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Environmental Implications of Dynamic Policies on Food Consumption and Waste Handling in the European Union

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Abstract: This study will review the environmental implications of dynamic policy objectives and instruments outlined in the European Union 7th Framework Programme (EU-FP7) Project DYNAmic policy MIXes for absolute decoupling of EU resource use from economic growth (DYNAMIX) to address reductions in food consumption, food waste and a change in waste handling systems. The environmental implications of reductions in protein intake, food waste reductions, food waste management and donations are addressed using a life cycle approach to find the greenhouse gas (GHG) emissions, land use and water consumption. Data are provided from the Statistics Division of the Food and Agriculture Organization (FAOSTAT) food balance sheets for the European Union (EU) with a base year of 2010 and life cycle inventory (LCI) data from a meta-study of available GHG, land use and water consumption data for major food products. The implications are reviewed using a number of scenarios for the years 2030 and 2050 assuming policy instruments are fully effective. Results indicate that reductions in animal-based protein consumption significantly reduce environmental impacts, followed thereafter by reductions in food waste (assuming this also reduces food consumption). Despite the positive implications the policy mixes may have for targets for decoupling, they are not enough to meet GHG emissions targets for the EU outlined in the DYNAMIX project, although land and water use have no significant change compared to 2010 levels.

Keywords: life cycle assessment; food; food waste; land use; water; policy; meat

1. Introduction

Food production and consumption have been found to account for roughly 20%–30% of anthropogenic greenhouse gas (GHG) emissions [1–3]. Ivanova, *et al.* [4] found that food accounts for 48%–70% of household impacts on land and water consumption. Additionally, several studies assert that over 30% of all food produced is eventually destined as waste [5–7].

In the developed world, consumption choices such as dietary choices, have a large influence on the environmental impacts of consumption [8]. Jones and Kammen [9] in addition to Reisch, *et al.* [10] identified dietary changes as one of the most economically effective abatement options for climate change in affluent countries. Many authors have consequently suggested the necessity for sustainable solutions to food production and waste handling in the future to reduce environmental impacts and resource consumption while feeding the growing population [11].

This study will review the environmental implications of possible changes in dietary choices and food waste handling in the European Union based on dynamic policy objectives, with corresponding figures for reduced consumption of protein and reduced wastes, outlined in the EU-FP7 Project DYNAMIX—DYNAmic policy MIXes for absolute decoupling of EU resource use from economic growth [12,13].

The main aim of the study is to understand what policy instruments offer most promise to reduce the environmental impacts and resource use in European food production, consumption and waste handling and whether these reductions can lead to a decoupling of environmental impacts and resource consumption from economic growth.

The environmental implications of policy instruments are reviewed using life cycle assessment (LCA) methodology. The policy instruments are tested in a number of scenarios addressing consumption and waste handling. These include: (1) changes in protein consumption; (2) shifting from consumption from bovine- and pork-based protein sources towards more poultry based protein; (3) providing more vegetable-based protein; (4) reducing landfilling of food wastes through changes in food waste handling; and (5) donations of food waste.

Results from the study suggest that reductions in protein consumption, through large reductions in meat consumption, offer the largest potential reductions of environmental impacts and resource consumption. Thereafter, reducing waste by 60 and 80% in 2030 and 2050, respectively, offer large potential environmental impact and resource consumption reductions if food consumption is also reduced. Despite the large reductions, further improvements will need to be made in the food production, consumption and waste management sectors as targets for decoupling of environmental impacts may be difficult to achieve, although resource consumption has been shown to remain stable.

2. Methodology

2.1. Food Consumption Model

In order to assess the environmental implications of policies on food consumption and production in the European Union (EU), the project utilized statistics on per capita consumption of food commodities from Food Balance Sheets by the Food and Agriculture Organization (FAO) with a base year of 2010 [2]. Food consumed in this study included only food for consumption and manufacturing, excluding food commodities used for fodder and seed.

As each food category comprises a large number of separate food products and commodities, representative food products (RFPs) were chosen from each category to represent at least 80% of the mass of that product category. A scaling factor was thereafter employed in order to compensate for the food products excluded by choosing the RFPs. Figure 1 provides a representation of this process for the meat category, where only bovine, poultry and pork products represent this category. More information on the modeling can be found in [3].

