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Joint Working Party on Agriculture and the Environment

AGRI-ENVIRONMENTAL INDICATORS: NUTRIENT BALANCES

The report presents a summary of the most recent trends of nutrient balance indicators in OECD countries. Nutrient surpluses are some of the leading causes of water contamination in OECD countries.

This report also performs an econometric analysis to understand some of the main drivers of nutrient surpluses, as well as the role of agricultural policies and agri-environmental policies to tackle nutrient pollution from agriculture. It ends with two country studies.

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The statistical data for Israel are supplied by and are under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

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Key messages

For the last two decades OECD countries have on average experienced declining trends in nutrient surpluses. From 1992 to 2014, the average nitrogen (N) surplus in OECD countries fell from 85 kg/ha to 67 kg/ha, while the average phosphorus (P) surplus fell from 13 kg/ha to 6 kg/ha. Almost all OECD countries are experiencing falling phosphorus surpluses, but the picture is more mixed in the case of nitrogen.

During the last decade, the rates of decline in phosphorus surpluses have accelerated while they decelerated for nitrogen, raising concerns about the ability of OECD countries to maintain nitrogen surpluses reductions in the future.

For some countries, progress towards reducing nutrient surpluses has deteriorated, and nutrient surpluses have even increased in the last decade. Austria, Iceland, Mexico and Turkey have reversed the reduction in P surpluses they made during the 1990s and have increased their surpluses per hectare since 2002. Likewise, Australia, Austria, Iceland, Italy, Japan, Latvia, Mexico, Norway, Portugal, the Slovak Republic and Turkey faced a similar issue with nitrogen. Moreover, some of those countries, such as Japan and Norway, already had large average N surpluses per hectare.

This report analysed some of the drivers affecting nutrient balances. Its key findings were:

- **Reduced fertiliser application rates** seem to be the main driver of reduced P surpluses, although livestock and crop-mix changes as well as policy interventions are associated with reductions in both N and P nutrient balances. Phosphorus fertiliser application rates fell for most OECD countries, possibly as a result of improved farm practices.
- Although nitrogen application rates also declined slightly, N nutrient balances have mainly been driven by **significantly increased crop uptake of nitrogen**, mainly due to changes in the crop mix.
- Among the countries that have reduced their N surpluses, changes in livestock composition and crop mix played a role in some. In particular, **an increase in oil crops** as a share of total harvested crops and **a decrease in cattle as a share of total livestock**, significantly reduced nutrient surpluses.
- Finally, **distortionary support policies** seem to be associated with larger surpluses while countries that adopted **policies targeting nitrogen pollution** also reduced both N and P surpluses.

Korea and Denmark show how two different approaches to reducing nutrient surpluses can be effective. Korea has gradually removed distortionary agricultural support policies, while Denmark acted early and persistently to adopt a mix of policies with aligned objectives and clear targets on reducing both N and P, combined with monitoring and evaluating the impact of policies to improve their effectiveness.

1. Nutrient surpluses are falling in OECD countries overall but the rate of decline may be slowing

Phosphorus (P) and nitrogen (N) are two essential nutrients for supporting plant growth. Nitrogen is necessary for protein build-up and phosphorus is required for energy use and transfer (Conley et al., 2009^[1]). Nutrient inputs in agriculture are thus fundamental to maintaining and increasing crop and forage productivity (OECD, 2013^[2]). Agricultural areas with sustained nutrient deficits may suffer reductions in soil fertility, while nutrient surpluses are likely to contribute to water and air pollution (OECD, 2013^[2]; OECD, 2008^[3]).

A complex range of physical processes drive the nutrient cycle in the environment (OECD/EUROSTAT, 2012^[4]; OECD/EUROSTAT, 2012^[5]). Agricultural activities contribute to nutrient build-up and have significantly affected nutrient cycles (Liu et al., 2010^[6]). Fertiliser use and manure application are some of the most significant ways agriculture supplies nutrients to the environment. While some of those nutrients are taken up by crops and forage, in most agricultural land nutrient inputs exceed nutrient outputs, creating nutrient surpluses (Liu et al., 2010^[6]; Bouwman, 2013^[7]).

