



Benchmarking Eco-Efficiency and Footprints of Dutch Agriculture in European Context and Implications for Policies for Climate and Environment

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The agricultural sector in the Netherlands is per unit of land the most productive and efficient sector in the European Union (EU). However, emissions of ammonia, surpluses of nitrogen and phosphorus, and use of pesticides per hectare of agricultural land are also among the highest in the EU. In spite of successful policies and farm measures to reduce this pollution, agriculture still constitutes the largest environmental pressure on biodiversity. Dutch agriculture, including horticulture, also contributes 14% (32 Mton CO₂-eq in 2016) to the national emissions of greenhouse gases (GHG). These emissions hardly decreased since 2000. In the current bid to meet the Paris Climate Agreement (PCA), the agricultural sector will need to reduce emission by 3.5 Mton in 2030. The relative reduction target for GHG by agriculture is 11% and less than the national target of 49%, but still is a challenge because the technical potential for reduction of methane and nitrous oxides is relatively small. Apart from technical measures and innovations, there is an increasing call in society for structural measures, like reduction of livestock, to assure an appropriate reduction of GHG emission from agriculture. However, there are also concerns about leakage effects when livestock production would increase elsewhere, e.g., in the EU, causing a net increase of GHG emission and increased local environmental pollution. We carried out a Life Cycle Analysis for production of milk, pork, poultry, potato, and wheat in other EU countries which disclosed that GHG emission per unit of product in the Netherlands is similar to that in Germany and France, while lower than in central and southern EU. Nitrogen and phosphorus surplus per unit of product for Dutch products often are higher due to the high use of manure. These results indicate that the risk of transboundary leakage effects likely is small when implementing PCA for agriculture in the Netherlands or stricter environmental policies, also when including reduction of livestock production. Further, growth of livestock production in other European regions might be avoided by climate policies or when consumption of livestock products would decrease due to increased consumer awareness or targeted interventions.

Keywords: eco-efficiency, greenhouse gas, nutrients, agriculture, European Union

INTRODUCTION

Toward More Sustainable Agro-Food Systems

Sustainable and efficient management of natural resources and the environments that support (and surround) the agro-food system is imperative to sustain food production for future generations. Indicators to measure progress toward a more sustainable agro-food system are embedded in the 17 United Nations Sustainable Development Goals (SDGs). Globally and regionally the agro-food system is the dominant user of land, biodiversity, fresh water, nitrogen and phosphorus, and a major cause of biodiversity loss, soil degradation, water depletion and greenhouse gas emissions, and contributor to pollution of water and air (UNEP, 2016).

The three major intervention routes to decrease resource demand and adverse environmental and health impacts of the agro-food system are (1) increasing the efficiency of agricultural production, (2) decreasing food waste, and (3) adoption of less resource-intensive and healthier diets (Figure 1). Options (2) and (3) could be coined as increasing the efficiency of food consumption (van Grinsven et al., 2015). A fourth category of measures could be labeled as adoption of agricultural practices aimed at increasing services of the agro-food system to local biodiversity, environments, livelihoods and general well-being, and could be linked to the One Health Initiative (www.onehealthinitiative.com). Examples are practices improving soil health, local air quality or animal welfare. Adoption of some of these responsible practices without change of diets may decrease resource efficiency and increase environmental pressure, e.g., in the case of improved animal welfare. However, preferences of consumers and producers for these practices tend to go along with more sustainable food choices (Baudry et al., 2017). Particularly the change of diets has a large potential to reduce resource demand and environmental pollution, but adoption of food policies or regulation tends to meet more political and economic barriers than the other interventions routes (Westhoek et al., 2014). In this paper, we analyze the eco-efficiency and environmental pressure (footprints) of Dutch agriculture in comparison to other EU countries.

Key Features and Metrics of Dutch Agriculture in EU and Global Perspective

The mean economic value of the gross export of the Dutch agro-food sector in 2016–2017 was 94 billion USD/year (United Nations Department of Economic and Social Affairs, 2018) and includes 10 billion USD for ornamental products (like live trees, flower bulbs, cut flowers, and ornamental foliage). The Netherlands ranks second in the world after the US (142 billion USD/year) and before Brazil (74), China (72) and much larger EU countries like Germany (82), France (66), and Spain (51).

Abbreviations: EU-MS, European Union Member State; FPCM, Fat-Protein Correct Milk; FCR, Feed Conversion Ratio; FEV, fertilizer equivalency; GVA, gross value added; NEC, National Emission Ceilings; ND, Nitrates Directive; LUC, Land Use Change; LW, Live Weight; PCA, Paris Climate Agreement; PM, Particulate Matter; WFD, Water Framework Directive.

Ranking countries by gross export gives a distorted picture of the economic relevance of national agro-food sector as, particularly for the Netherlands, a large share of imported commodities is almost directly re-exported e.g., via Rotterdam harbor and Schiphol airport. Therefore, the net export value in 2016–2017 is more meaningful. For the Netherlands net export was 31 billion USD/year (one third of gross export) and still ranked 3rd after Brazil (63 billion USD/year), Argentina (33) but before New Zealand (17.3), Indonesia (16.2), and Australia (16.1), and EU countries like Spain (12.4), Poland (8.3), and France (5.8). This 3rd position is a remarkable achievement considering that the Netherlands (NL) only holds 0.04% of global agricultural land and 1% of that in the EU (Table 1) and inspired the claim that “A tiny country feeds the world” (National Geographic Magazine, 2017). This position is made possible by a combination of a favorable climate, fertile soils, high levels of agricultural science and technology, high cost-efficiencies, a very profitable horticultural sector (including greenhouses and ornamental), but also a high intensity primary production system with high imports of agricultural products like livestock feed. This allows NL to produce more than 9% of EU dairy production, and to house 8% of the EU pig and poultry livestock and 6% of meat production in the EU (Table 1).

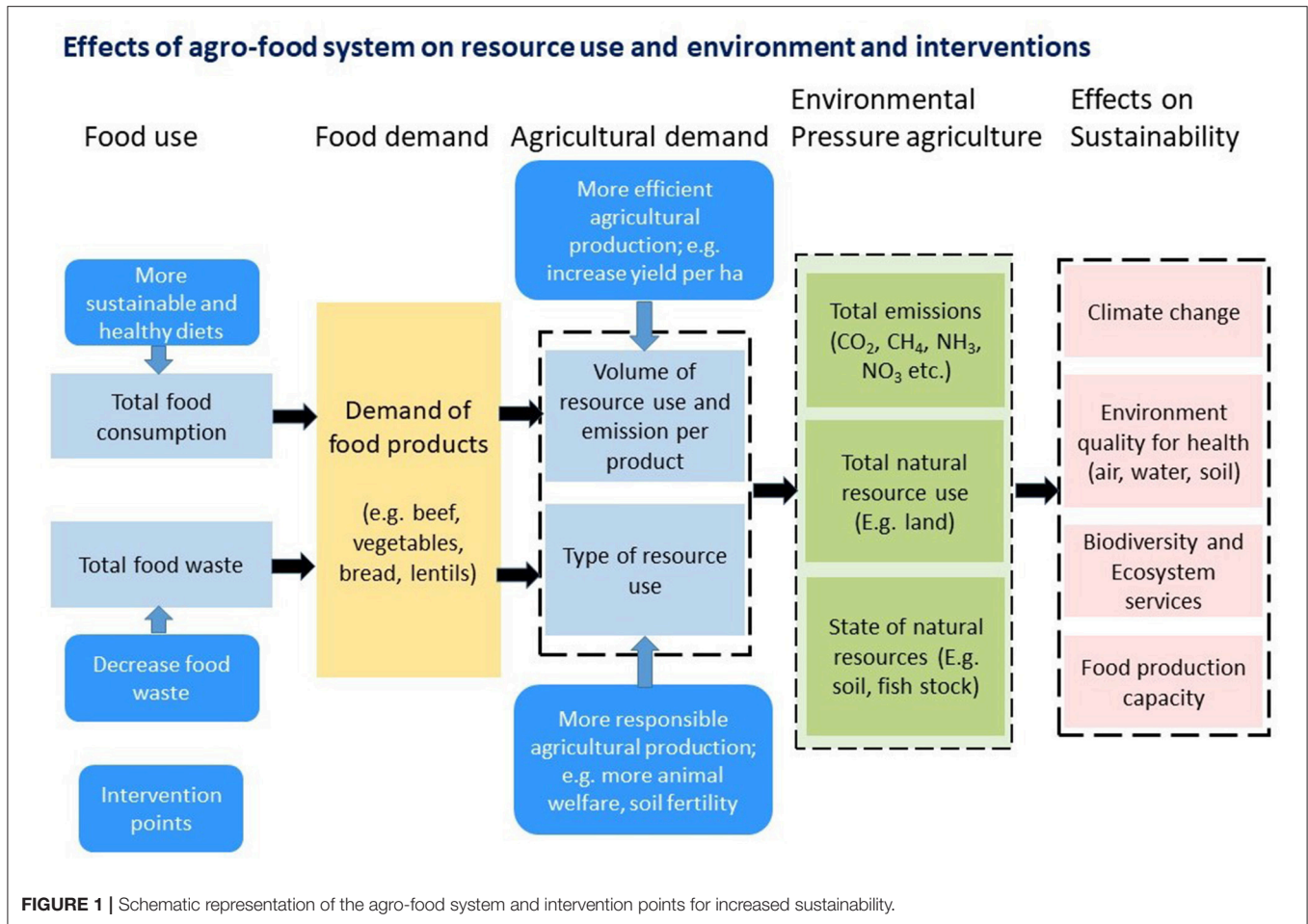
Degrees of self-sufficiency, and related to this the share of national production that is exported, are 295%/66% for eggs, 172%/41% for poultry meat, 230%/57% for pork, and 241%/58% for cheese, but the degree of self-sufficiency for cereals is only 18% and for protein rich feed stuffs 1.4% (Westhoek et al., 2011).