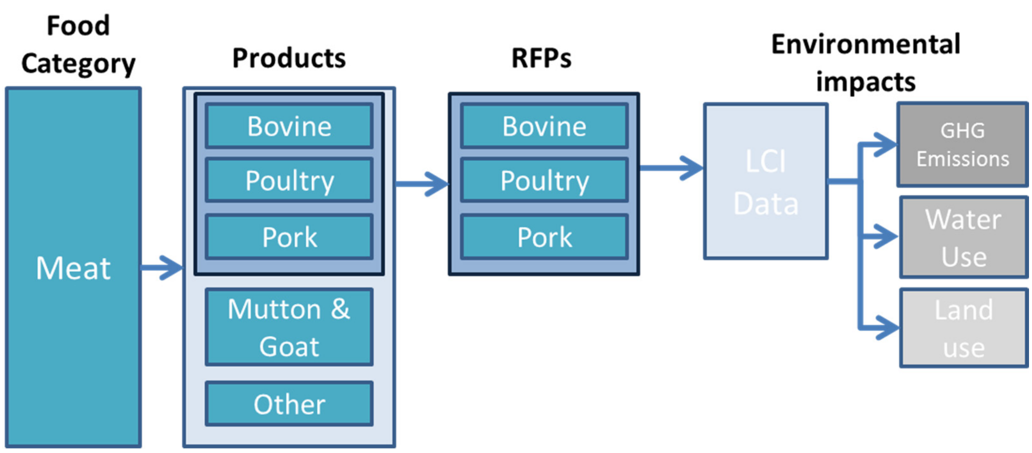

Figure 1. Method used to identify Representative Food Products (RFPs) and link to Environmental Impacts using Life Cycle Inventory (LCI) data.

The impact categories reviewed are limited to greenhouse gas emissions, blue water use and land use. This was due to the limited availability of datasets for food products and commodities in addition to address goals in the DYNAMIX project on resource and environmental decoupling. Greenhouse gas emissions and land use data for the life cycle inventory (LCI) were collected through a meta-study of previous LCAs for the chosen RFPs for each food category per kilogram of the different RFPs. Land use was outlined as occupied land (which includes all land required for cultivation of crops, grazing of animals and land use for operations). Data for water use figures were provided from [4] for blue water use of food products and commodities. All data are provided per kilogram of each respective RFP. When data were not available, comparable data were obtained from databases such as Thinkstep [14] and EcoInvent 3.1 [15]. See the Supplementary Material for a review of all data used and references. Results are provided per annual consumption of food in the EU-27 as the final consumption, and subsequent amount of different foods, increases with increasing population in 2030 and 2050.

In order to understand the effects of the different policy instruments, scenarios are created for the years 2030 and 2050 assuming policy instruments are fully effective; the results of which are compared to the reference year of 2010. Scenarios, described in the next section, review changes in food consumption and waste handling while also taking into account population increases for future years in the EU. The assumed population includes 518 million and 526 million inhabitants in 2030 and 2050, respectively [5]. For each modeled scenario and year, the environmental impacts and resource consumption are computed by compiling the environmental impacts of RFPs, see Figure 1.

In the analysis the results are also compared to per capita emissions in order to understand if there is a relative increase, decrease or stagnation of impacts to assess the implications on decoupling. For decoupling to be achieved, according to Umpfenbach [13], GHG emissions per capita in Europe should not be more than 2 tonnes CO_2-eq/capita annually. Furthermore, when assessing other impact categories, *i.e.*, water consumption and land use, resource consumption should remain the same or be reduced.

In the waste management scenarios, food waste was modeled using typical European waste handling systems, including incineration, anaerobic digestion, composting and landfilling based on Eurostat statistics for municipal waste handling [16]. Incineration of food waste was modeled as incineration of biodegradable waste [14]. For the incineration of waste with energy recovery, the incineration process was assumed to produce 0.5 MJ of European electricity and 1.3 MJ of heat per kilogram of biodegradable waste [14]. Incineration with no energy recovery is assumed to have no replaced conventional energy sources. Anaerobic digestion of the food waste is modeled as *Biowaste to anaerobic digestion* [14]. It is assumed that 85% of the food waste is digested while 15% is classified as reject and incinerated. Biogas produced from the anaerobic digestion process is assumed to be upgraded to roughly 96% biomethane with a lower heating value of 23 MJ/Nm^3. Digestate produced from the anaerobic digestion process is assumed to replace conventional fertilizer. Every tonne of digestate produced in the biogas plant (wet weight) is assumed to replace 8.00 kg N, 5.00 kg NH_4, 1.00 kg P and 1.50 kg K [17]. Composting is assumed to replace an avoided amount of produced inorganic fertilizer, and the amount is assumed to be equal to the digestate produced in the biogas plant.

2.2. Scenarios

The scenarios modeled aim at addressing the policy instruments on land use to address consumption and waste management through targeted information campaigns on changing diets and food waste handling in addition to food redistribution programs and donations to reduce food waste; see Ekvall *et al.* [12]. The consumption and waste prevention targets are outlined in the subsequent sections.

2.2.1. Consumption Scenarios

Consumption scenarios are based on targets outlined in Ekvall *et al.* [12] for policy instruments including reducing animal based protein consumption in the EU by reducing general protein intake, reducing meat, dairy and egg based protein in addition to shifting toward consumption of meats with lower land requirements and GHG emissions (*i.e.*, less bovine and pork, and more poultry consumption). The figures for decreases and consumption limits are based on input from experts conducted in the DYNAMIX project to reach goals for reductions in resource inputs, per capita protein intake and protein shifts set out in the Roadmap to a Resource Efficient Europe (COM(2011) 571) [18] in the years 2030 and 2050 (for more information, see [12]). In the consumption scenarios, no waste management is accounted for, as only changes in consumption are reviewed and as changes in waste management are reviewed in Scenarios W1–W4.