Nitrogen is an abundant element in the atmosphere, mainly present in gas form. It is a key nutrient for crop growth, added in inorganic fertilisers and manure. It is estimated that 40-60% of N fertiliser is absorbed by crops and the remainder is lost to the environment (Sebilo, 2013^[8]). Some nitrogen stays in the soil and some volatilises during and shortly after fertiliser application and manure spreading, in the form of ammonia (NH₃) and nitrite oxide (NO) (Mosier et al., 1998^[9]). Ammonia volatilisation also occurs after animal excretion and during storage of livestock manure. Nitrogen is highly mobile and can reach groundwater reservoirs by leaching; it can also reach surface water via runoff.

An excess of nitrogen in surface water leads to excessive plant and algal growth, producing eutrophication. Eutrophic water bodies can suffer biodiversity losses and fish deaths. Nitrate concentrations in groundwater pose risks to livestock and human health. Nitrogen volatilisation contributes to higher concentrations of nitrous oxide (N₂O), a potent greenhouse gas, and can lead to soil and water acidification, potentially affecting crop yields and biodiversity (Goulding, 2016^[10]).

In contrast to nitrogen, phosphorus sources are naturally limited as it comes from mineral sources. Phosphorus uptake rates by plants are estimated to be relatively low, between 10% to 15%; the remainder stays in the soil or ends up in water bodies (Roberts, 2015^[11]). Phosphorus is relatively immobile so it can remain in the soil for years. Soil P retention depends on several soil characteristics. In many OECD countries, phosphorus application rates have been declining due to the fact that soils are already P saturated (OECD, 2013^[2]).

Phosphorus deficiency in the soil can lead to declining fertility in areas under crop or forage production (OECD, 2008^[3]; OECD, 2013^[2]). In contrast, a phosphorus surplus is associated with environmental risks as excess P can lead to surface water contamination due to runoff and soil erosion (EUROSTAT, 2017^[12]; Bomans E., 2005^[13]). While phosphorus concentrations in water do not pose a direct risk to human health, they are an indirect risk as they favour the growth of cyanobacteria and algal blooms in bodies of water. An excess of algae diminishes the amount of oxygen available for other organisms and leads to

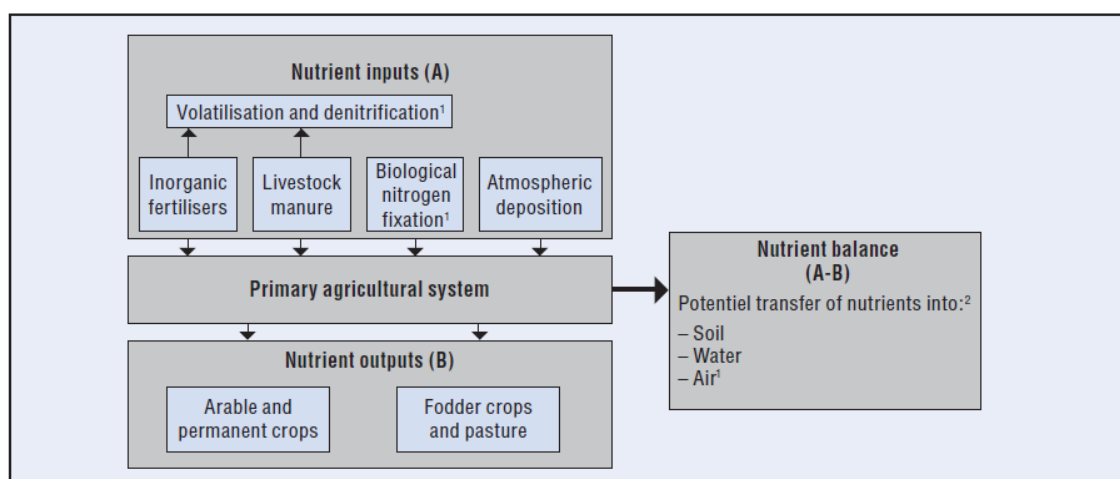
biodiversity losses and fish deaths. Cyanobacteria can produce toxic substances that can affect human and animal health (Chorus, 1999^[14]; Hitzfeld, 2000^[15]).