The national gross value added (GVA) of the Dutch agro-complex (including supply, processing and distribution) in 2015 was 48 billion euro, of which 9.5 billion euro was generated by primary agriculture, and 18 billion euro was generated from imported products (e.g., feed; PBL, 2018). Relative shares of GVA of primary agriculture based on domestic resources (30 billion euro) were 34% by horticulture, 29% by the land based livestock sector (mainly dairy), 19% by the landless livestock sector (pigs, broilers, layers, and veal) and also 19% by the arable sector.

Effects of Agri-Environmental Policies in the Netherlands

The high economic efficiency, e.g., measured as GVA per unit of end product, of the Dutch agro-food sector was made possible by the high use of inputs such as artificial fertilizer, imports of animal feed and pesticides. In the 1980s and 1990s the adverse environmental impacts of the intensive agricultural sector were revealed and gradually policies were introduced to prevent and mitigate the impacts (Table 2). Many current Dutch policies to reduce water and air pollution are national implementations of European Environmental Directives (see e.g., van Grinsven et al., 2016). In spite of these effective policies various environmental targets currently still are far from being achieved (Table 2). The steady decrease of many emissions or polluting uses of compounds since 1990 is stagnating in recent years or sometimes even reversed (Figure 2).

Also the emission of greenhouse gasses (GHG) by the agricultural sector has stagnated due to an increase of methane



emissions by the growth of dairy livestock and dairy production in response to the abolishment of the EU milk quota system in 2015. But new policies have been introduced in 2016 and have decreased the dairy livestock to around 2012 levels.

The production volume of the agricultural sector (for which added value using constant prices is a good proxy) has steadily increased since 1990 and caused an absolute decoupling of all emissions and uses with the exception of PM_{2.5}. The latter is the result of legislation to increase welfare for poultry.

Agriculture and Global Climate Challenge

The primary agricultural sector emitted 28 Mton CO₂-eq greenhouse gasses (GHG) in 2016 as compared to a highest value of 34 Mton in the early 1990s and lowest values of 26 Mton in 2003–2004 (Figure 3). Recent increases are caused by the earlier mentioned growth of the dairy sector. The livestock sector contributes two thirds (66%) to the total emission of GHG by agriculture in 2014–2016, of which 46%-points as methane and 18%-points as nitrous oxide. Current Dutch environmental policies give the highest priority to agreed commitments in the PCA to reduce greenhouse emissions and was recently reconfirmed in view of the alarming messages in the 8th IPCC assessment report (AR8; IPCC, 2018). Although the relative reduction target for the agricultural sector of about 11% in

2030 (3.5 Mton CO₂-eq) is lower than the national target of 49%, meeting the target as well as verifying achievement is an immense challenge. A large part of the reduction will have to come from land use change (LUC; reduced drainage of peatland and conversion of arable to grassland; note that in IPCC accounting GHG emissions from LUC are not attributed to the agricultural sector) and improved manure management, the effects of which cannot be directly measured and effectiveness is uncertain. Given the national task to reduce multiple emissions from agriculture to increase target achievement for water and air quality, an additional challenge is to increase positive feedbacks of climate measures in agriculture and reduce the risk of negative feedbacks (trade-offs).

Research Hypothesis and General Approach

A dominant view in Dutch society is that its agro-food sector is world leading for feeding the next generation of the world population and that can do so with “the lowest impact on the environment, climate and biodiversity per kilogram of food worldwide” (<https://topsectoragrifood.nl/en/over/>). Our research hypothesis is that the environmental pressure per unit of agricultural product (including greenhouse gas emissions) in the Netherlands is not significantly different from those for

TABLE 1 | Characteristics of Dutch agriculture as compared to the world and the EU in 2015 [source FAOstat, Eurostat and Statistics Netherlands (CBS statline)].

	Stock/volume 2015			Share of NL		Relative intensity NL ^b	
	World	EU28	NL	World	EU28	World	EU28
Population ($\times 10^6$)	7,418	507	17.0	0.23%	3.35%	6.1	3.3
Land area (10^6 ha)	12,733	423	3.38	0.03%	0.80%	0.7	0.8
Agricultural land (10^6 ha)	4,775	179	1.80	0.04%	1.01%	1.0	1.0
Cropland (10^6 ha)	1,391	119	0.81	0.06%	0.68%	1.5	0.7
Grassland ^a (10^6 ha)	3,384	59	0.98	0.03%	1.65%	0.8	1.6
Nitrogen use (10^6 t/y)	115	11.3	0.2	0.17%	1.70%	4.4	1.7
Cereal production (10^6 t/y)	2,519	317	1.62	0.06%	0.51%	1.7	0.5
Milk production (10^6 t/y)	656	153.1	14.3	2.18%	9.35%	57.9	9.3
Meat production (10^6 t/y)	307	45	2.72	0.89%	6.04%	23.5	6.0
Cattle ($\times 10^6$)	1,694	89	4.3	0.25%	4.76%	6.7	4.7
Pigs ($\times 10^6$)	977	149	12.5	1.28%	8.39%	33.9	8.3
Poultry ($\times 10^6$)	21,873	1402	106.4	0.49%	7.59%	12.9	7.5
Sheep and goats ($\times 10^6$)	2,177	98	1.3	0.06%	1.31%	1.6	1.3

^aPermanent grassland.

^bper hectare of used agricultural land relative to world and EU28.

other Northwest European countries with similar climates and similar productivity potentials and with comparable access to agricultural science and technology. If true, this will have implications for options toward a more efficient European agricultural production system with less emissions and adverse environmental impacts. The ambition to increase the eco-efficiency of production aims at production of goods and services with minimal environmental degradation and therefore is an operationalization of the more encompassing ambition to make economies more sustainable (Kuusmanen and Kortelainen, 2005) and relates to revival of ambitions for increased circularity in the agro-foodsystem (Ministry of Agriculture Nature and Food Quality of the Netherlands, 2018).

Therefore, we chose to test our hypothesis by benchmarking the eco-efficiency (GVA per unit of resource input or pollution) and intensity (resource use or emission per unit of land or product) of agricultural production in the Netherlands and other EU countries. Intensity is also referred to as pressure of footprint. We quantify efficiencies and intensities at two levels; for national agricultural sectors and for individual products. At product level we explored efficiencies and intensities for a selection of products and EU countries giving 30 product-country combinations. We looked into to five (environmental) indicators: land use, distinguishing between grassland and arable land at home and abroad (including cattle feed); greenhouse gas emissions (including and excluding land use and land use change); N and P surplus/excretion and ammonia emission. At the national level we benchmark both eco-efficiency and environmental pressure per unit of land and make a distinction between global environmental issues (land use change as a driver of biodiversity loss, climate change by GHG emissions and antibiotic resistance), for which impacts are relatively independent of the location of emission, and local issues (NH₃ emission, N and P surplus, pesticide use) where impacts on human health and biodiversity do depend on the location of emissions.

In the discussion we address the question whether the environmental impacts of the Dutch agriculture could be decreased, and the sustainability of its agro-food system can be increased by outsourcing part of the agricultural production to other EU member states. Theoretically, there is a large potential in the European Union (EU) to improve allocation of agricultural production, given common environmental regulations and policies for trade and agriculture. By this, either land use for Dutch agriculture could be decreased or agricultural production on current land use could be intensified. Such a development is a possible future direction to increase achievement of national and international policy targets for biodiversity, environment and climate change (van Grinsven et al., 2018).