Scenario C0-Default

This scenario reviews the impacts associated with food consumption in the European Union (EU-27) based on the reference year for this study, *i.e.*, 2010 with no policy intervention. For each subsequent time series (*i.e.*, 2030 and 2050), the consumption of different foods is based on the per capita consumption in 2010, but increases with increasing population.

Scenario C1-Reduced Protein

Scenario C1 takes into account a reduction of the proportion of protein consumption from animal-based sources from 51% in 2010 to 35% in 2030 and 25% in 2050 by reducing meat, dairy and poultry consumption as outlined in Ekvall *et al.* [12]. In order to achieve the overall reduction in protein and limit the amount from animal based sources, a decrease of animal based protein of 52% in 2030 and 76% in 2050 was necessary. Vegetable based protein was also increased compared to 2010 levels. Tables 1 and 2 provide a review of the protein changes.

Table 1. Protein intake from different sources used in Scenario C1.

		2010	2030	2050
Total Protein Animal and Fish	g protein/capita/day	61.3	29.6	14.7
Total Protein Vegetable	g protein/capita/day	43.5	54.9	44.2
Total	g protein/capita/day	104.8	84.5	58.9
Total Protein Animal, Milk, Eggs (no fish)	g protein/capita/day	53.0	25.6	12.7
% from Animal, Milk & Eggs	%	51%	35%	25%

Table 2. Change in protein from animal and vegetable sources.

		2030	2050
Animal Protein	% change	–52%	–76%
Vegetable Protein	% change	26%	2%

Scenario C2-Shifting Protein Consumption

In Scenario C2, limits to the proportion of animal-based protein sources with large land requirements and resource consumption (including pork and bovine products) are reviewed. This is accomplished by shifting toward more poultry products and decreasing the consumption of bovine products and pork products based on figures outlined in Ekvall *et al.* [12], see Table 3 for a review of these changes.

Table 3. Intake and percentage of various animal protein sources used in Scenario C2 to model limits for bovine, pork and poultry meat consumption.

	2010		2030		2050	
	g protein/ capita/day	Percentage	g protein/ capita/day	Percentage	g protein/ capita/day	Percentage
Bovine	6.2	24%	2.6	10%	1.3	5%
Pork	11.2	43%	10.4	40%	5.2	20%
Poultry	8.6	33%	13.0	50%	19.5	75%
Total [1]	*26.0*	*100%*	*26.0*	*100%*	*26.0*	*100%*

[1] Total includes only bovine, pork and poultry and not other protein from animal based sources such as milk products and other meat.

2.2.2. Waste Reduction Scenarios

The following scenarios will review the implications of policy instruments and targets outlined in Ekvall *et al.* [12] to reduce avoidable food wastes through reductions of waste throughout the supply chain. The targets are based once again on the Roadmap to a Resource Efficient Europe (COM(2011) 571) [18] and extrapolating the reductions to the years 2030 and 2050 (see [12]). This is done by reviewing the implications of measures for reductions in avoidable food wastes, altering waste management systems and increasing food donations from the retail sector. The scenarios are based on consumption figures in Scenario C0 above for 2010, 2030 and 2050 but take into account waste management with a larger system boundary as seen in Figure 2.

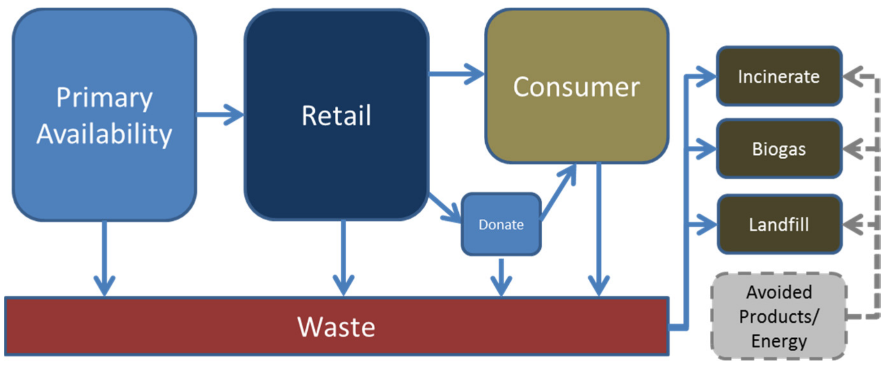

Figure 2. Life cycle stages for modeling food wastes. Avoided products and energy have also been included from the different waste handling methods to account for fertilizers, products and energy replaced (denoted with a grey box and dashed arrows).