1.1. Nutrient balance indicators

Nutrient balance indicators can act as a signal for the potential environmental impact of agriculture on water and air. The OECD agricultural nutrient balance indicators are gross balances. They are calculated at the national level, and measure the difference between the total quantity of nutrient inputs entering an agricultural system (mainly fertilisers and livestock manure), and the quantity of nutrient outputs leaving the system (mainly the uptake of nutrients by crops and grassland) (OECD/EUROSTAT, 2012^[4]; OECD/EUROSTAT, 2012^[5]). In the case of nitrogen, the gross nutrient balance includes all emissions of environmentally harmful nitrogen compounds from agriculture into the soil, water and the air, while the net balance excludes air emissions (OECD/EUROSTAT, 2012^[4]). In the case of phosphorus, there are no air emissions so the gross balance is the same as the net balance (Figure 1.1).

Gross balances are expressed in kilogrammes of nutrient surplus per hectare of agricultural land per annum. It is important to bear in mind that these indicators are proxies for environmental pressures at the national level, and do not consider sub-national differences. There are several limitations that could limit cross-country comparisons of nutrient balance levels such as the precision and accuracy of the underlying nutrient conversion factors and the uncertainties involved in estimating nutrient uptake by pasture areas and some fodder crops (OECD, 2013^[2]).

Figure 1.1. Main components of the gross nitrogen and phosphorus balance calculation



Source: *Environmental Performance of Agriculture in OECD Countries since 1990* (OECD, 2008^[3]).

1.2. Trends in nutrient surpluses in OECD countries

Overall, nutrient surpluses show a decreasing trend in OECD countries since 1992. From 1992 to 2014, the average nitrogen surplus fell from 85kg/ha to 67kg/ha (Figure 1.2) and the phosphorus surplus from 13kg/ha to 6kg/ha (Figure 1.3). Although almost all countries recorded a reduction in their phosphorus surplus over the analysed period, the picture is more mixed for nitrogen balances.

While the nitrogen surplus in OECD countries overall has decreased since 1992, the pace of the reduction has slowed over the period 2002-14. Australia, Austria, Iceland, Italy, Japan, Latvia, Mexico, Norway, Portugal, Slovak Republic and Turkey even reversed the declining trends seen in the period 1992-2004 and exhibited positive growth rates in the last decade (Figure 1.2). Notably, this happened in countries that already had high levels of N surplus per hectare, such as Japan and Norway.