MATERIALS AND METHODS

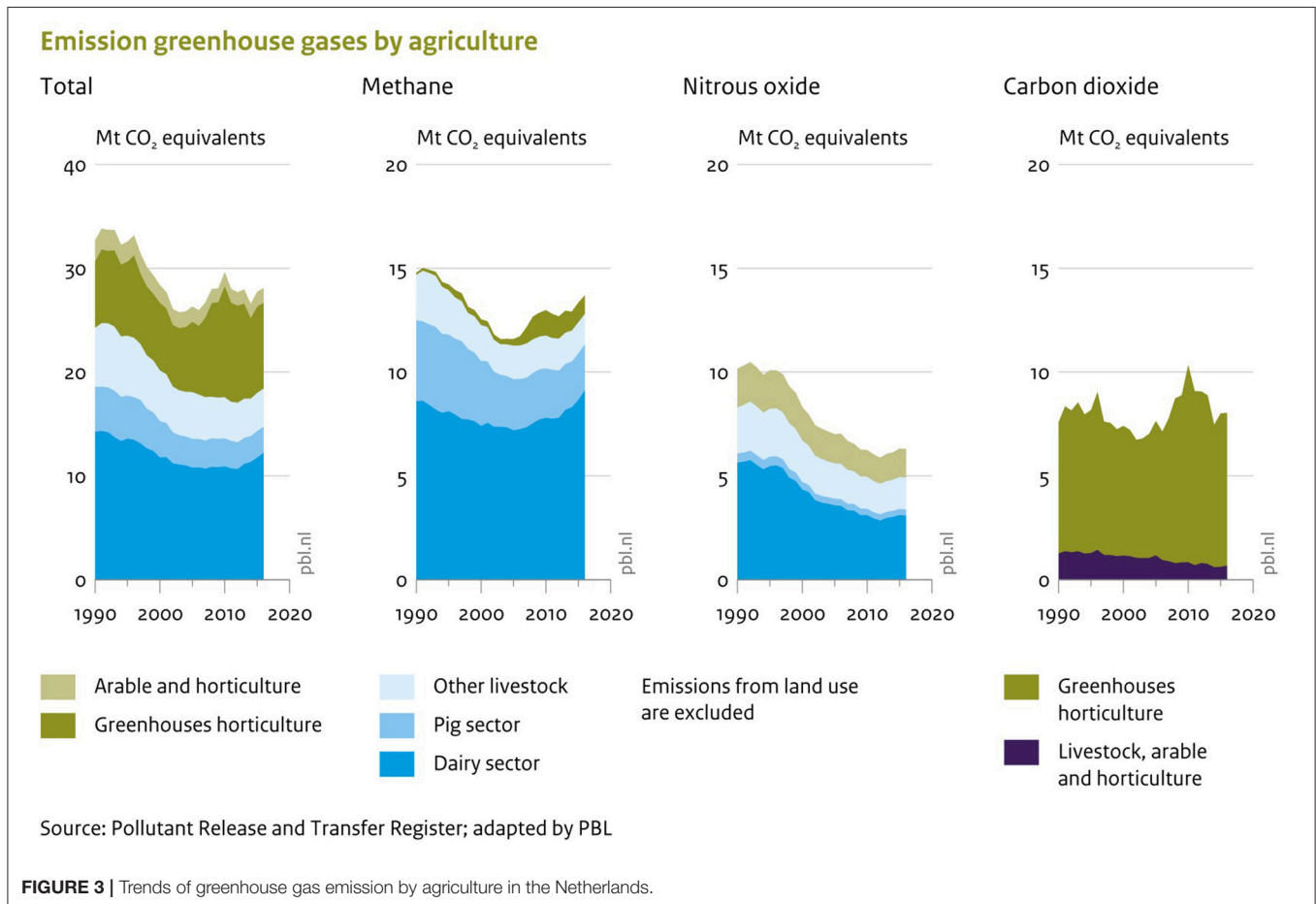
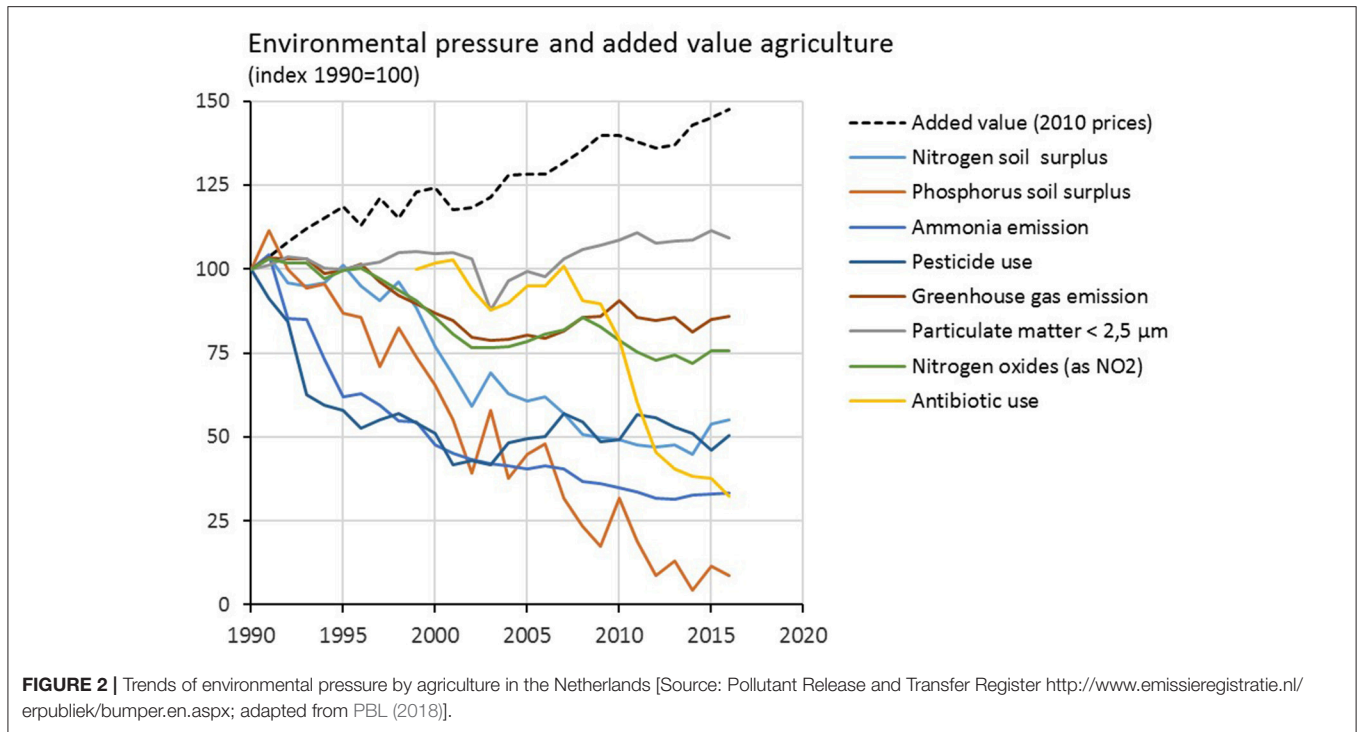
Eco-Efficiencies and Environmental Pressures

Eco-efficiencies are used to quantify the environmental degradation associated with the production of goods and services. de Wit (1992) stated that efforts to increase efficiency while serving both agriculture and its environment should not be so much directed toward the search for marginal returns of variable resources, as toward the search for the minimum of each production resource that is needed to allow maximum utilization of all other resources. This is an implicit warning against narrow (or exclusive as opposed to all-inclusive) approaches to maximize eco-efficiencies. The standard definition of eco-efficiency is “economic value added per unit of environmental damage” (Kuusmanen and Kortelainen, 2005) or, more simply and applied for agriculture, the level of agricultural output per unit of input of ecological resources like land water, nutrients etc. (Keating et al., 2010). However, as for the concept of sustainability, there are many other operational definitions of eco-efficiency (Gancone et al., 2017).

TABLE 2 | Policies, targets, and target achievement for emissions, environmental pressures, and use of pesticides and antibiotics in the Netherlands for environmental issues with a strong linkage to agricultural production.

Indicator	Policy	Target	Year (ref.)	Target achievement by dutch agriculture	Contribution of dutch agriculture to total problem	Most important measures agriculture
NH ₃ emission	EU-NEC directive	133 kton NH ₃ -N—13% reduction relative 2005	2029	100% (2016)	88% (2017)	Reduction of emission from housing, spreading, and manure storage
N deposition on terrestrial ecosystems	EU-Habitat directive	Protection Natura 2000 areas, no degradation, eventually no exceedance critical loads	No target year; no decline	32% no exceedance, 35% exceedance <7 kg N/ha, 34% >7 kg N/ha (2010). N = 160	37% (2011)	Reduction of NO _x emission from powerplant, industry and transport, and NH ₃ from agriculture
N and P in regional fresh waters	EU-WFD	All necessary measures are taken in 2027 to assure achievement of a good ecological status	2027	50% sites meets N and P targets (N = 172)	55% runoff from agricultural land	Reduction of emission from WWTP and direct input from agriculture
Biological state regional freshwater	EU-WFD		2027	Biological indicators 10–20% good, 60–80% good or moderate; 5% good one out all out	Unknown	
NO ₃ in groundwater under farmland	EU-ND and NL Fertilizer and manure act	50 mg/l	No target year; no decline	54% of farms on sandy soils, 36% on loess, 93% on clay and 100% on peat (2012–2015) (N = 400)	>95%	Reduction of use of synthetic N fertilizer, Manure N, closed periods
PM concentration in ambient air	EU-Air quality Directive and national policy	Annual average PM ₁₀ < 40 μg/m ³ , <35 d 50 μg/m ³ > PM _{2.5} < 25 μg/m ³ , reduction 37% relative to 2005 TSAP ceiling 2020 PM _{2.5} 16 kton	2029	No exceedance of annual PM _{2.5} and PM ₁₀ standards in 2009–2015	Mass fractions - Emissions: 5% in PM _{2.5} , 25% in PM ₁₀ . - NH ₄ NO ₃ aerosols contribute 40% to PM _{2.5} (2013) Exceedance in spring caused by ammonia emission by manure spreading	Air scrubbers, low emission application
GHG emission	Kyoto + NL Urgenda court case EU-UNFCCC 2017 PCA and NL draft agreement	–25% relative to 1990. –40% ETS –30% non ETS (CH ₄ , N ₂ O) –3.5 Mton in 2030 (11%)	2020 2030 1995	All sectors (2017) CO ₂ -eq: –13% CO ₂ : –13% CH ₄ , N ₂ O–50% Agriculture (2016) CO ₂ -eq: –14% CO ₂ : +5% CH ₄ , N ₂ O –32%	14% (2016), excluding land use	Manure management and reduction of use of synthetic N-fertilizer and manure N
Pesticide use	EU-directive sustainable use of pesticides (SUD) + NL policies	Hardly any exceedances of water quality standards	2023	Exceedance on 60% of monitoring sites	>95% of national use of active substances	Spray-drift-reducing techniques, buffer strips and substitution of pesticides
Antibiotics use	NL	Reduction of antimicrobial resistance; –70% for livestock use relative to 2009	2020	63% in 2017	About 70% in 2017, but human antibiotic use is not regulated	Improvement of animal welfare and robust breeds

NEC, National Emission Ceilings; ND, Nitrates Directive; WFD, Water Framework Directive; WWTP, Waste Water Treatment Plant; UNFCCC, United Nation Framework Convention on Climate Change. Urgenda court case: case of Dutch NGL against the Dutch government, see <https://www.urgenda.nl/en/themes/climate-case/climate-case-explained/>.



In assessments of eco-efficiency for agriculture, environmental emissions or pollution impacts can be considered as an input, just like e.g., input of synthetic fertilizer. An example of such a pollution input is the nitrogen surplus. The resulting value added per unit of pollution is also referred to as environmental efficiency (Reinhard et al., 1999).

We calculate efficiencies of agricultural production by accounting for resource uses and environmental emissions up to the farm gate, and therefore do not consider add-on effects of food processing, food distributions or food consumption. We benchmark eco-efficiency and environmental pressure in order to assess current performance of national agricultural sectors and systems and explore the potential to improve and combine performance on both indicators.