Scenario W0

Scenario W0 will review the environmental implications of no policy intervention in the years 2030 and 2050 based on consumption and waste figures from 2010 with no change in handling methods and increasing population. In Scenario W0, it is assumed that all food waste is avoidable in the retail and household sectors. See Supplementary Material for a review of the waste from each food category for the different sectors.

Scenario W1—Reducing Food Waste in Retail and Households

Scenario W1 reviews the implications of reductions in waste (total and avoidable) at the retail and consumer sectors, including reductions of 60% and 85% in 2030 and 2050, respectively, as outlined in Ekvall *et al.* [12]. This was done by reviewing the waste from each food category and reducing the amount of waste from the different foods by 60% and 85% in 2030 and 2050, respectively. It was assumed that 100% of the food waste in the retail and household sectors is avoidable and reductions are used to model the amount of waste going into food waste handling systems. See Supplementary Material for a review of the waste from each food category for the different sectors.

Scenario W2—Reducing Consumption to Account for Waste Reductions

Scenario W2 reviews the same reductions in waste as W1, but will also reduce the food input due to less waste (and less required food inputs). This is done by finding the difference in the amount of food waste in each food category in comparison to W0 and reducing the amount of food consumption for the said food category. This resulted in, e.g., a reduction of 12% total food production in 2030 and 16% in 2050. See Supplementary Material for a review of consumption figures for the different scenarios.

Scenario W3—Food Donations from Retail

Scenario W3 reviews the implications that food donations (20% of otherwise wasted food) from the retail sector may have on the environmental impacts. An 80% efficiency is assumed (*i.e.*, 80% of food donated is consumed with 20% ending as a waste). Donations are assumed to only occur from the retail sector. Waste management systems are similar to previous scenarios.

Scenario W4—Changing Waste Handling Methods

Scenario W4 reviews the implications of changes in waste handling based on waste reductions provided in Scenario W1. Scenario W4 includes the potential benefits from avoided products and energy from an increase in, e.g., biogas production and less waste incineration. The change in waste handling systems is provided in Table 4. See Table 5 for a review of average wastes for production, retail and household waste for Scenarios W0–W4 in 2010, 2030 and 2050.

Table 4. Waste management of food wastes in all scenarios for 2010, 2030 and 2050.

	2010	2030		2050	
	W0–W4	*W0–W3*	*W4*	*W0–W3*	*W4*
Incineration	7%	7%	5%	7%	0%
Incineration w/Energy Recovery	24%	24%	35%	24%	45%
Anaerobic Digestion	10%	10%	30%	10%	40%
Composting	9%	9%	5%	9%	5%
Landfill	50%	50%	25%	50%	10%

Table 5. Average waste from different sectors in scenarios W0–W4.

	2010	2030				2050			
	W0–W4	*W0*	*W1 & W2*	*W3*	*W4*	*W0*	*W1 & W2*	*W3*	*W4*
Production	21%	21%	21%	21%	21%	21%	22%	21%	21%
Retail	4%	4%	2%	3%	4%	4%	1%	3%	4%
Household	14%	14%	5%	14%	14%	14%	2%	14%	14%

In Scenario W4, biomethane from food waste is modeled to be used in increasing levels for vehicle fuel in 2030 and 2050 (see Table 6). Incineration without energy is also modeled to be reduced from roughly 7% in 2010 to 0% in 2050. Incineration with energy recovery is increased from 24% in 2010 to 45% in 2050. Landfilling of food waste is assumed to decrease from 50% in 2010 to 10% in 2050.

Table 6. Assumptions for biogas utilization in Scenario W4.

	2010	2030	2050
Electricity	99.5%	80%	70%
Vehicle Fuel	0.5%	20%	30%

A large share of European countries use biogas for electricity production [19]. It is assumed that biogas will continue to grow as a vehicle fuel in Europe to meet targets for renewable fuels in the transportation sector, *i.e.*, 20% by 2020 [20] and thereafter 30% in 2030. The amount of biogas that is upgraded for vehicle use and that used for electricity is provided in Table 6.

2.3. Environmental Implications

In order to assess the potential for the policy instruments to lead to decoupling of environmental impacts and resource consumption from growth, current GHG emissions and resource use (land occupation and water consumption) were reviewed. The reference figure for GHG emissions per capita of 9.4 tonnes CO_2-eq was provided from EEA [21]. Furthermore, in order to assess the potential to reduce impacts, a maximum of 2 tonnes CO_2-eq per capita in 2050 is recommended to achieve decoupling and to ensure that a global temperature of two degrees Celsius is not exceeded (which is a reduction of roughly 80% [13]). For 2030, it was assumed that a reduction of roughly 40% would take place with GHG emissions of roughly 5.64 tonnes CO_2-eq per capita in 2030 (see Table 7).

Table 7. Emissions of GHG per capita in 2010, 2030 and 2050.