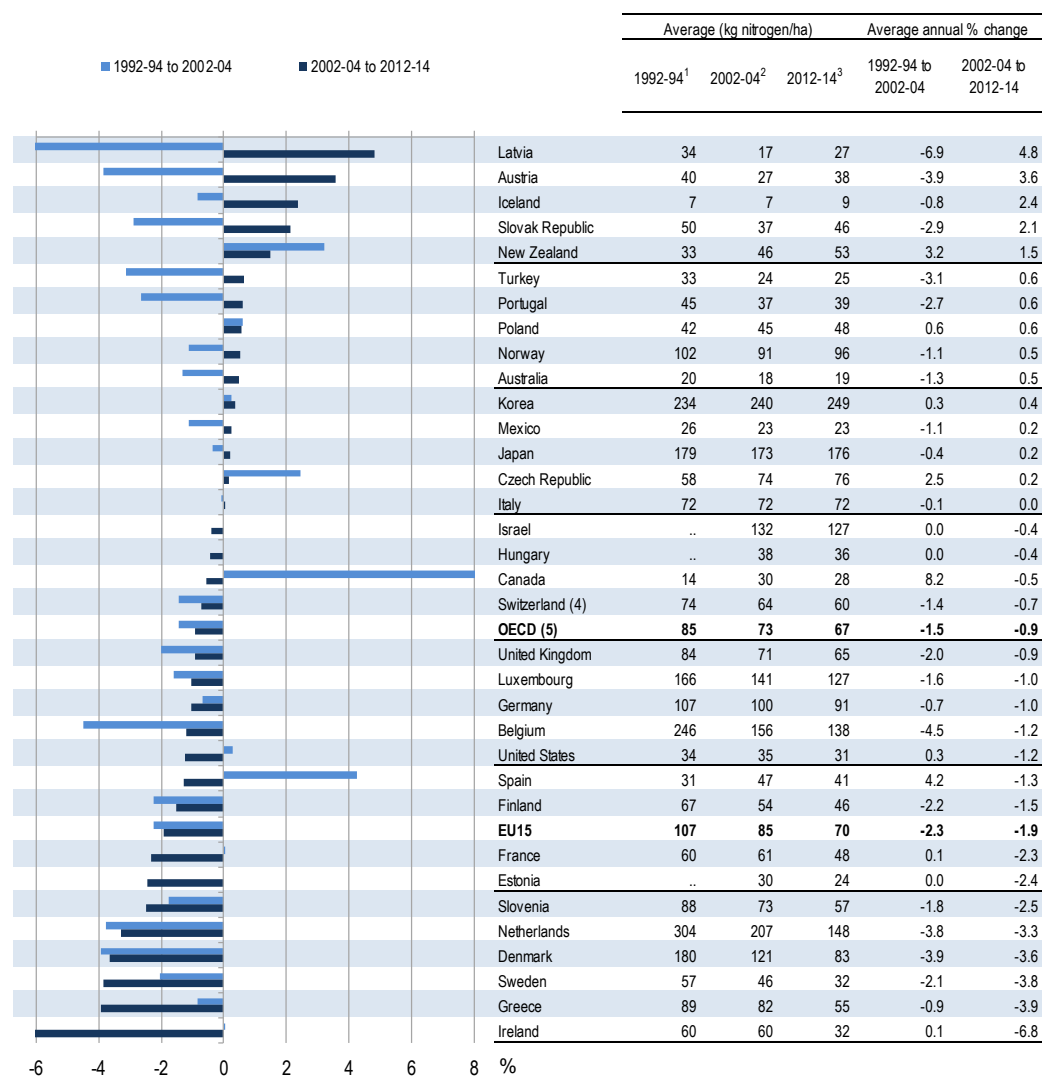
Since 2002, OECD countries have enhanced their efforts to reduce phosphorus surpluses. The P surplus for OECD countries fell, on average, more quickly in the period 2004-14 (4.1%) than the period 1992-2002 (3%) (Figure 1.3), signalling these increased efforts. Almost all countries exhibited a steeper downward trend in the most recent period analysed. Only a few countries, such as Austria, Iceland, Mexico and Turkey, reversed the reduction they experienced in the 1990s and increased their surpluses per hectare in the 2000s.

Several countries that significantly reduced the growth rates of N surpluses from the period 1992-2002 to 2002-14 also reduced the growth of P surpluses. For countries such as Canada, France, Greece, Ireland, New Zealand, Spain and the United States, progress in reducing the growth rates of N surpluses between the first period analysed and the latest has been accompanied by similar progress in P surpluses trends.

On average, OECD countries slightly reduced N inputs. In parallel, crop uptake significantly increased, further lowering the overall N surplus. For most countries that experienced reductions in N surpluses in the period 2002-04 to 2012-14, fertiliser and net inputs of manure also declined. Some countries, such as Canada, Estonia, Hungary, Israel and the United States, increased both inputs and outputs, but the rate of change in N outputs was large enough to compensate for the increase in N inputs (Figure 1.4), leading to overall reductions in N surpluses in those countries.

Fertiliser was the main component driving the reduction in P surpluses. Most OECD countries, with the exception of Canada, Latvia, Mexico and Turkey, saw reductions in P inputs in the period 2002-2004 to 2012-2014 (Figure 1.5). Declining fertiliser use explains most of the reductions in P inputs and surplus. Interestingly, most countries that experienced increases in P input also experienced N input growth.

Figure 1.2. Nitrogen balance per hectare of agricultural land, OECD countries (1992-2014)



Note: .. Not available. Average annual % change is calculated as geometric average growth rates between three-year period averages.

Balance (surplus or deficit) expressed as kg nitrogen per hectare of total agricultural land.

