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How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture

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ABSTRACT

To meet the 2 °C climate target, deep cuts in greenhouse gas (GHG) emissions will be required for carbon dioxide from fossil fuels but, most likely, also for methane and nitrous oxide from agriculture and other sources. However, relatively little is known about the GHG mitigation potential in agriculture, in particular with respect to the combined effects of technological advancements and dietary changes. Here, we estimate the extent to which changes in technology and demand can reduce Swedish food-related GHG emissions necessary for meeting EU climate targets. This analysis is based on a detailed representation of the food and agriculture system, using 30 different food items.

We find that food-related methane and nitrous oxide emissions can be reduced enough to meet the EU 2050 climate targets. Technologically, agriculture can improve in productivity and through implementation of specific mitigation measures. Under optimistic assumptions, these developments could cut current food-related methane and nitrous oxide emissions by nearly 50%. However, also dietary changes will almost certainly be necessary. Large reductions, by 50% or more, in ruminant meat (beef and mutton) consumption are, most likely, unavoidable if the EU targets are to be met. In contrast, continued high per-capita consumption of pork and poultry meat or dairy products might be accommodated within the climate targets. High dairy consumption, however, is only compatible with the targets if there are substantial advances in technology. Reducing food waste plays a minor role for meeting the climate targets, lowering emissions only by an additional 1–3%.

Introduction

Climate change mitigation efforts have mainly focused on carbon dioxide (CO_2) emissions from fossil fuel use and deforestation, which is sensible since these account for over three quarters of total current greenhouse gas (GHG) emissions (Edenhofer et al., 2014, p. 6). However, if the global 2 °C target (UNFCCC, 2010) is to be met, focusing on fossil fuels and deforestation may not be enough, because methane (CH_4) and nitrous oxide (N_2O) emissions from agriculture may become too large (Hedenus et al., 2014).

In response to the global 2 °C target, the European Union (EU) has adopted targets for reducing its total GHG emissions by at least 80%, or possibly up to 95%, by 2050 relative to 1990 levels (European Commission, 2011). For Sweden, this corresponds to a total emission allowance per capita of 300–1300 kg CO_2-eq per year (including all sectors, not only agriculture),[1] given expected population change. For agricultural CH_4 and N_2O emissions, the EU roadmap allocates about 500 kg CO_2-eq per capita per year for the 80% reduction level (European Commission, 2011). This is to be compared with current food-related emissions, which range from 1.4 to 2.7 metric tons CO_2-eq per capita per year in Western Europe (Barker et al., 2007; Berners-Lee et al., 2012; Pradhan et al., 2013; Risku-Norja et al., 2009) depending on system boundaries and data sources. Hence, for the 80% reduction level, the implied necessary emission reduction for food and agriculture is roughly 65–80%.

Options for reducing CH_4 and N_2O in food and agriculture may be grouped into four broad categories: (i) increase in agricultural productivity and efficiency (e.g. of nitrogen use); (ii)

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[1] Swedish base year (1990) emissions were 73 million metric tons CO_2-eq per year (Naturvårdsverket, 2012). A reduction by 80–95% corresponds to an allowance of 3.7–15 million metric tons CO_2-eq per year. Expected population in 2050 is 11.5 million (SCB, 2012), which gives a per-capita allowance of about 300–1300 kg CO_2-eq per year.

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implementation of specific technology options (e.g., low-emitting manure storage); (iii) change of human diets towards less emission-intensive food; and (iv) reduction of food waste.

In many regions of the world, there is great scope for increasing crop and livestock productivity and thereby reducing the amount of greenhouse gases emitted per unit of meat and dairy produced (Tilman et al., 2011; Valin et al., 2013; Wirsenius et al., 2010). However, in Sweden and most of the EU, agricultural productivity is already relatively high (cf. Grassini et al., 2013) and the remaining potential is unlikely to contribute substantially to reducing agricultural emissions.

In contrast, specific technology options could offer substantial reductions, at least for some sources, such as manure management (Montes et al., 2013). However, many other, potentially significant, options, such as nitrification inhibitors that reduce N_2O emissions from soils (Akiyama et al., 2010), and fat additives that reduce CH_4 from ruminants (Grainger and Beauchemin, 2011), are still only at the experimental or pilot-scale level, and do not yet have any proven long-term records of sustained emission reductions. Hence, for these large sources – N_2O from soils and CH_4 from ruminants – specific mitigation technologies offer only relatively limited and uncertain reduction potentials (Smith et al., 2008).

Diets greatly affect GHG emission levels, since vegetable protein sources generally give rise to lower emissions than protein sources of animal origin (Davis et al., 2010). Ruminant meat (beef and mutton) causes particularly high emissions, far higher than most other types of food. Consequently, dietary change holds a large theoretical mitigation potential, which has been shown in several studies (Berners-Lee et al., 2012; Risku-Norja et al., 2009; Saxe et al., 2012; Westhoek et al., 2014). However, apart from a few studies (e.g. Green et al., 2015; Wirsenius et al., 2011), such analyses have largely been based on purely hypothetical changes in diets, with little consideration of existing constraints, such as consumer preferences, which tend to be conservative, at least in the short term.