	2010	2030	2050
Per Capita Emissions (tonnes CO_2-eq per capita)	9.4	5.6	2.0

According to Umpfenbach [13], decoupling of resource use may be achieved if the land use and water consumption are stagnated or reduced. In order to assess land use, it was estimated that the European Union had roughly 164 million hectares of cultivated land and 76 million hectares of permanent pasture land [22] as a reference for 2010. It was also estimated that a withdrawal of 288 km^3/year of freshwater took place in 2010 [23]. These figures were thereafter compared with figures for the years 2010, 2030 and 2050 outlined in the quantifications above.

3. Results

The results indicate that the largest potential for GHG emissions reductions come from reducing excess protein intake. Large GHG emissions reductions are apparent in 2030 and 2050 from Scenario C1, with a 42% reduction in GHG emissions in 2050, resulting from reductions in animal protein consumption. Scenario W4, aiming at changing food waste handling and W2, including reduced waste and food consumption, also led to large reductions in GHG emissions. Shifting protein source toward more poultry in Scenario C2 did not have large reductions; see Figure 3 and Table 8.

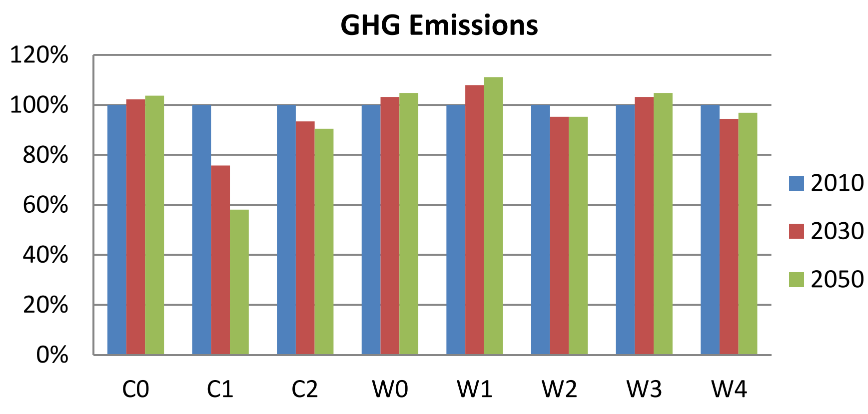

Figure 3. GHG emissions for Scenarios C0C2 and W0–W4 normalized to 2010 values.

Table 8. Results for GHG Emissions, Land Use and Water Consumption for all Scenarios in 2010, 2030 and 2050. Reductions and increases compared to 2010 values are provided in brackets.

Scenario	GHG Emissions (M tonnes CO_2-eq/year)			Land Use (Million ha)			Water Consumption (Million m^3)		
	2010	*2030*	*2050*	*2010*	*2030*	*2050*	*2010*	*2030*	*2050*
C0	1360	1390 (+2%)	1410 (+4%)	312	320 (+3%)	324 (+4%)	98,700	101,200 (+3%)	102,500 (+4%)
C1	1360	1,030 (−24%)	790 (−42%)	312	281 (−10%)	216 (−31%)	98,700	97,300 (−1%)	78,900 (−20%)
C2	1360	1270 (−7%)	1230 (−10%)	312	306 (−2%)	300 (−4%)	98,700	101,600 (+3%)	105,500 (+7%)
W0	1260 [1]	1300 (+3%)	1320 (+5%)	312	320 (+3%)	324 (+4%)	96,900[1]	99,400 (+3%)	100,700 (+4%)
W1	1260	1360 (+8%)	1400 (+11%)	312	320 (+3%)	324 (+4%)	96,900	100,500 (+4%)	102,300 (+6%)
W2	1260	1200 (−5%)	1200 (−5%)	312	293 (−6%)	291 (−7%)	96,900	89,400 (-8%)	87,000 (−10%)
W3	1260	1300 (+3%)	1320 (+5%)	312	320 (+3%)	324 (+4%)	96,900	99,400 (+3%)	100,700 (+4%)
W4	1260	1190 (−6%)	1220 (−3%)	312	319 (+2%)	323 (+4%)	96,900	96,600 (0%)	97,100 (0%)

[1] In the scenarios for the base year 2010, in addition to 2030 and 2050, GHG emissions in addition water consumption for C0 and W0 differ due to the expanded system boundaries in W0 (which includes waste management and avoided processes due to outputs from the waste management).

When reviewing the land use for the different scenarios, the largest reductions for 2030 and 2050 come from scenarios C1 and W2, which, again are related to reducing food consumption. Scenario C1 reduced land use in 2050 by roughly 30%. In Scenarios W0, W1 and W3, land use did not change significantly and increased slightly in 2030 and 2050 (see Figure 4 and Table 8).