Countries are ranked in descending order according to average annual percentage change 2002-04 to 2012-14. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

1. Data for 1992-94 average refer to 1995 for the United Kingdom and 1995-97 average for Portugal.

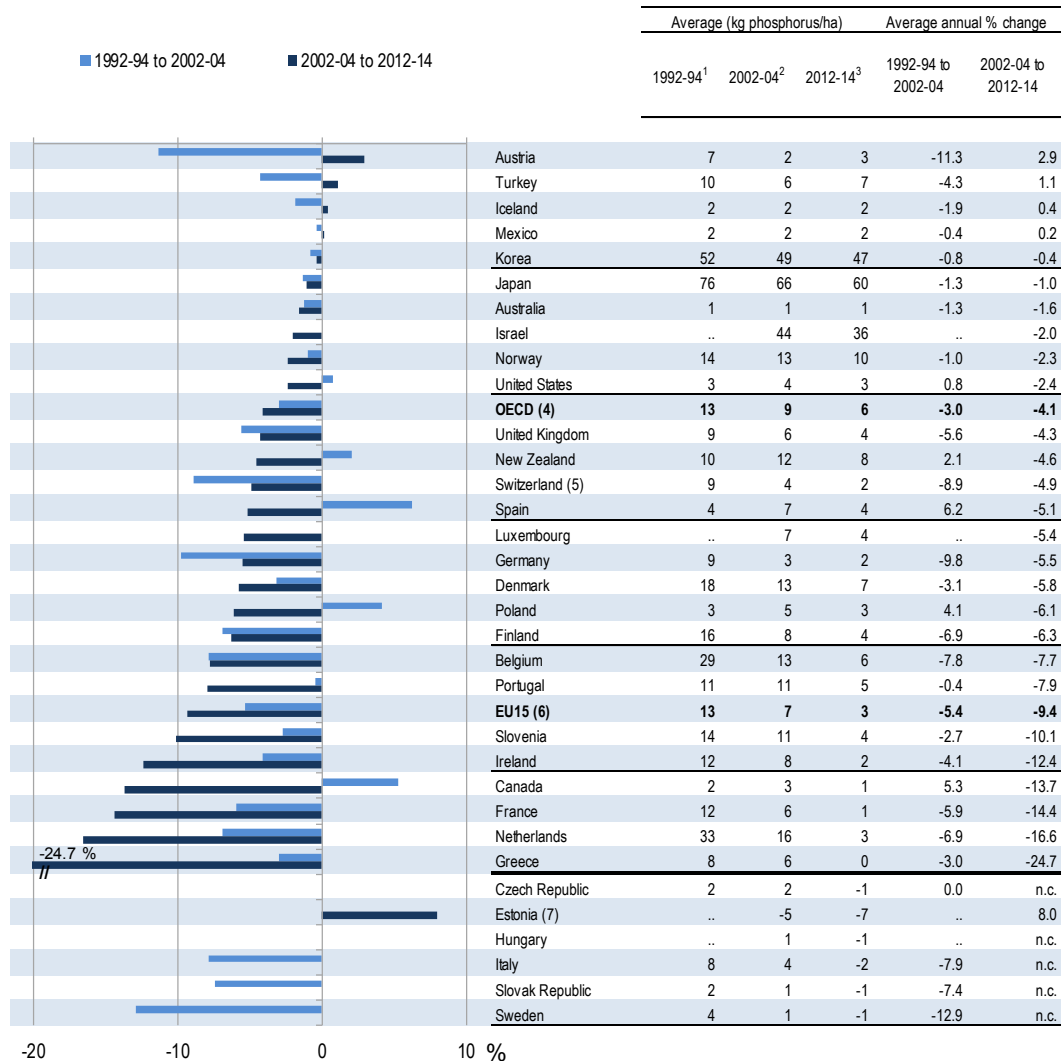
2. Data for 2002-04 average refer to 2004-06 for Estonia.

3. Data for 2012-14 average refer to 2011-13 average for Germany, Ireland, Sweden and Switzerland.

4. In the case of Switzerland, total agricultural area includes summer grazing.

5. The OECD total excludes Chile, Estonia, Hungary and Israel.

Source: OECD Agri-environmental Indicators database (OECD, 2018_[16]).

Figure 1.3. Phosphorus balance per hectare of agricultural land, OECD countries (1992-2014)

Note: .. Not available. Average annual percentage change is calculated as geometric average growth rates between three-year period averages.

Balance (surplus or deficit) expressed as kg phosphorus per hectare of total agricultural land.

Countries are ranked in descending order of their average annual percentage change 2002-04 to 2012-14.