EU Benchmark of Emissions and Resource Use for National Agricultural Sectors

Metrics and values of efficiencies and intensities of agricultural production depend on aggregation over time and space. Using the definition of eco-efficiency as “economic value added per unit environmental damage or pressure,” we calculate national efficiencies as the ratio of an emission (or use) by the agricultural sectors per unit of Gross Added Value (GVA) of agriculture. Emissions or uses related to imports of inputs for the national agricultural sector were not taken into account. Single efficiencies were calculated for land use, emission of GHG, emission of ammonia, N surplus, P surplus for the agricultural sector as a whole. In addition such efficiencies were determined for the use of pesticides (based on sales data of kg of active ingredients in plant protection products) in the arable and horticultural sector and use of antibiotics in the livestock sector (also sales data). Data for national emissions and uses apply to the period 2010–2016 and were obtained from Eurostat (GHG, ammonia, N and P surplus and pesticide use; for data see <https://ec.europa.eu/eurostat/data/statistics-a-z/abc> and for further explanation <https://ec.europa.eu/eurostat/statistics-explained/>) and the European Medicines Agency (2017) (for Antibiotic use). Next, resulting efficiencies were indexed on the average value for the EU (**Supplementary Table 1**). We used equal weights to calculate mean national efficiency for the seven parameters. Values for the national N and P surplus can be both negative and positive. Positive values are an indicator of potential N and P loads to water, negative values are an indicator of soil mining. N and P mining can be valued as a positive environmental impacts when the soil N and P status is very high (e.g., due to over-fertilization in the past) or as a negative impact (resource depletion) when the soil status is low. For our calculation we valued a soil N or P surplus and depletion both as negative environmental impacts. We also benchmarked emissions, surpluses and pesticide use per hectare of agricultural land, and use of antibiotics per PCU (livestock “Population Correction Unit” which accounts for differences in livestock numbers and in animal weights at the time of treatment with antibiotics).

EU Benchmark of Emissions and Resource Use at Product Level by LCA-Analysis

The score on the 5 environmental indicators (land use, GHG, emission of ammonia, N surplus, P surplus) is based on the Life Cycle Analysis (LCA) methodology. LCA collects and evaluates the inputs and outputs of a production system and its potential environmental impacts throughout its life cycle (Guinée et al., 2004). We used an attributional LCA and followed the PEF (Product Environmental Footprint) guidelines of the European Commission (Pef Guidance 6.2; 2017; Blonk Agri-footprint, 2017). For the Netherlands, Germany, France, Poland, Spain, Romania and Italy an inventory is made of the inputs and outputs of materials, energy and emissions at each stage in the life cycle of a product. This is then translated into one or more environmental impact categories. Land use and greenhouse gas emissions are part of the regular range of impact categories used in LCA. For the other 3 indicators (production value, N and P surplus and ammonia emission) indicators have been derived on the basis of the same way of thinking. Ammonia emission factors are taken from the emission factor database of European Environment Agency (2016: <https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/emission-factors-database>) and for greenhouse gases from IPCC (<https://www.ipcc-nggip.iges.or.jp/EFDB/main.php>). Land use or emission per unit of agricultural product in fact is the reciprocal of the environmental efficiency.

Six products were selected that are important for Dutch agriculture: three animal products (milk, pig meat, and poultry meat) and three crop products (wheat, ware potato, and fresh tomato). For our benchmark we selected for each product the five EU-countries with the largest production sizes in 2014–2016 (see **Table 5** for the countries selected), for reasons of data availability we took pork data from the Czech republic instead of Poland. The system boundary is cradle to farm gate. The functional unit is kg live weight (LW) for pork and poultry, kg FPCM (Fat-Protein Corrected Milk) for milk and kg crop for tomato, potato, and wheat. For multifunctional production processes, allocation is required for partitioning the economic and environmental effects; economic allocation was applied for milk, ingredients for concentrates (e.g., soybean), of roughage (crop residues), wheat (straw) (Blonk Agri-footprint, 2017). For milk the guidelines of the International Dairy Federation were used (IDF, 2015).

Economic value is expressed per kg of the primary product. Land use distinguishes between direct use in country and indirect land use related to import. Considered greenhouse gases (GHG) are CO₂, N₂O and CH₄. They are expressed in kg CO₂ equivalents/kg using Global Warming Potential for 100 years and the IPCC tier 2 (IPCC, 2013) and include effects of LULUCF in the past 20 years following ISO (2013) and Technical Secretariat Dairy PEF (2016) standards. Calculation of GHG emission related to LUC from imported products for animal feed takes into account the actual countries for trade in EU and an EU average for feed stuffs imported from the actual countries outside Europe. Feed data for EU countries were taken from Britz and Witzke (2012).

Calculation of N and P surplus for tomato, potato and wheat only considers inputs of synthetic fertilizer and manure, the crop harvest accounts for N output; inputs from atmospheric deposition and biological fixation were not considered in our benchmark. The manure application rates are estimated using statistics for number of animals, the manure produced and the total area on which manure can be applied (Blonk Agri-footprint, 2017; Kuling et al., 2018). This estimate represents an average amount of manure applied per hectare (independent of the crop being cultivated). In reality, the amount of manure applied will depend on the specific crop that is being grown and on the geographic and temporal availability of manure. However, such detailed information is not available for all countries considered.

The gross N and P excretion is based on the balance of N and P by feed intake and export in milk and meat and does not account for gaseous N losses from housing and storage. Emission of ammonia is accounted for across the full production chain, including emissions from housing, storage and at application to food and feed crops, using the Tier 2 approach as proposed by the European Environment Agency (2016).

For benchmarking, the five indicators for the Netherlands efficiencies were quantified using two sets of input data. The first set only used data sources that were available for all countries in the benchmark. The second set uses the best data available for the Netherlands. An example is the calculation of emissions of ammonia and nitrous oxide where the first set uses default EU emission factors and the second set uses Dutch emission factors reflecting the effect of the most recent measures. The second set also uses more accurate values for the application of manure to cropland in the Netherlands.

RESULTS

Benchmark of Efficiencies and Pressures for National Agricultural Sectors

The aggregated eco-efficiency for national agricultural sectors vary by a factor of five (highest over lowest index in **Table 3**). For individual emissions or uses the range is much larger; 4.5 for pesticide use, 5.0 for ammonia emission, 11.4 for GHG emission, 12.9 for N surplus, 20.2 for use of antibiotic, 31.5 for land use and 57.1 for P surplus. The large ranges illustrate the current differences of agricultural structure and practices in the EU and also provides an indication of the scope for improvement. The five EU members states (MS) with the highest eco-efficiency are (1) The Netherlands, (2) Greece, (3) Italy, (4) France, and (5) Sweden; the bottom five (25) Czech Republic (24) Estonia, (23) Latvia, (22) Ireland, and (21) Poland (**Table 3**). While the worst performing countries are mostly new EU MS in Eastern and Central Europe, the top five may be a mix of countries with either high or low levels of GDP, technology, implementation of environmental regulation and intensity of agriculture. GVA per hectare varies from 170 to 5,300 euro/ha. Typical values for new MS in Eastern Europe range from 170 (Latvia) to 970 (Slovenia), values around 1,000 euro/ha are typical for the large older MS's Germany, France Denmark and the UK, while highest values are found for Belgium, Italy and a maximum of 5,300 euro/ha in the

Netherlands. Differences in GVA per ha are caused by differences in agricultural structure, yields per hectare and costs of labor and capital. One important reason for the very high GVA per hectare in the Netherlands, is the presence of a large horticultural sector (greenhouse, both food and ornamental), mainly for export, and which contributes about 60% to the national GVA of the primary agricultural sector and 34% of GVA of the agro-complex.

The high eco-efficiency for Greek agriculture is remarkable and reflects a combination of a fairly high GVA per ha and relatively low inputs of chemistry. The high efficiency is also caused by a combination of a relatively small livestock sector and low P surpluses. For France, Ireland and the Netherlands, with a large agricultural sector and contribution to EU food supply by export, attaining the efficiency of Greek agriculture likely goes along with lower inputs of agrochemicals per hectare and smaller livestock sectors. At the low end of the spectrum, the very low eco-efficiency of the Czech Republic may illustrate that new EU MS where agriculture is in transition, the increase in GVA per hectare lags behind on the increase of environmental pressure due to increased use of agro-chemistry.

The flip side of the coin for EU member states with high eco-efficiencies can be a high environmental pressure per hectare of land and the risk of local impacts of agriculture on natural ecosystems and human health. The three countries with the highest environmental pressure (with ranking for eco-efficiency also given) are the Netherlands (25; 1), Belgium (24; 15) and Italy (23; 3); those with the lowest pressure Latvia (1; 23), Lithuania (2; 16), and Slovakia (3; 20).

While the Netherlands, Italy, Slovakia and Latvia combine high and low rankings for eco-efficiency and pressure, some countries combine high rankings (Greece, Sweden, Romania, Austria, France) or low rankings (Belgium, Czech Republic, UK). The top three countries with the highest combined score, using equal weights for all environmental issues and for eco-efficiency and environmental pressure, are (1) Greece, (2) Sweden and (3) Romania (**Figure 4**). Also the combined score for France (rank 4), a major agricultural sector and exporter of cereals in Europe is noteworthy and Austria (5). The lowest combined scores are found for Belgium (25), the Netherlands (24) Czech Republic (23), Spain (22), and the UK (21).

The message of the EU benchmark of eco-efficiencies and environmental pressures for national agricultural sectors seems to be that a middle of the road approach to agriculture, with a medium production intensity and use of agro-chemistry could be the way forward to increase the sustainability of European agriculture. This direction implies that environmental pressure has to decrease in the old MS and GVA has to increase in the new MS, while securing that total production satisfies current and future demand for food, fibers, fuels etc. in the EU. When developing policies in this direction, national outliers of eco-efficiency and environmental pressure should be given attention. Regarding environmental pressure (**Table 4**) these outliers are: pesticide use in the Netherlands, Belgium and Italy; the use of antibiotics in Spain, Italy and Hungary; ammonia emissions in the Netherlands, Belgium, Germany, and Slovenia; N and P surpluses in the Netherlands, Belgium and Denmark; nutrient

TABLE 3 | Indexed eco-efficiencies for EU28 in period 2010–2015.

