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The contribution of food waste to global and European nitrogen pollution

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ABSTRACT

The global demand for food is responsible for a massive increase in the anthropogenic nitrogen input to the environment, with negative impacts on human and ecosystem health. However, despite the economic and environmental costs, the quantity of food that is wasted is substantial. This study quantifies the nitrogen loss to the environment related to food waste at consumption at the global and European scale and analyses its relative impact on the environment. We estimated that globally 2.7 Tg of nitrogen (N) are lost per year due to food waste at consumption (i.e. 9% of global food consumption), and that the virtual nitrogen (nitrogen delivered to the environment) associated with the global food waste is 6.3 TgN/yr. We performed a streamlined life cycle assessment on nitrogen emissions related to food waste in the European Union (EU27) to assess the impact on different environmental compartments. The results of this study are relevant for resource efficiency and pollution control policies related to nutrients, water, energy, climate, biodiversity and land use, as well as for scenario analysis of societal change in diet. The case of the EU27 is discussed.

1. Introduction

One of the greatest challenges of the 21st century is to meet the demand for food of the growing population while reducing the adverse impacts of the production system on the environment (Godfray et al., 2010; Foley et al., 2011). Indeed, the demand for food is a major driver for global environmental changes and it is expected to increase in the next 40 years, exacerbating the competition for land, water and energy (Tilman et al., 2001).

In particular, agriculture has shown to be a major force affecting the environment through conversion of forest to cropland and the consequent loss of natural habitat and biodiversity, and by the intensification of practices, involving mechanisation and increasing use of mineral fertilisers and chemicals (Foley et al., 2005). These practices have in turn produced a degradation of soils and waters, through the significant loss of nutrients, nitrogen and phosphorus, in the aquatic system, contaminating surface and underground water resources and causing eutrophication in coastal waters (MEA, 2005; Sutton et al., 2011, 2013). Eutrophication has many negative effects on the aquatic ecosystem, including harmful algal blooms, biodiversity and habitat loss, water hypoxia and fish kills. In addition, it reduces the aesthetic value of the water body and impairs its use for drinking purposes (Smith and Schindler, 2009).

The intensification of agriculture is the major source of the anthropogenic creation of reactive nitrogen (i.e. any nitrogen compound other than N_2 gas) and the disruption of the nitrogen cycle, although the energy sector also plays a role, by fossil fuel combustion and the rapidly increasing production

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of biofuels (Galloway et al., 2008). Overall, the global demand for crops is forecasted to double by 2050 as a result of the growing population, and further intensification of agriculture is expected to increase nitrogen pollution and the loss of biodiversity (Tilman et al., 2011).

When looking at the projections of future crop demand, the 850 million people still undernourished in 2008 (FAO, 2011), the social unrest related to poor food governance and the harmful impacts of the food production system on the environment (MEA, 2005; Foley et al., 2005; Diaz and Rosenberg, 2008; Sutton et al., 2013), and comparing all these figures with the recent estimates reported by FAO on food waste (Gustavsson et al., 2011), the contrast is striking. According to the FAO statistics, about one-third of the food produced globally for human consumption is lost or wasted through the steps of the supply chain, with higher per capita values of food waste in Europe and North America (95–115 kg/yr) and lower values in Sub-Saharan Africa and South/South-East Asia (6–11 kg/yr) (Gustavsson et al., 2011).

Besides the ethical implications, food waste has substantial economic and environmental costs. It is wastage of precious natural resources, such as land, water, nutrients and energy. It increases the cost of food production and generates a supplementary and unnecessary burden for the environment, affecting biodiversity, climate and nutrient losses. For these reasons, estimating the environmental and economic costs related to food waste appears important to inform policy and design alternatives and more sustainable strategies for food production and consumption.

Recent regional and global assessments (Sutton et al., 2011, 2013) have drawn attention to the relevance of nitrogen and phosphorus to global food security and at the same time to the negative effects of their increasing loss to the environment, highlighting how the excessive input of nutrients into the environment poses threats to human and ecosystem health and significant economic costs. These studies have emphasised the need to improve the nitrogen and phosphorus use efficiency at all levels of the food supply chain. Reducing food waste is one of the measures indicated to improve nutrient use efficiency and reduce nutrient loss in the environment (Sutton et al., 2013). It is also a key action clearly identified by the European Commission's strategy for a resource-efficient Europe (European Commission, 2011a,b).

To date studies at the regional scale on the environmental impacts related to food production (and waste) have mainly concerned the impact on climate change (Tukker et al., 2006; European Commission, 2010) and energy consumption (Cuellar and Webber, 2010), but to our knowledge no studies have specifically addressed the wastage of nitrogen due to food waste and the related environmental consequences.

The aim of this study was to quantify the nitrogen loss to the environment related to the fraction of food that is wasted at consumption at the global and European scales and to analyse its potential impact on the environment. We focus on the consumption level to target the analysis on the role of societal behaviour. The first part of the paper addresses the quantification of food waste and the associated wastage of nitrogen. The second part estimates the impact of nitrogen delivered to the environment due to food waste, considering the effects on water quality and greenhouse gas (GHG) emissions. The quantification of nitrogen loss stemming from food waste is provided at the global scale. Then the analysis of impacts is focused on Europe (EU27). Finally, we discuss the results in the perspective of global environmental challenges and resource-efficient policies, with a special focus on the EU27.

2. Methodology

2.1. *Definition of "Food Waste"*

Parfitt et al. (2010) defined food waste as the "wholesome edible material intended for human consumption, arising at any point of the food supply chain that is instead discarded, lost, degraded or consumed by pests." In the literature, food waste is also indicated as 'post-harvested food losses' or 'spoilage'. Similarly, the terms 'food supply chain' and 'post-harvest systems' are both used to describe the sequence of processes from food production to final consumption. However, the term 'food waste' is used more often to indicate the food discarded at the consumption level as a result of consumer behaviour (Parfitt et al., 2010).

The food supply chain (FSC) includes many processes from harvesting to transport, storage, processing, packaging, distribution and consumption. Food losses occur at each step of the FSC and greatly depend on the specific characteristics of a country, involving economic and climatic conditions, production and infrastructure systems, and market and consumption features (FAO, 1981; Parfitt et al., 2010). In developing countries, food losses mainly take place in the first steps of the FSC and technological progress could improve the efficiency of the whole FSC. On the contrary, in developed countries the production and processing systems have been significantly improved but important food wastage occurs at the retail and consumption levels (Gustavsson et al., 2011).

In this study, we refer to the representation of the FSC in five steps as used by Gustavsson et al. (2011), which includes: (1) agricultural production; (2) post-harvest handling and storage; (3) processing; (4) distribution; and (5) consumption, and we focus on food waste in the last step of the FSC, consumption. Accordingly, in this study we refer to food waste as the food loss occurring at the consumption level.

2.2. *Nitrogen embedded in food waste*

We based our quantification of nitrogen wastage relative to food waste on the estimates reported by Gustavsson et al. (2011), who published the first comprehensive study on food waste at the global scale. In this study, for different world regions and for the main food item groups, the authors estimated the food loss as a percentage of what enters each of the five steps of the FSC. The world regions included in the study are (1) Europe; (2) USA, Canada & Oceania; (3) Industrialised Asia; (4) Sub-Saharan Africa; (5) North Africa, West and Central Asia; (6) South and South-East Asia; and (7) Latin America. The food item groups considered are (1) cereals; (2) roots and tubers; (3) oilseed and pulses; (4) fruit and vegetables; (5) meat; (6) fish and seafood and (7) milk (Gustavsson et al., 2011).