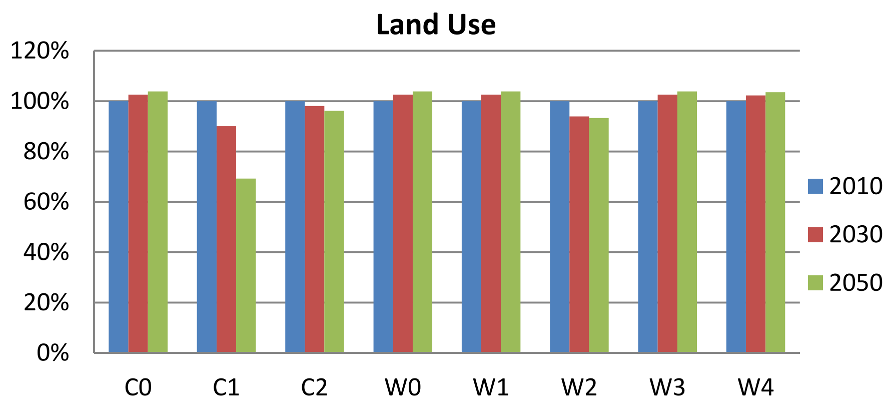

Figure 4. Land use for Scenarios C0–C2 and W0–W4 normalized to 2010 values.

Consequently, reductions in water consumption once again follow GHG and land use, with the largest in scenarios C1 and W2. Scenario C1 and W2 reduced water consumption in 2050 by roughly 20% and 10%, respectively. In Scenario C2, an increase in water consumption was observed due to changing protein and increased vegetable production. Scenarios W1, W3 and W4 had no significant changes in water consumption (see Figure 5).

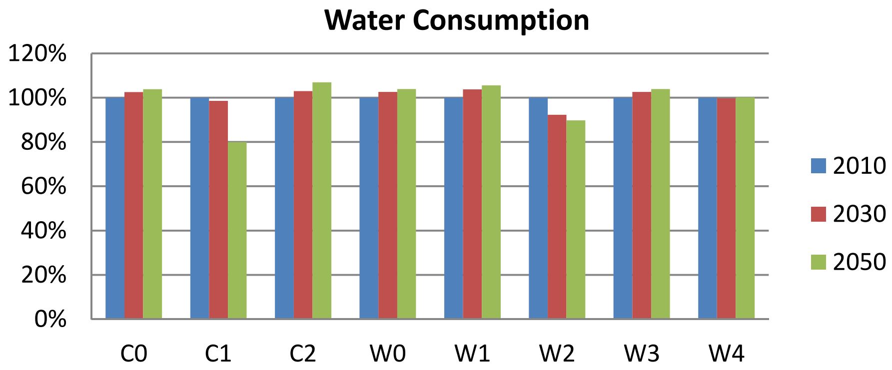

Figure 5. Water Consumption for Scenarios C0–C2 and W0–W4 normalized to 2010 values.

4. Analysis

The aims of the DYNAMIX project are to decouple environmental impacts from resource use and economic growth. While the results of the scenarios illustrate reduced emissions of greenhouse gases in addition to reduced land use and water consumption, in order to show if decoupling occurs it is important to review the changes in comparison to population increases.

Currently, EU citizens emit roughly 9–10 tonnes CO_2 per capita and year [21]. Table 7 provides the emissions per capita in 2010 along with the estimates for 2030 and 2050 as outlined in Umpfenbach [13] and in the methodology section. Currently food production and waste management account for roughly 2 tonnes CO_2-eq per capita and year, similar to previous studies with food accounting for 20%–30% of overall GHG emissions [3,8,24].

Table 9 provides results of the comparison of GHG emissions per capita in the years 2010, 2030 and 2050 for the food sector compared to overall emissions in the EU-27 in 2010. Furthermore, Table 9 additionally reviews the GHG emissions from the food sector compared to targets outlined in Umpfenbach [13]. The results illustrate that, despite the policy measures, the share of GHG emissions from the food sector will continue to increase as targets become more stringent for European emissions. In 2030, the food sector will account for roughly 41%–46% of the EU GHG emissions. This is increased to 114%–133% of the GHG emissions in 2050.

Table 9. Emissions from the Food Sector compared to 2010 European Emissions Levels. Emissions compared to targets outlined in [13] are provided in parentheses.

	2010	2030	2050
Scenario C0	29%	29% *(44%)*	30% *(125%)*
Scenario C1	29%	22% (46%)	17% *(133%)*
Scenario C2	29%	27% *(41%)*	26% *(114%)*
Scenario W0	27%	27% *(46%)*	28% *(133%)*
Scenario W1	27%	25% *(44%)*	25% *(125%)*
Scenario W2	27%	27% *(46%)*	28% *(133%)*
Scenario W3	27%	29% *(41%)*	29% *(116%)*
Scenario W4	27%	25% *(45%)*	26% *(131%)*

Table 10 provides a review of the land use for production of food (including livestock) for the different scenarios in the years 2010, 2030 and 2050. Normalized figures are based on the land use in 2010. The results indicated that food consumption accounts for more than 100% of land used for agricultural production in the EU; this is due to imports of foods and excludes a balance of imports and exports. No significant changes are seen, except for Scenario C1 where overall protein consumption is reduced, which corresponds to a reduction in land use by nearly 30%. Scenarios C2 and W2 also had reductions of land use by roughly 5 and 9%, respectively. The results are sufficient to conclude that net demand for EU agricultural land remains relatively stable, and in some scenarios lower thus meeting DYNAMIX land use targets.