		Gross value added per unit of emission or use (Index 100 = mean value EU)								
		Pesticides use	Antibiotics use	Ammonia emissions	N surplus	P surplus	GHG emissions	Land use	Mean score	Rank
AU	Austria	155	128	102	194	60	107	107	122	6
BE	Belgium	70	20	81	101	108	63	181	89	15
BU	Bulgaria	190	103	97	102	12	87	35	90	14
CR	Croatia	98	82				107	78	91	12
CZ	Czech Republic	47	64	52	25	29	49	44	44	25
DK	Denmark	150	64	91	94	75	75	112	95	9
ES	Estonia	98	83	63	56	7	62	32	58	24
FI	Finland	68	263	96	76	40	53	57	93	11
FR	France	84	97	111	93	382	100	105	139	4
GE	Germany	82	31	69	64	300	78	118	106	8
GR	Greece	185	173	219	42	422	171	103	188	2
HU	Hungary	69	41	94	56	44	133	60	71	18
IR	Ireland	133	52	44	69	56	31	49	62	21
IT	Italy	102	55	199	122	72	278	258	155	3
LV	Latvia	45	109	52	88	60	33	18	58	23
LT	Lithuania	79	204	76	109	36	64	38	87	16
NL	Netherlands	180	89	205	150	125	144	556	207	1
PO	Poland	75	36	75	53	51	79	63	62	22
PT	Portugal	42	35	125	193	62	102	69	90	13
RO	Romania	128	63	107	323	37	106	53	117	7
SK	Slovakia	55	102	44	59	121	53	31	66	20
SV	Slovenia	88	193	66	83	53	74	102	94	10
ES	Spain	63	21	126	73	37	186	78	83	17
SE	Sweden	150	403	83	90	116	68	60	138	5
UK	United Kingdom	101	61	103	41	26	66	93	70	19
	EU mean	501	42	44	52	1209	365	950		
	Unit	€/g	€/mg	€/kg	€/kg	€/kg	€/g CO2-eq	€/ha		

Values for the small EU members states Cyprus, Luxembourg and Malta were removed from analysis. Combination of EU mean values and indices allow calculation of national values. Use of traffic light colors of green, yellow to red for index values indicates decreasing sustainability.

mining in Estonia and Romania. Regarding low eco-efficiencies (Table 3) the outliers are: pesticide use in Portugal, Latvia and the Czech Republic; use of antibiotics in Spain, Belgium, Germany, Poland, and Portugal; ammonia emissions in Slovakia, Ireland, Latvia, Czech Republic; nutrient surplus in the Czech Republic, UK, Estonia, Poland; GHG emissions in Ireland, Czech Republic, and Latvia.

Using mean scores to rank eco-efficiency and environmental pressure in Tables 3, 4 does not yet make a distinction between global and local environmental issues. Figure 5, however, does plot mean scores for eco-efficiency for global environmental issues (land use, GHG, and antibiotics) against the score for environmental pressure for local issues (NH₃ emission, N and P surplus, pesticide use) and clearly reveals that Dutch, and to a lesser extent also Belgian and Italian, agriculture take outlying positions. Agriculture in Sweden and Greece appear to be more successful in combining relatively high eco-efficiencies with low environmental pressure per hectare. We do acknowledge that giving equal weights to the five selected indicators of environmental pressure is arbitrary.

Highlights of Differences in Production of Selected Agricultural Products Between Countries

To see whether the high score for eco-efficiency of the agricultural sector in the Netherlands also holds for individual products, six of them were benchmarked against other main producers in Europe. For this benchmark an important notion is that differences between national eco-efficiencies and also emission or resource per unit of agricultural product to a large extent are the result of different production systems e.g., regarding availability and use of local feeds and forages in livestock farming and manure in crop farming, or the presence of mixed or specialized farms. National production systems were analyzed in detail for the LCA approach and some highlights are summarized below to help understand results for different scores for the same product in different countries: (for details see Supplementary Table 2).

Dairy Production

Farm gate prices for dairy in Italy (IT) are with 0.40 €/kg FPCM 0.06–0.08 €/kg higher than in the Netherlands (NL), France (FR)

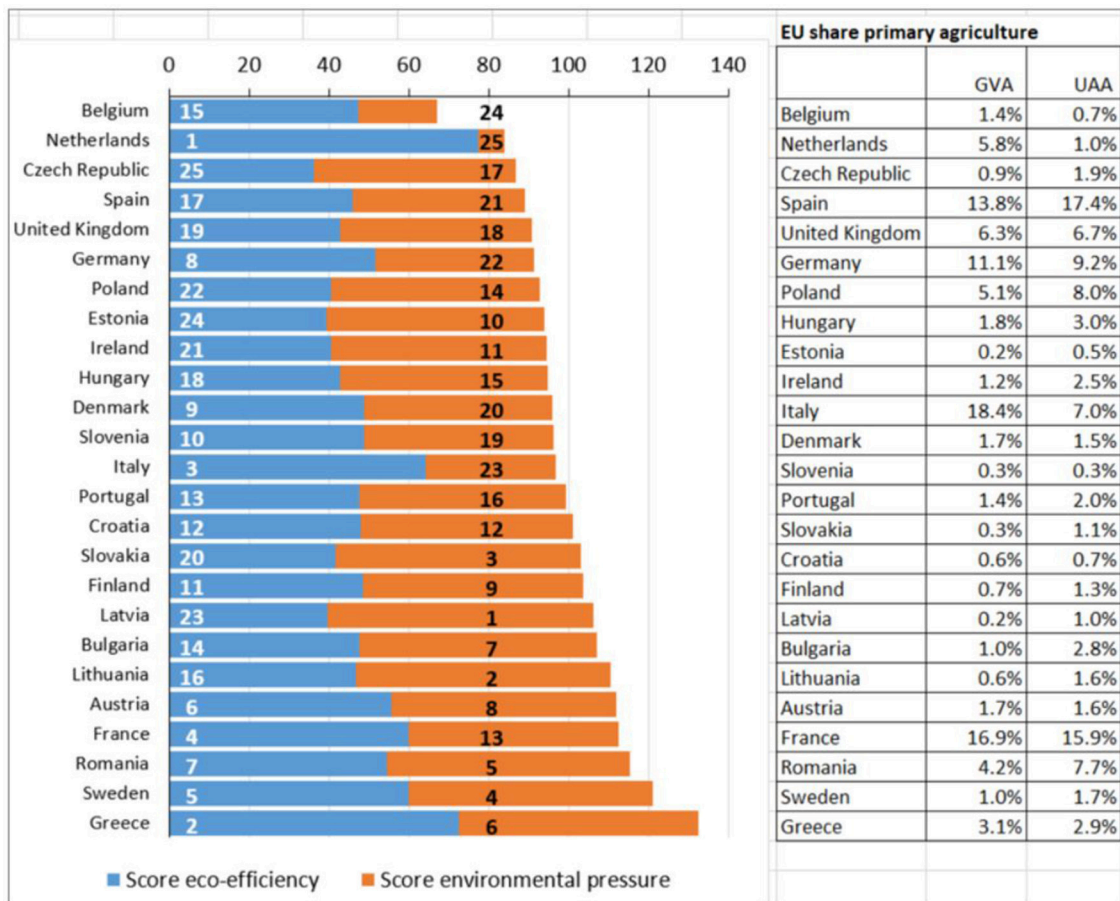


FIGURE 4 | Combined score of eco-efficiency for global environmental issues in **Table 3** and environmental pressure for local issues in **Table 4**. In order to get equal weights, both scores were indexed to obtain a mean EU score of 50. Numbers in bars are the rankings as in **Tables 3, 4**. In addition percentages are given for the EU share of GVA and Used Agricultural Area (UAA) of national primary agricultural sectors.

and Germany (GE) and even 0.13 €/kg higher than in Poland (PL). High prices as in IT increase the eco-efficiency. The use of agricultural land per kg FPCM is between 1.0 and 1.2 m² in NL, GE, FR and IT, which is almost twice as low as in Poland (PL). The share of land for feed used abroad ranges from about 20% in GE, FR and PL to 40% in IT and 47% in NL.

Pork Production

Farm gate prices for pork are around 1.2 €/kg LW in GE, Czech Republic (CZ) and Spain (ES), while being 0.1 €/kg lower in NL and 0.1 €/kg higher in France. Land use per kg LW varies considerably; from 3.5 m² in GE, FR and NL up to 5.2 m² in CZ and 6 m² in ES, reflecting differences in feed conversion efficiencies. The share of land use related to imported feed ranges from 2% in CZ, to 20% in FR to almost 30% in GE and ES to over 90% in NL.

Poultry Meat Production

Farm gate prices for chicken meat range from around 0.9 €/kg LW in GE, NL and Poland (PL), to 1.2 €/kg in ES and 1.8 €/kg in France. Chicken meat is traded in regional French

markets at considerably higher prices than on the common EU market. Land use per kg LW is between 2.5 and 2.8 m² in GE, FR and NL up to 3.3 m² in PL and 3.5 m² in ES, reflecting lower feed conversion efficiencies in the latter two countries. The share of land used abroad ranges from 36% in PL, to 42% in FR, to around 55% in GE and ES to over 90% in NL.

Ware Potato

Farm gate prices in FR and RO (0.3–0.4 €/kg) are much higher than in GE, NL, and PL (0.1–0.2 €/kg), again, indicating the presence of local markets with higher prices. Land use per kg of potato shows an opposite pattern with low values (so high yields) ranging from 0.22 to 0.25 m²/kg in NL, GE and FR, and high values in PL (0.52) and RO (0.92).