The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

1. Data for 1992-94 average refer to the 1993-95 average for the Slovak Republic, 1995 for the United Kingdom and 1995-97 average for Portugal.

2. Data for 2002-04 average refer to the 2004-06 average for Estonia.

3. Data for 2012-14 average refer to the 2011-13 average for Germany, Ireland, Sweden and Switzerland.

4. The OECD total excludes Chile, Estonia, Hungary, Israel and Luxembourg.

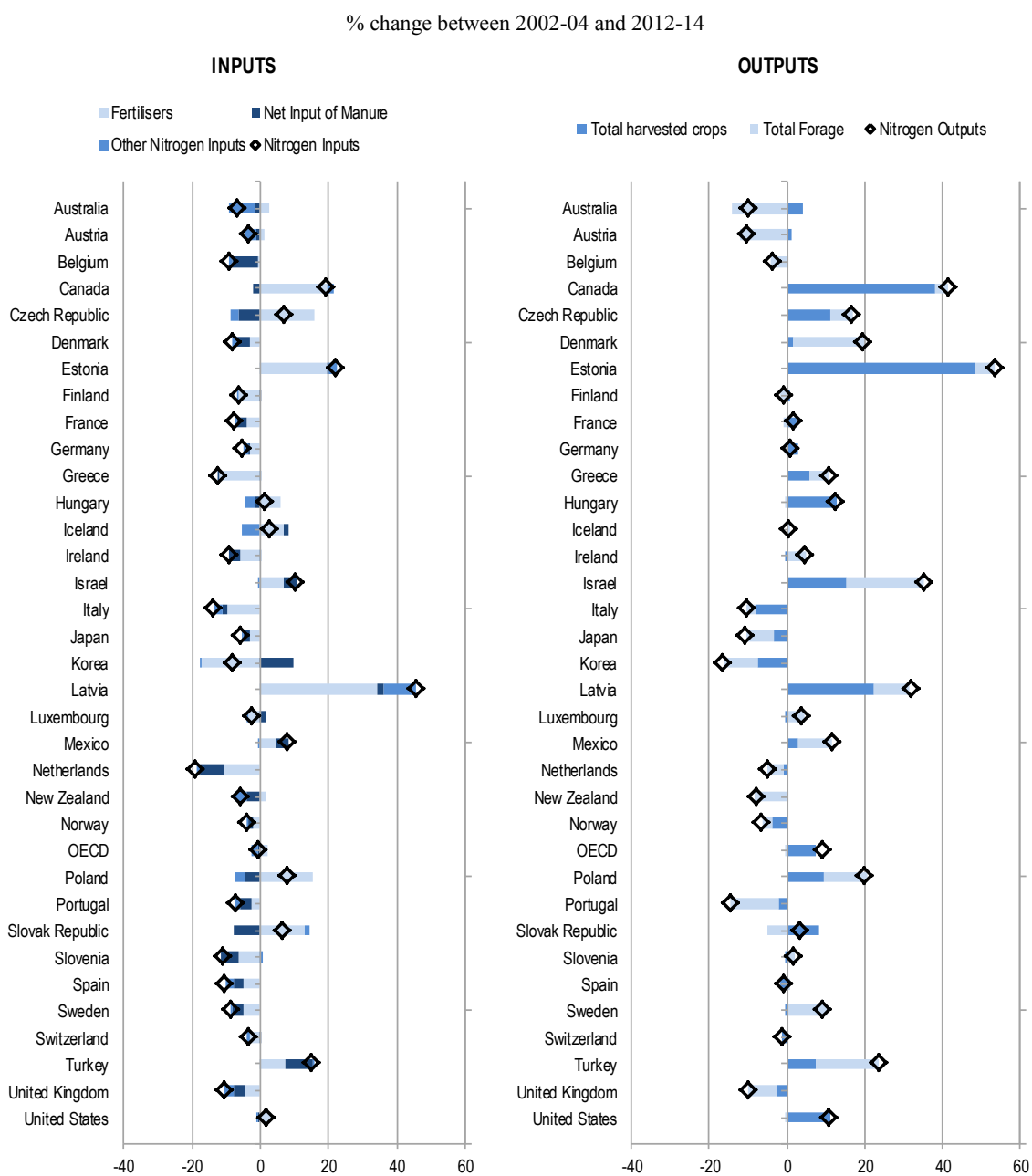
5. In the case of Switzerland, total agricultural area includes summer grazing.

