, 2015).

One serving of fruits or vegetables has a nutritional energy content of respectively 102 or 74 calories, respectively. Hence, we investigated the following per person daily dietary scenarios:

A. Add a serving of fruits (or vegetables), with no change to the rest of the diet.
B. Add a serving of fruits (or vegetables) while subtracting an equal caloric quantity of trans-fat.
C. Add a serving of fruits (or vegetables) while subtracting an equal caloric quantity of red meat.

2.2.2. Environmental assessment

The environmental assessment in our analysis follows a traditional LCA approach. Food group-specific emission factors for GHG and ammonia (NH_3) were retrieved from the work by Meier and Christen (2012), accounting for production, processing, packaging and transportation to retail. Other PM-related emission (primary $PM_{2.5}$, NO_x, SO_2) were extrapolated from GHG as described by Stylianou et al. (2016) since such information is not routinely reported in food LCA studies. Emissions are coupled with characterization factors (CF) to give human health impact in DALYs/FU. More specifically, CFs from Gronlund et al., (2015) and Bulle et al., (manuscript in preparation) were used for PM-related and a 100-year horizon global warming health impacts, respectively.

In regards to the pesticide residue exposure, human health impacts are determined based on the work by Fantke et al. (2012). Human health impacts have been quantified by crop class accounting for human exposure resulting from 133 pesticides applied in 24 European countries in 2003 and individual substances distinct environmental behavior and toxicity. Active ingredients found in pesticides were then associated to publically available consumption data. Adjusting for current European fruits and vegetables consumption (EFSA, 2015) and under a linear assumption, the human health impact estimate from pesticide residues on fruits and vegetables is 2.5×10^{-7} and 2.4×10^{-6} DALYs/year/person, respectively.

2.2.3. Nutritional assessment

For the nutritional assessment, there are numerous epidemiological studies investigating the association of fruit, vegetable, trans-fat, and red meat intake with various health outcomes. In our study, we focus on the various health outcomes considered in the GBD for each of these dietary risk factors. More specifically, cardiovascular diseases are the main health outcome associated with low fruit (86%), low vegetable (100%), and high trans-fat (100%) consumption while high red meat consumption is associated with diabetes (60%) and colorectal cancer (40%). We combine the total European burden reported by the GBD for each food group (IHME, 2015) with the corresponding current consumption (EFSA, 2015) to estimate the overall nutritional health effect, benefit or impact, per FU, accounting for the respective theoretical minimum risk intake (as defined by the GBD in the work by Forouzanfar et al., 2015).

3. Results

3.1. Environmental assessment: PM-related health impacts

Figure 1 illustrates the PM-related human health impact in μDALY/serving corresponding to the iso-caloric food portions. Our analysis indicates that one serving of fruits is linked to a total of 0.065 g PM2.5-eq, corresponding to a health impact of 0.08 μDALY, mainly due to NH3 (38%). The iso-caloric red meat equivalent is associated with substantially higher health impact (about 7 times), with NH3 as the main PM-precursor contributor at 85%. For the vegetable serving we estimate PM-related health impact of 0.03 μDALY/serving, again mainly attributable to NH3 emissions (40%). The iso-caloric red meat equivalent had 6.5 times higher impact than a serving vegetable. The PM-related health impacts for the trans-fat substitutions are considered negligible.