Wheat

In contrast to potato, wheat prices are uniform across the EU around 0.21 €/kg. Sale of straw adds on an average 0.06 €/kg to the income from wheat cultivation. Land use per kg of wheat

TABLE 4 | Indexed environmental pressure per hectare of agricultural land for EU28 in period 2010–2015 (for antibiotics per PCU).

Emission or use per hectare UAA (PCU for antibiotics): (Index 100 = mean value EU)								
	Pesticides use	Antibiotics use	Ammonia emissions	N surplus	P surplus	GHG emissions	Mean score	Rank
Austria	53	48	93	34	63	84	63	8
Belgium	198	140	199	206	109	245	183	24
Bulgaria	14	89	32	25	114	34	52	7
Croatia	61	94				62	72	12
Czech Republic	73	68	76	127	63	76	80	17
Denmark	57	38	110	129	92	128	92	20
Estonia	25	60	46	44	189	44	68	10
Finland	64	19	53	80	86	93	66	9
France	95	86	84	83	11	89	75	13
Germany	111	147	154	143	17	128	117	22
Greece	43	50	42	102	6	51	49	6
Hungary	66	187	57	64	46	38	76	15
Ireland	28	45	99	65	46	135	70	11
Italy	194	291	116	84	80	79	141	23
Latvia	30	33	30	14	11	45	27	1
Lithuania	37	31	45	23	40	50	38	2
Netherlands	236	68	242	286	195	329	226	25
Poland	64	121	75	78	46	68	75	14
Portugal	126	147	50	29	52	58	77	16
Romania	32	91	44	12	57	43	47	5
Slovakia	43	47	62	55	15	50	46	3
Slovenia	89	29	139	91	80	117	91	19
Spain	95	310	55	65	74	36	106	21
Sweden	30	11	64	65	29	75	46	4
United Kingdom	70	52	80	111	97	120	89	18
EU mean	2.48	115	24.3	57.9	4.37	3.06		
Unit	kg/ha	mg/PCU	kg/ha	kg/ha	kg/ha	tCO ₂ -eq/ha		

N and P surplus were negative in some countries and therefore the absolute value was used for indexing. Values for the small EU members states Cyprus, Luxembourg and Malta were removed from analysis. Use of traffic light colors of green, yellow to red for index values indicates decreasing sustainability.

ranges from 0.96 to 1.14 m²/kg in NL, GE and FR, while in PL it is 1.9 and in RO 2.6 m²/kg.

Fresh Tomato

Price per kg ranges from 1.9 €/kg in IT to 1.2 €/kg in FR to 0.95 €/kg in NL and ES. Farm gate price differences in part are caused by different cultivars. While IT predominantly produces higher priced cherry tomatoes, other countries also grow larger and cheaper fresh tomatoes. Land use per kg shows a wide range, which in part is caused by dominant cultivation in greenhouses in NL and ES, while in FR and IT, respectively 40 and 60% of fresh tomatoes are cultivated outdoor in arable systems. Land use per kg is 0.02 m² in NL, 0.05 m² in FR, 0.12 m² in ES, and 0.28 m² in IT.

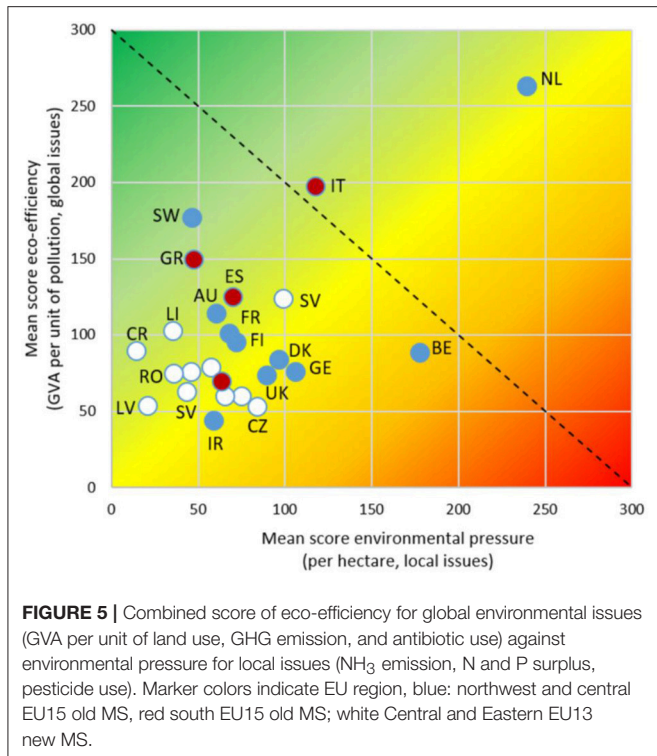
Benchmark of Greenhouse Gas Efficiencies for Agricultural Products

Greenhouse gas emissions for dairy in NL, GE, FR and IT are very comparable around 1.7 kg CO₂ eq/kg FPCM (Figure 6). Main GHG sources are enteric methane formation and N₂O from national forage production. In PL GHG emissions are significantly higher due to lower feed conversion ratios (FCR)

and, consequently, also higher enteric methane production. Using more accurate national data on Dutch feed use as an alternative for harmonized EU data from the CAPRI model (Britz and Witzke, 2012) slightly decreases GHG emissions for NL dairy.

For pork, total GHG values are quite comparable around 3 kg CO₂ eq/kg LW. GHG emissions in NL are slightly higher than in GE and FR in spite of more efficient feed conversion (lower FCR in kg LW per kg feed; see Supplementary Table 2) and due to higher GHG emission related to the origin of imported feed (Figure 6). GHG emissions for PL and IT are considerably higher due to lower FCRs. In NL, imported feed is by far the largest source of GHG, while in other countries contributions from domestic and imported feed are comparable. Using more accurate national data on average daily growth, litter size (number of piglets per litter), litters per sow per year, and parameters for methane losses from manure, the net CO₂-eq GHG emission for the Netherlands increases, mainly due to higher estimates of methane emission from manure storages.

For broiler systems, emissions in NL, GE, FR, ES and PL are very comparable (Figure 6), ranging between 2.0 and 2.3 kg CO₂ eq/kg LW, irrespective if more accurate data are used for

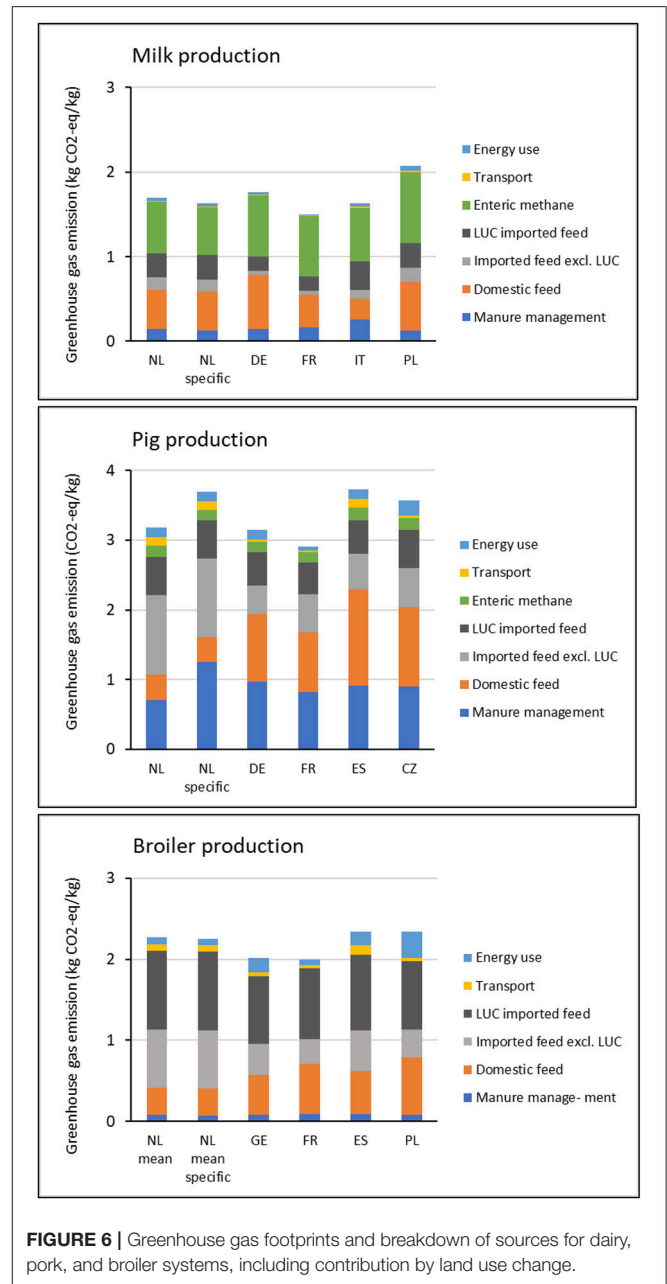


NL, indicating that technology and management, and resulting performance in broiler systems in the five considered countries are similar and more comparable than for pigs and dairy.