6. The EU15 total excludes Luxembourg.

7. For Estonia, the average annual percentage change refers to the change in phosphorus deficit.

Source: OECD Agri-environmental Indicators database (OECD, 2018_[16]).

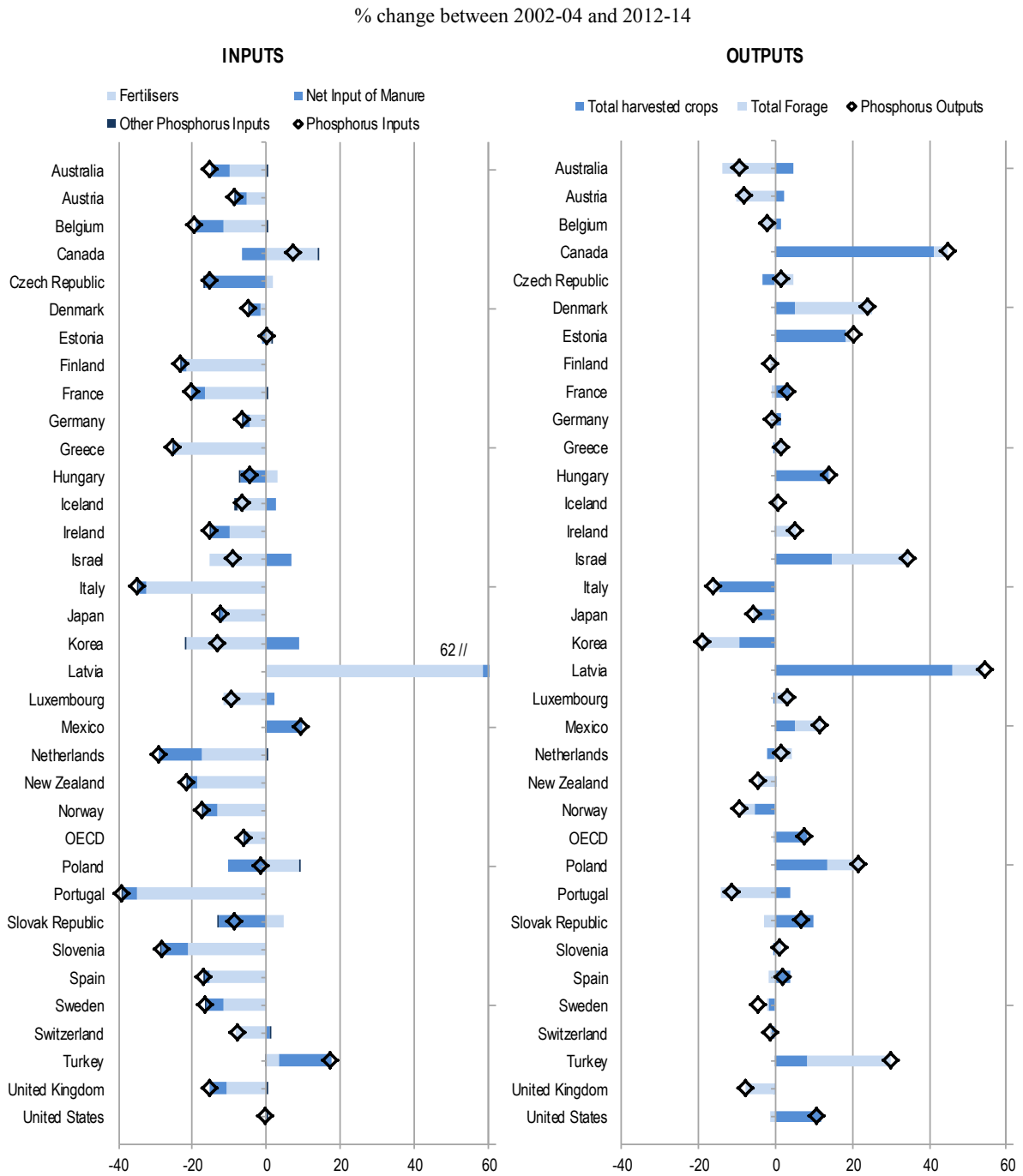
Figure 1.4. Contribution of specific nutrient inputs and outputs to total changes in nitrogen surplus (2002-14)



Note: For EU countries, Norway, the OECD and Switzerland, another output category (nutrient removal by crop residues removed from the field), is not shown on the graph.