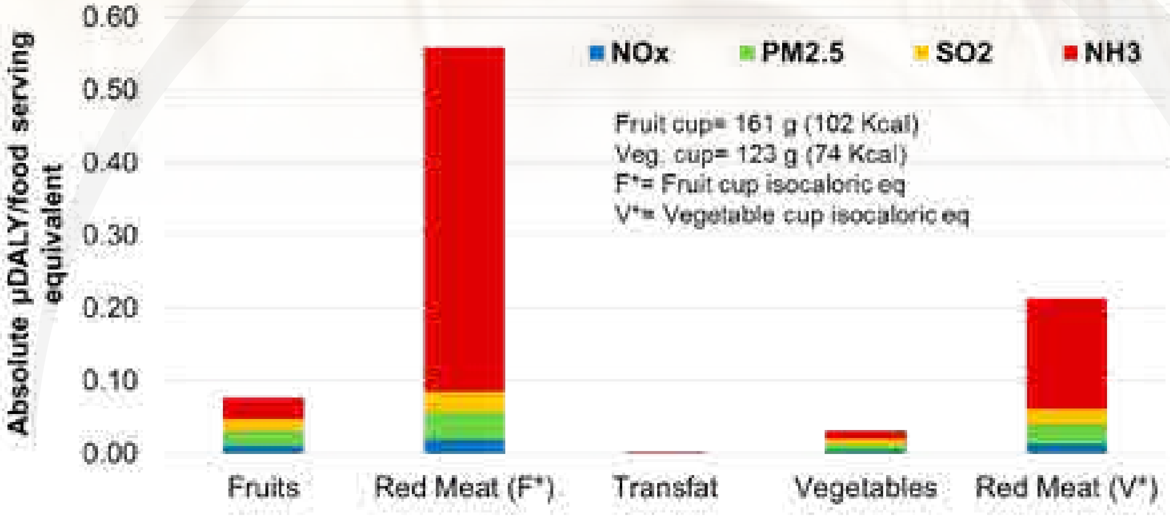

Figure 2. Particulate matter related human health impact measured in associated µDALY/serving with an iso-caloric equivalent portion of distinct food intakes: (1) fruits, (2) vegetables, (3) trans-fat, (4) red

3.2. Nutritional assessment

A linear dose–response relationship relates food intake, expressed in g/person/day to all cause outcomes impact in DALYs/person/day. We use such dose–response functions to estimate the nutritional health burden attributable to food intake shift from the current consumption. For fruit consumption, we found that one serving increase in intake over current consumption would results in a benefit of 34.7 µDALY (Figure 2). The analogous estimate for one additional serving of vegetable is a benefit of 17.2 µDALY. Using the same approach for the considered substitutions, the fruit (or vegetable) iso-caloric reduction in trans-fat and red meat portion is associated with reductions in health impacts of 0.5 (0.4) and 1.5 (1.1) µDALY, respectively.

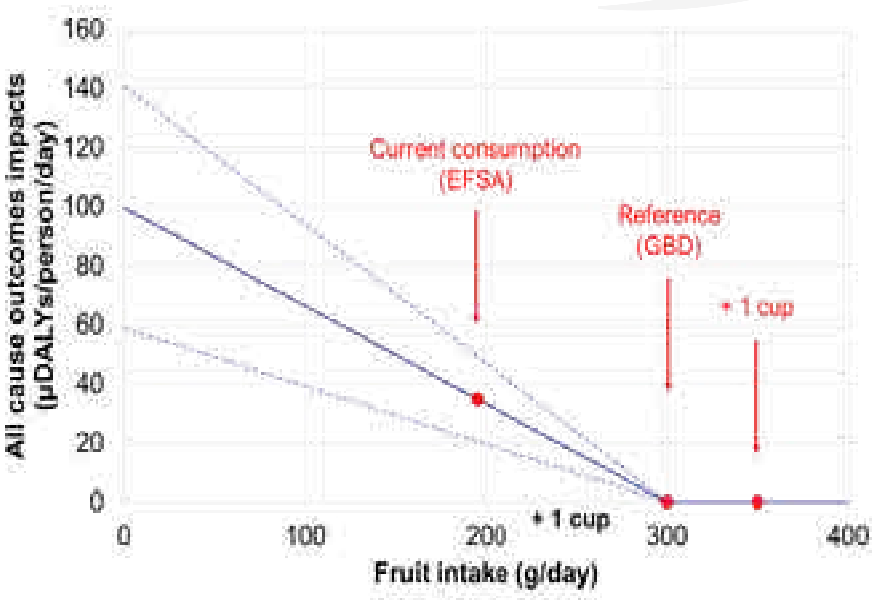

Figure 3. Dose–response function for fruit intake and all cause outcomes, with 95 % confidence intervals shown as dashed lines.

3.3. Overall comparison

Figure 3 represents the overall environmental and nutritional human health trade-offs associated with one serving of fruits without and with substitution scenarios. Adding one serving of fruits to the present European diet may lead to a considerable nutritional health benefits (35 μDALY/serving$_{fruit}$). The nutritional benefit is moderately enlarged when we consider the substitution scenarios since the substituted food items are associated with negative health effects and reduction in intake results in avoided human health impact. Overall environmental health impacts are substantially smaller, about an order of magnitude lower, compared to the nutritional benefits in each scenario. Benefits exceed impacts even when considering an uncertainty factor of 400 for the impacts of pesticide residues. Similar results are found for the case of adding one serving of vegetables to the average diet.