Table 10. Land use in all scenarios normalized to land use in the EU in 2010.

	2010	2030	2050
Scenario C0	130%	133%	135%
Scenario C1	130%	117%	90%
Scenario C2	130%	127%	125%
Scenario W0	130%	133%	135%
Scenario W1	130%	133%	135%
Scenario W2	130%	122%	121%
Scenario W3	130%	133%	135%
Scenario W4	130%	133%	135%

Water consumption was also reviewed based on current available supplies and consumption figures in the EU based on 2010 levels. For nearly all scenarios, the use of available water was around 4.3% of available sources in 2010. Table 11 also provides a review of the contribution of the food sector to European water consumption. Results indicate that the food sector accounts for roughly 34% of the water consumption in the EU. Results for the different consumption and waste scenarios showed no significant increase or decrease in water consumption, although a slight decrease can be seen in Scenario C1, where less overall protein is consumed, and in W2 where reduced waste leads to reduced food consumption. The results show no significant increase of water use, thus meeting DYNAMIX targets for water stress in some, but not all, scenarios.

Table 11. Use of available water and share of consumed water based on 2010 levels for the EU.

	2010		2030		2050	
	% of Available	% of Consumed	% of Available	% of Consumed	% of Available	% of Consumed
Scenario C0	4.3%	34.3%	4.5%	35.1%	4.5%	35.6%
Scenario C1	4.3%	34.3%	4.3%	33.8%	3.5%	27.4%
Scenario C2	4.3%	34.3%	4.5%	35.3%	4.6%	36.6%
Scenario W0	4.3%	33.6%	4.4%	34.5%	4.4%	35.0%
Scenario W1	4.3%	33.6%	4.4%	34.9%	4.5%	35.5%
Scenario W2	4.3%	33.6%	3.9%	31.0%	3.8%	30.2%
Scenario W3	4.3%	33.6%	4.4%	34.5%	4.4%	35.0%
Scenario W4	4.3%	33.6%	4.4%	33.5%	4.5%	33.7%

5. Discussion

The results show that the food sector alone will result in more GHG emissions per capita than the targets for 2050 in the majority of scenarios. While changes in the food sector are modeled *ceteris paribus*, based on European policy, it is important that reductions are also seen in other sectors, and regions. As the European food sector relies on imports from other countries, it is important that changes also occur abroad. In studies on decarbonization trajectories, with focus on the EU and other regions, Schandl *et al.* [25] show that policy intervention may allow for a decoupling toward the 2°C targets of the United Nations and as outlined in the DYNAMIX project. Nonetheless, there is also a need to address improvements in technologies if the decarbonization trajectories are to hold.

The studied systems review only changes in food consumption and waste management. However, improvements in agricultural processes may also lead to large improvements to reduce environmental impacts and provide sufficient supplies of food [26]. As an example, the agricultural sector uses large inputs of fossil energy. In studies by Ahlgren *et al.* [27,28], the use of biobased raw materials to produce alternative fertilizers to reduce many environmental pressures of the primarily fossil based production processes for fertilizers are reviewed, which may reduce impacts. Alternative agricultural practices, such as organic production, also show promise to reduce many environmental impacts, although studies do not converge on reductions of GHG emissions [26,29–32]. Nonetheless, the introduction of organic agriculture has put alternative food products in the agenda, providing consumers with information to change their behavior toward more sustainable food products in light of increased debate on the origins, contents and safety of food [33].

5.1. Changing Consumption

The results have shown potential to reduce environmental impacts of food consumption through reduced meat consumption. Similar findings have been found in many previous studies focusing on global warming potential [1,34–38] and land and water use [39,40] for European and country specific dietary reviews. As Tukker *et al.* [24] suggest, growing populations and the advent of growing wealth may cause even greater emissions in the future, due in part to increased meat consumption, thus calling for further measures to reduce the environmental impact of the food sector.

While the policies outlined aim at reducing and shifting meat consumption, practically reducing meat consumption is a complex tax. Besides the environmental impacts, the consumption of meat has both positive and negative attributes: being a source of high quality protein and nutrients but linked to a number of chronic diseases [1,41]. Furthermore, reducing meat consumption across the EU will need to address the social and cultural aspects which may make it hard to reduce in certain cultures and countries [41]. Retailers may also be reluctant reduce their offerings of meat products, which account for a large share of their income and provides competitive advantages [42].

5.2. Reducing Waste

The results from this study indicate a clear reduction in environmental impacts, land use and water use, from reduced wastes in the EU. This is most apparent when food consumption is also reduced due to a reduction in waste. There are a large number of studies that agree, indicating the potential for large reductions in environmental impacts from reducing food wastes [5,43–47]. As such, Dorward [43] suggests that food waste in combination with reduced food consumption are needed to address the sustainability of food production.