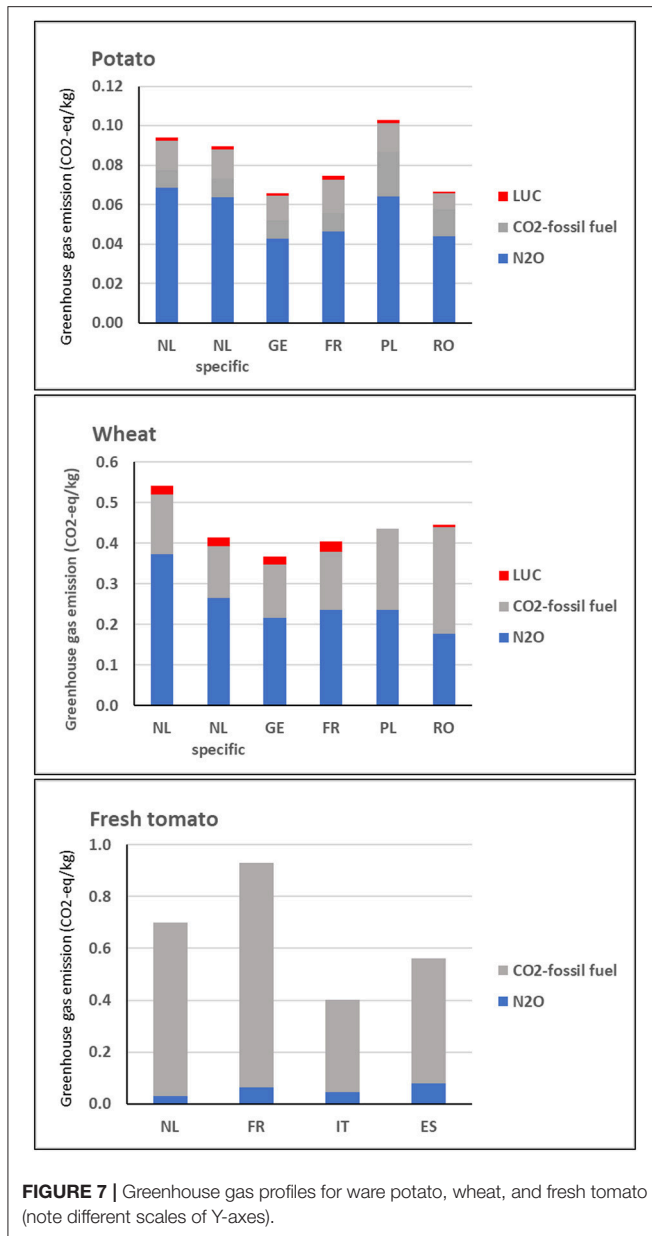
In conclusion, for pork and poultry GHG footprints related to feed have the largest share in total GHG footprints. Differences between countries are related to the FCR, while whether countries import most of their feed (NL) or whether they produce it themselves (GE, FR) has a much smaller effect on the GHG footprint.

For dairy, the share of GHG emission due to LUC -historic conversion of natural land to land for cultivation of feed crops-ranges from 11% (GE and FR) to around 20% for NL and IT (Figure 6 and Supplementary Table 2). Differences are caused in the use of peat lands for grazing and origin of feed imports. Further differences are caused by differences in the relative shares of local fodder (grass, forage maize) and by regions from which feed stuffs (soy cakes, cereals) for concentrated feed are imported. For pig production the shares of GHG from LUC are similar to dairy but vary less between the selected countries (13–18%) because feed rations are more similar. For poultry the shares of GHG from LUC are much higher due to larger shares of imported soy cakes and corn in rations, ranging from 36% in PL and 42% in FR to 93% in NL. So particularly for broiler systems in the EU, the GHG footprint is fairly independent of the location. Emission related to LUC are for 90% or more due to imported feed, mainly soy products from outside the EU.

For cultivation of ware potato and wheat in Europe the dominant source of GHG is emission of N₂O (Figure 7) and due to use of N fertilizers (synthetic and manure). The composition of the GHG profile of crop products is much simpler than



for animal products as there are only a few upfront processes. GHG emissions due to LUC only due to discounting for local LUC in the past 20 years and therefore small for EU countries. GHG emissions for ware potatoes in NL and RO are between 0.09 and 0.10 kg CO₂ eq per kg, and considerably higher than in GE, FR and PL (Figure 7). For NL this is due to the high emissions of N₂O caused by the high inputs of total N from both synthetic fertilizer and manure, adding to around 300 kg/ha, as compared to 160–175 kg/ha in GE and FR and 60–70 kg/ha in PL and RO (see Supplementary Table 2). Application rates of manure and associated N₂O emissions in NL are 5–15 times higher than in the other four countries (see Supplementary Materials). High manure use in NL is caused



by the combination of the high national availability of manure in NL and the use of statutory fertilizer equivalencies (FEV) for manure N in the EU (Webb et al., 2013). For the Netherlands, FEVs range from 0.45 to 0.7 and allow exchange of 1 kg of synthetic N by 1.5 to more than 2 kg of manure N, as long as the maximum amount of 170 kg N is not exceeded, as required by EU Nitrates directive (van Grinsven et al., 2012). This effect cancels out the reduction of GHG emission per kg of Dutch potato production by the higher yields. These effects persist when we use best available data instead of harmonized data for NL. In the best data variant we account for export of about one quarter of the national Dutch manure production (40 million tons of P₂O₅ of a total national production of about 175) to allow compliance with legal application standards for N and

P₂O₅. In RO the high GHG foot print is related to lowest yield per hectare.

For wheat similar results are found as for potato, but differences between countries are smaller because, compared to potato, N fertilization of wheat in other countries is somewhat higher and for NL somewhat lower (Figure 7). In the best data variant the Dutch GHG profile becomes comparable to that of the other countries.

For Dutch tomato, the dominant source of GHG is direct and indirect use of fossil fuel. The positive effect of higher yields on the GHG profile is partly canceled out by the high use of fossil energy to heat Dutch greenhouses (Figure 7). However, Dutch greenhouse systems increasingly produce electricity and heat from renewable energy sources (solar and geothermal), which improves the GHG profile. Conversely, the decrease of GHG profiles in FR, ES and IT by growing tomato outdoor is canceled out by far lower yields than in NL.

Benchmark of Nutrient Efficiencies for Agricultural Products

While for GHG the location of the emission is irrelevant for the impact on climate, location is relevant for emission of nitrate, phosphorus, and ammonia and its impacts on human health and ecosystems. Particularly emissions of ammonia are a reason for concern in Europe in view of significant contributions to health damage by air pollution (Pozzer et al., 2017) and loss of terrestrial biodiversity (Sutton et al., 2011). Ammonia profiles for livestock products in NL, GE and FR are quite similar when using harmonized EU data (Table 5). However, when using best data for NL, accounting for effects of stringent ammonia policies both for controlling emission from housing and manure application, ammonia profiles are about twice as low. This illustrates that, in contrast to GHG profiles, end-of-pipe measures to a large extent mitigate ammonia pollution.

The consequence of ammonia reduction is an increase of the nitrogen content in manure, which, on the one hand, potentially increases the beneficial use of N by crops, on the other hand, increases the risk of leaching and water pollution. For livestock products the N and P surplus is calculated at animal level and in fact are gross excretions; for crop products N and P surplus are quantified at soil level. Therefore, the surplus for livestock products are less indicative for impacts than surplus for crop product. When using harmonized EU data, the N surplus per kg milk in NL, GE, and FR is very similar and lower than for IT and PO, mainly because of higher milk yields per unit of land and cow (Table 5). Using best data for the Netherlands, N excretion decreases by 37% and is caused by lower average N in Dutch feed rations. P excretions per kg milk are similar in NL, GE, FR, and also IT, but in CZ higher due to lower yields and FCRs. Using specific Dutch data lowers P excretion by 20%, again due to use of low P feed concentrates. In NL there is an economic incentive in dairy farming to use low N and P feed, as this reduces the cost of manure disposal (van Grinsven and Bleeker, 2017). For meat production, using harmonized data results in comparable N excretions, for pork ranging from 31 (NL) to 36 (GE) g/kg and for poultry ranging from 20 (NL and PO) to 23

TABLE 5 | Nutrient losses in gram per kilogram of agricultural product for a selection of commodities and EU countries (milk per kg FPCM, pork, and poultry per kg live weight).

Product	NL	NL spec	GE	FR	IT	ES	PO	CZ	RO
N surplus (g N / kg product)									
Milk	26.1	16.5	25.6	26.3	30.3		34.3		
Pork	31.1	38.8	36.4	35.4		33.2		46.6	
Poultry	20.1	21.8	19.0	22.7		22.5	20.1		
Ware potato	3.7	2.6	0.5	0.7			-0.1		0.6
Wheat	23.0	5.7	2.3	4.3			3.6		-5.6
Fresh tomato	1.5			4.5	2.1	6.3			
P surplus (g P / kg product)									
Milk	3.0	2.4	2.9	3.3	3.2		4.4		
Pork	4.7	6.7	5.6	5.5		5.1		7.5	
Poultry	2.1	3.4	1.9	2.4		2.4	2.1		
Ware potato	0.9	0.2	0.4	0.4			0.2		0.3
Wheat	2.7	-0.9	-1.3	-1.7			1.0		-1.7
Fresh tomato	0.0			0.1	1.1	2.0			
Ammonia emission (g NH₃ / kg product)									
Milk	14.1	7.7	14.6	14.9	17.4		16.6		
Pork	24.4	13.7	27.1	28.1		29.1		37.1	
Poultry	15.0	6.6	13.6	15.6		16.8	14.9		
Ware potato	1.4	0.4	0.6	0.6			0.6		0.8
Wheat	7.0	2.2	2.9	2.9			3.1		2.1
Fresh tomato	3.1			2.9	2.9	7.0			

(FR) g/kg. For P differences between countries are similar as for N (Table 5). Excretions in CZ are higher due to lower FCR. In contrast to milk, using best data for NL increase excretions to values exceeding those in all countries but CZ. N and P contents in Dutch feed are higher than default values we used for EU feed compounds. In contrast to the dairy sector, for most Dutch pig and poultry farmers there is no economic incentive to buy feed with low N and P contents. The feed is more expensive and, as most farms are nearly landless, all manure needs to be disposed in any case.

For crops only results for potato and wheat are relevant, as the acreage for tomato is very small and tomato cultivation hardly contributes to eutrophication. Irrespective of use of harmonized data or best data, N surpluses in NL are higher than in all countries due to high fertilizer inputs and the high share of manure N. P surpluses for both crops vary strongly between countries, with generally negative values for wheat (except PO) and low P surpluses for potato (Table 5). When using harmonized values, P surpluses for NL are the highest, when using best data (correction for manure export) they are in the same range as for other countries.