Given that the remaining potential for emission reductions from productivity increases is small, that specific mitigation technologies offer rather limited and uncertain reductions, and that diets are constrained by conservative preferences, it seems likely that combining all of them would be the most effective strategy of meeting the emission targets for EU agriculture. To date, however, most analyses of GHG mitigation in food and agriculture have not investigated the combined effect of technology and diets in a consistent manner. In studies that have included the reduction potential of specific mitigation technologies, this has often been done simplistically, with no explicit differentiation between mitigation potentials based on dietary developments (see e.g. Lucas et al., 2007; Stehfest et al., 2009). Similarly, in most studies that have investigated mitigation potentials from dietary changes using current life cycle assessment (LCA) data (Berners-Lee et al., 2012; Risku-Norja et al., 2009) or models (Westhoek et al., 2014), the effect of productivity increases and specific mitigation technologies on the GHG intensity in supply has been ignored.

Here, we address these knowledge gaps by systematically assessing the combined mitigation potentials of (i) productivity and efficiency increases, (ii) specific technology options, (iii) dietary changes, and (iv) food waste reductions. The aim of this paper is to estimate the mitigation potentials of Swedish food-related emissions from such technological and demand-side changes, as a basis for assessing how the EU climate targets for agriculture in 2050 can be met. We also examine the implications of our findings for climate policy.

Method and data

This study consists of three parts. We first focus on demand-side options, through the design of a baseline scenario, which describes changes in the current average diet up to 2050, as well as five alternative scenarios with less GHG intensive diets. In the second part, we estimate GHG emission intensities in current food supply systems. In the third part, we assess potentials for reducing the emission intensities in supply by a broad range of technology options.

These estimates were based on a representation of the food and agriculture system using 30 different food items (Table 1). These items cover all types of food consumed in current diets, with the exceptions of game meat, reindeer and offal, which amount to less than 0.5% of total food consumption in energy terms (Jordbruksverket, 2014). In the design of this food system representation, higher disaggregation was chosen for livestock products and vegetable protein substitutes, since these items were in focus in the demand-side scenarios. For other food items, the level of disaggregation was determined by the need to capture variation in GHG emission intensity and nutritional properties.

Scenarios of food demand in 2050

Major features of diet scenarios

To obtain a baseline of food consumption in 2050, two scenarios were created. The *Current* diet scenario represents average consumption per capita in Sweden in 2013, estimated using data from Jordbruksverket (2014) and Livsmedelsverket (2012). *Baseline* represents a continued development of current and recent trends of increasing meat consumption at the expense of dairy products and carbohydrate-rich food (Jordbruksverket, 2014). We assumed that there is a saturation level of meat consumption at about 120 kg (in carcass weight) per capita per year, which corresponds to current meat consumption in the USA (FAOSTAT, 2014).

To assess the mitigation potential from dietary changes, we created five alternative diet scenarios: *Less Meat, Dairy Beef, Vegetarian*, *Climate Carnivore*, and *Vegan* (Fig. 1). Each diet scenario is less GHG intensive than the baseline by having lower amounts of livestock products and fish, which are by far the most GHG intensive products, and together account for about 75% of all food-related emissions (Table 1). The focus on livestock products for demand-side mitigation is particularly relevant because this group accounts for about 90% of food-related CH_4 and N_2O emissions (Table 1), and technological options for these are more limited and costly compared to CO_2 mitigation from fossil fuels (Wirsenius et al., 2011).

The diet scenario *Less Meat* is based on the baseline, but all meat consumption (including fish and eggs) is decreased by 50%. This is compensated for by an increased consumption of legumes, oil, and cereals to maintain protein and fat intake at high levels. In this scenario, total meat consumption per capita is significantly lower, but protein intake is still roughly equivalent to current levels (see Table S3 in the Supplementary Material).

Dairy Beef is based on baseline developments, but all beef except that from the dairy sector is here replaced by poultry meat, which gives a ruminant meat consumption about 80% lower than the *Baseline*. Here, there is no production of beef from single-purpose (i.e., non-dairy) systems, which is more GHG intensive than beef from dairy systems. However, beef from culled dairy cows is consumed, and surplus dairy calves are raised for beef. Hence, in this scenario, total meat consumption is not reduced, but beef consumption is lowered to the point where no single-purpose beef cattle production is needed.

In the *Vegetarian* diet scenario, meat is replaced by legumes, eggs and significant quantities of cheese. Beef from culled dairy cows is eaten in this scenario; in contrast to the *Dairy Beef* scenario, however, surplus dairy calves are culled at birth. Consumption of legumes and eggs is increased to maintain a high protein intake (see Table S3 in the Supplementary Material).