It is also important to address the importance of modern waste management systems. In many studies, the focus is primarily related to the impacts from avoided food production [43]. Nonetheless, food waste is often used as a resource, becoming a source of energy and nutrients from, e.g., anaerobic digestion, incineration and landfilling. The results indicate that only reducing waste may lead to slightly higher impacts of GHG emissions. This is a result of the avoidance of marginal energy sources, from methane production during anaerobic digestion and landfilling and heat and power from incineration. Nonetheless, it is difficult to assess the marginal sources of energy in the future, which are assumed today to be of fossil origin.

While this study assumes an avoidable waste share of 100%, studies such as WRAP [47] outline that avoidable waste from retail and households varies greatly among different food products. It may also be difficult to reduce food waste at the household level to targets addressed in Ekvall *et al.* [12]. Campaigns and information will need to be addressed to different groups with respect to economic status, geography, culture, education, *etc.* as food waste varies among groups, and policy should reflect these differences [7,48]. As Thyberg *et al.* [7] suggest, there are many obstacles to decrease food waste through policy intervention. These include, e.g., poor public participation, uncertainty, lack of efficient indicators, applicability across countries and regions, *etc.*

5.3. Donations

The results indicate no significant change in the environmental impacts and resource consumption from food donations for the EU food sector. This is due primarily to the relative scale of the impact of reducing waste through donations in the study. Nonetheless, the donation of 20% food wastes from the retail sector equates to roughly 4.8 million tonnes of food (compared to the estimated 724 million tonnes of food available for consumption in this study), less than 1% of the production. There is a very limited literature basis reviewing environmental implications of food donations. Thyberg [7] also suggests that it may be difficult to increase food donations due to the feasibility of distribution and the fact that some food waste is unavoidable. Furthermore, while this study reviews donations of all food from retailers, Schneider [49] outlines that generally dairy products, biscuits, cereals and fruits and vegetables are donated from retailers. Furthermore, in European foodbanks, the primary source of the products are from producers, with aim to stabilize market prices of commodities (see [49]). Disregarding whether there is environmental performance benefits for the food sector, there are many studies have considered the socio-economic aspects of food donations [44]. These include providing underprivileged persons with food security and more purchasing power, which is often spent on housing and further purchases of food [49].

6. Conclusions

Sustainable food production will become more important in coming years in order to reduce environmental impacts and reduce the consumption of resources. Results from this review outline that policy instruments may have the potential to reduce GHG emissions, land use and water consumption. Large reductions in meat consumption can reduce GHG emissions by over 40% compared to 2010 levels in 2050, in addition to reducing land use and water consumption. Changes in the type of meat, *i.e.*, an increase in more poultry and reductions of pork and bovine products, do not have as large of resource and environmental impact reductions, although scenarios reviewing reductions in meat offers evidence to great reductions in environmental impacts.

Reductions in European food waste may also result in large environmental impact and resource consumption reductions when a reduction in food consumption is also taken into account. Finally, a change in food waste handling toward less landfilling and more energy production may reduce environmental impacts and resource consumption.

Nonetheless, the results show that while the policy measures outlined in the DYNAMIX project may reduce environmental impacts and resource consumption, a decoupling of these impacts from growth may not be possible for all categories and scenarios. Land use and water consumption have been shown to remain relatively stable in all scenarios suggesting that the policies outlined may have the potential to meet goals in the DYNAMIX project. However, the policies will not allow for a decoupling of GHG emissions with the target of 2 tonnes CO_2 eq/capita; the food sector alone will, in the majority of the scenarios, have emissions per capita higher than the targets without accounting for the emissions of other sectors.

This study provides information that can be used by policy makers in addition to the food, feed, retail and waste sectors to reduce environmental impacts and resource consumption associated with food consumption in Europe. Nonetheless, the study only reviews a limited set of impact categories. It is also important to review additional impact categories, e.g., nutrient use, land use changes, acidification and eutrophication, which may have significant implications from agricultural practices. However, the importance of consumers to reduce their animal based protein consumption, reduce their creation of food waste and make environmentally conscious dietary choices is stressed in addition to the need for improved sustainable agricultural practices.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/8/3/282/s1, Table S1: Representative food products and amounts from FAO stat for reference year 2010, Table S2: Waste percentages from different sectors for each food category used in Scenario W0, Table S3: Food Waste from different categories and sectors in 2010, 2030 and 2050 in Scenario W1 and W2, Table S4: References for LCI data used for food products.

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Abbreviations

The following abbreviations are used in this manuscript:

DYNAMIX	DYNAmic policy MIXes for absolute decoupling of environmental impacts of EU resource use from economic growth (an EU FP7 research project)
EU	European Union
FAO	Food and Agricultural Organization
FP7	7th Framework Programme
GHG	greenhouse gases
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
RFP	Representative Food Products

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