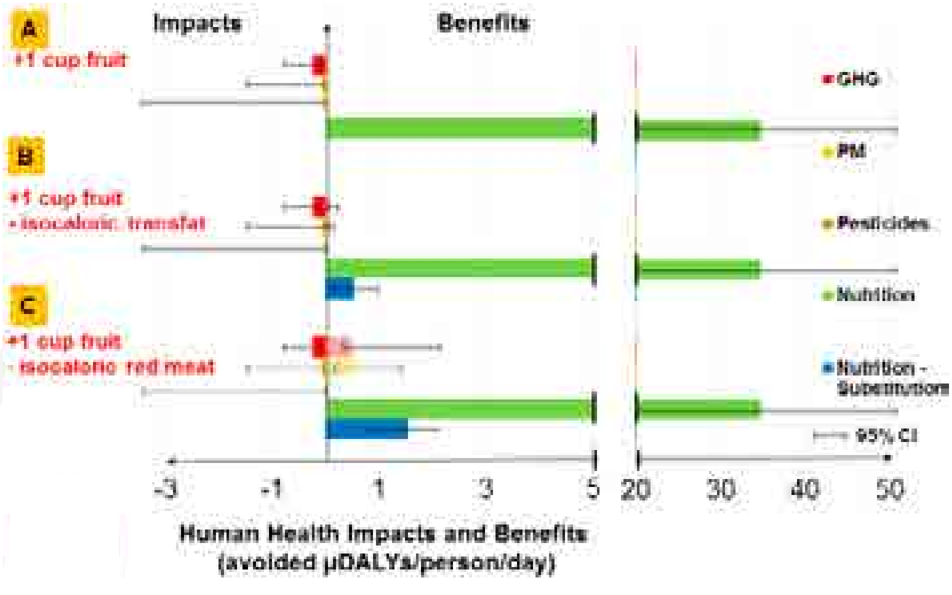

Figure 4. Comparison of daily environmental impacts and nutritional effects for a potential one serving fruit increase consumption, accounting for iso-caloric substitutions of trans-fat or red meat.

4. Discussion

In this paper, we use the CONE-LCA framework that enables a comparison between environmental and nutritional human health effects in a common end-point metric within a LCA context. In addition to the traditional environmental mid-point categories that are linked to human health impacts in LCA (GHG, PM), we also consider pesticide exposure in this case study since we are investigating consumption of fruits and vegetables. Although we limited our analysis to only three relevant environmental impact categories contributing to human health, it should be emphasized that the CONE-LCA framework can be extended to other human health-related environmental impact categories.

Specific to this case study, nutritional human health benefits associated with the addition of one serving of fruits or vegetables to the current European diet exceeded by far the corresponding environmental impacts in all three dietary scenarios. In scenarios B and C, where we considered potential substitution from trans-fat and red meat using an iso-caloric basis as a first proxy, the nutritional benefit was further reinforced due to avoided health impacts related to reductions of harmful food items. We acknowledge that such substitution choices come with limitations in terms of scenario comparison and results interpretation. However, under the as assumption of an increase in healthy dietary choice consumption such as fruits and vegetables, an ideal substitution would occur from unhealthy food products such as trans-fat and red meat. We acknowledge that the trans-fat reduction as suggested in scenario B could be considerably hard to implement in practice. Although the content of trans-fat in food products has reduced and started to be labelled in food packaging (nutrition facts label), it still remains difficult to actually monitor and reduce daily intake due to the number of food items that contain trans-fat. Specific to our case study, the trans-fat substitution with fruits would require a reduction of 11.3 grams of trans-fat that could be achieved, for example, by removing 1.4 pieces of chocolate icing doughnut or 4 table spoons of margarine in stick form from the daily diet. To identify and assess realistic scenarios, substitutions should ideally build on detailed market-based and consumption-based surveys.

Finally, it should be mentioned that these are initial findings that depend on toxicological studies for the pesticide residue assessment and on epidemiological studies for the nutritional assessment. In addition, our findings are highly dependent on the quality and uncertainty of the data used. Hence, our findings should be interpreted within the context of this study and with caution. In the future our study aims to also consider epidemiological data that associate pesticide exposure to human health so that human health effects are assessed in a consistent manner with nutritional effects.

5. Conclusions

The present CONE-LCA framework enables us to compare in conjunction environmental impacts and nutritional effects on human health using a common end-point metric. The preliminary results of this case study indicate that nutritional health effects of food items, and specifically of fruits and vegetables, during the 'use stage' can be substantial and exceed by far any potential environmental impacts. In addition, our results emphasize the importance of affordability and accessibility to fruits and vegetables for the general public.

6. Acknowledgments

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