Synthesis Benchmark Efficiencies for Agricultural Products

When aggregating the indexed scores for land use and the four impacts, results indicate that Dutch environmental performance for the six products studied, even when using best data, differs not very much from that in Germany and France, but generally is better than in developing agricultural systems in Poland, Czech Republic, Romania, and agriculture in the Mediterranean

countries Spain, Italy (Table 6). Environmental performance of fresh tomatoes in the Netherlands stands out, but its contribution to environmental pollution and resource use is small. The position of the Dutch arable sector is somewhat ambiguous due to large differences of scores when using harmonized EU data and best national data. Further, scores for especially Germany and France could also improve when using best national data and taking their national policies into account.

This raises the issue of uncertainties. These were not quantified for this study, but a previous study on the GHG footprint of pig production systems in the Netherlands, Germany, Denmark and the UK estimated uncertainties at 10–15% (Kool et al., 2009). If this uncertainty would apply to indexed scores in Table 6, together with the fact that we lack best data variants for other countries, this would confirm that differences between NL, GE and FR in environmental performance for all six products, and with respect to potato and wheat also for PO, are not substantial. Differences between NL and all other countries are significant for livestock products and tomato only. Assuming a generic uncertainty of 15% also indicates that Dutch dairy may perform somewhat better than in GE and FR.

As for the analysis at national sector level, we visualize the presence trade-offs between local and global environmental impacts and the position of product performance for the different countries by plotting the aggregated score for N and P surplus and ammonia against land use and greenhouse gas emission per kg of product (Figure 8). There is weak tendency that local pollution increases with increasing use of land and emission of GHG. Countries with a high index (>1) for land use and GHG are almost exclusively in Central, Eastern and Southern EU.

TABLE 6 | Mean environmental pressure index for land use, greenhouse gas emission, nutrient surplus, and ammonia emission per kg of product. Scores for N and P surplus are combined, as well as the scores for tomato in Spain and Italy.

Product	Netherlands		Germany	France	Poland Czech Republic	Spain Romania Italy
	EU data	Best data				
Milk	0.91	0.73	0.91	0.92	1.28	0.99
Pork	0.86	0.88	0.92	0.91	1.21	1.10
Poultry	0.98	0.93	0.89	0.98	1.03	1.11
Ware potatoes	1.54	0.88	0.70	0.75	0.74	1.26
Wheat	1.52	0.70	0.71	0.81	0.91	1.05
Fresh tomatoes	0.53	0.53		0.84		1.18

Use of traffic light colors of green, yellow to red for index values indicates decreasing sustainability.

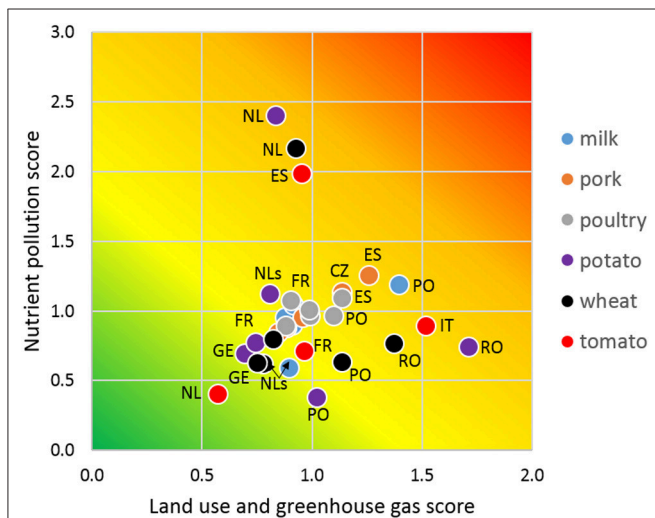


FIGURE 8 | The relation between local nutrient pollution impacts of agricultural products against potentially global impacts of land use and greenhouse gas emission.

When using best Dutch data (NLs) most other scores are in a narrow cluster, where NL does not stand out.

DISCUSSION AND CONCLUSIONS

Our analysis leads to acceptance of our hypothesis that environmental pressure and GHG emission per unit of agricultural product in the Netherlands are not notably different from those for other Northwest European countries. Due to high yields, land use for arable and horticultural products in the Netherlands is low compared to the other countries studied. However, nitrogen surplus and GHG emission per unit of product are relatively high for the arable products from the study, due to the large share of manure in fertilizer application. The associated increase of losses of reactive nitrogen and GHG (N₂O and CH₄) is not compensated by the high yields. For tomato, GHG emission per kg are average despite the large amount of natural gas used for heating greenhouse. The environmental pressure per kilogram of pork or chicken meat in the Netherlands

is not much different from that in Germany or France and probably also not per liter of milk.

In view of the “hole-in-the-pipe-concept,” risks of negative feedbacks and pollution swapping regarding the environmental quality tend to be higher for end-of-pipe measures (Davidson et al., 2000) and lower for more fundamental structural measures, like restriction of consumptive demand or reduction of the most polluting economic activities. There is an ongoing and tenacious political debate in the Netherlands about reduction of the livestock sector in view of climate and environmental issues, but until now there was no political support for direct policies in this direction, or more general, interventions to change the structure of demand and supply in the Dutch agro-food system. However, structural policies are anew on the table in the implementation of PCA in the Netherlands and the negotiations on the national climate agreement. The recent vision of the Dutch government on the future of agriculture shows an increasing ambition to reduce GHG emissions, environmental impacts and make agricultural more circular and nature inclusive (Ministry of Agriculture Nature and Food Quality of the Netherlands, 2018). However, this vision does not mention the ambition to reduce the production volume of most polluting agricultural sectors, except for the pig sector. The Dutch government has reserved a budget of 120 million euro for reduction of the pig stock, which would allow a buy up of maximum of 5% of the current stock (Hekkenberg and Koelemeijer, 2018). But livestock could also be reduced as an indirect effect of increased production costs due to stricter environmental regulations to reduce emissions of GHG, ammonia, nitrate, and phosphorus. When foreign demand for livestock products remains unchanged, a reduction of livestock in the Netherlands likely would cause an increase of livestock elsewhere in the EU or in the America’s.

Our results indicate that claims in politics and business that relocation of meat and dairy production to elsewhere in the EU would cause a net increase of environmental emissions are not valid. When embedded in adequate policy schemes, moving some of the Dutch livestock farming elsewhere may reduce environmental and nature problems in the Netherlands, and without risks of increased GHG emissions and land use. Important aspects to take into account for optimal allocation of agricultural production in Europe are, among others, natural differences in environmental efficiencies of regional land based

agriculture and differences in sensitivities of ecosystems and emission-exposure relation for humans and ecosystems. For example, critical loads of terrestrial ecosystems in Eastern EU tend to be higher than in northwestern EU (van Grinsven et al., 2018). Concerns are legitimate that an increase of livestock production in Central, Eastern and Southern Europe on short-term will be accompanied by expansion and intensification of feed production and which would increase the total environmental impact of EU agriculture. These risks could, however, be managed and reduced by a combination of targeted EU economic and environmental, regionally differentiated, policies guiding environmentally responsible growth. Ideally, developments in this direction should be accompanied by programs to transfer knowledge and technology in order to narrow the gap between resource use efficiencies between these regions and Northwest European agriculture.

A dilemma in our analysis is the relative weighting of global vs. local environmental issues. Because the agro-food system creates a multitude of environmental effects brought about by specific agricultural practices and production systems, it is important to look for integrative indicators for the suite of possible impacts. Our analysis suggests that in Europe there are no national agricultural systems for specific products that can combine high eco-efficiencies, efficient land use and low GHG emissions, with low local environmental pressure. This dilemma touches the discussion on land sparing or land sharing. Extensive field data suggest that impacts on biodiversity would be greatly reduced through boosting yields on existing farmland so as to spare remaining natural habitats (Phalan et al., 2011). However, high-yield farming may generate high levels of externalities such as greenhouse gas emissions and nutrient losses. But these metrics also underestimate the overall impacts of lower-yield systems (Balmford et al., 2018). Therefore, accomplishment of sustainable, eco-efficient agriculture systems demands difficult societal choices, including reduction of consumption of food products with high resource use and pollution profiles (UNEP, 2016; Kok et al., 2018). Moreover, aiming for high productivity or high eco-efficiency ignores immaterial aspects of sustainability (e.g., soil fertility and animal welfare) and planetary boundaries such as those for N, P, and GHG (Steffen et al., 2015).

In conclusion, solution of the global climate and biodiversity problems and local or regional—sometimes

transboundary- eutrophication problems would benefit from a European rather than a national approach. Reduction of livestock in the Netherlands could be an alternative for current choices in the draft climate agreement to reduce national GHG emissions by reduced peat drainage and improved manure managements, because of more certain national GHG reduction and more side-benefits for air and water quality. The most important barrier for such an approach, including optimal allocation of production targets and resources to European regions are loss of vested economic interests and returns from current infrastructure of the agro-food supply chain and investments in a new production infrastructure elsewhere (van Grinsven et al., 2018). Also optimization targets can be problematic in view of existing and changing national values regarding climate or biodiversity, and food and sustainability in general (Candel and Pereira, 2017; de Krom and Muilwijk, 2018). There appears to be a need for development of new narratives and scenarios for exploring options for an EU agro-food system with minimum resource use, GHG emission and environmental pollution, that consider, in addition to alternative diets, also alternative economic structure and spatial layout. These narratives could be superimposed on the current set of IPCC shared socio-economic pathway scenarios (Van Vuuren et al., 2017).

AUTHOR CONTRIBUTIONS

HvG was the lead author and carried out the analysis for national agro-food sectors. MvE synthesized the LCA results, and together with SK drafted the policy conclusions and with HW reviewed and co-authored.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2019.00013/full#supplementary-material>

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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