Source: OECD Agri-environmental Indicators database (OECD, 2018_[16]).

Figure 1.5. Contribution of specific nutrient inputs and outputs to total changes in phosphorus surplus (2002-14)



Note: For EU countries, Norway, the OECD and Switzerland, another output category (Nutrient removal by crop residues removed from the field), is not shown on the graph.

Source: OECD Agri-environmental Indicators database (OECD, 2018_[16]).

2. Livestock, cropland composition, policies and management practices all contribute to changing nutrient balances

This section relates the trends in nutrient balances described in Section 1.2 to the potential drivers. The existing literature identifies three key drivers: 1) livestock composition, crop mix and the adoption of improved cultivars; 2) agricultural policies; and 3) management practices. For each driver, an attempt is made to empirically relate nutrient balance indicators to variables that reflect those drivers.

2.1. Livestock composition and crop mix

Livestock density and livestock composition are relevant to nutrient surpluses. Cattle usually have higher N and P excretion rates (kg per animal) than pigs and poultry (Sebek et al., 2014^[17]; Velthof, Hou and Oenema, 2015^[18]), with dairy cows having the highest rates among cattle. The crop mix in a given country is another crucial factor, which is in turn influenced by demand and trade policies (Billen, Lassaletta and Garnier, 2015^[19]). The N uptake of oil crops is relatively high compared to other crops such as cereals and fruits and vegetables (Zhang et al., 2015^[20]).

To better relate changes in the crop mix and livestock composition to changes in inputs and outputs observed in the period 2002-14 (Figure 1.4 and Figure 1.5), t-tests of equality of annual growth rates of livestock densities and cropland types over the same period were performed, comparing countries that increased their inputs or outputs, and those that decreased them. Table 2.1 and display the results for nitrogen and phosphorus respectively.

Countries that increased their N inputs also increased the area under oil crops at a higher rate (6.5% per year) than those that decreased their N inputs (2.7% per year) and the difference is statistically significant at the 5% level (Table 2.1). In the case of N outputs, there were statistically significant differences between the growth rates in the areas cultivating oil crops and fruit and vegetables, as well as livestock densities, between countries that increased versus those that decreased N outputs. Countries that increased N uptake experienced a stronger expansion in the area of oil crop cultivation, a larger decrease in the area of fruit and vegetable cultivation, and a reduction in livestock density, compared to countries that reduced N uptake.

Similar results are found for changes in P inputs and outputs (Table 2.2). Countries that increased both P inputs and outputs expanded their oil crop cultivation and reduced fruit and vegetable cultivation. They also reduced livestock densities, although the difference is not statistically significant.

Table 2.1. Differences in livestock density and crop mix for countries that increased versus those that decreased N inputs and outputs

Groups	Inputs			Outputs		
	Observations	Mean	Difference (mean decrease-mean increase)	Obs	Mean	Difference (mean decrease-mean increase)
	Oil crops (ha)			Oil crops (ha)		
Decrease	264	0.027	-0.04**	168	0.011	-0.05***
Increase	216	0.065		312	0.062	
	Fruit and vegetables (ha)			Fruit and vegetables (ha)		
Decrease	264	-0.002	0.02	168	-0.001	0.01***
Increase	216	-0.022		312	-0.017	
	Cereals (ha)			Cereals (ha)		
Decrease	264	-0.006	-0.006	168	-0.008	-0.007
Increase	216	0.000		312	-0.001	
	Livestock heads/ha			Livestock heads/ha		
Decrease	264	0.001	0.005	168	0.008	0.01*
Increase	228	-0.004		324	-0.002	
	Cattle/ha			Cattle/ha		
Decrease	264	0.005	0.007	168	0.008	0.006
Increase	228	-0.002		324	0.002	
	Chickens/ha			Chickens/ha		
Decrease	264	0.034	0.004	168	0.046	0.02
Increase	228	0.030		324	0.025	
	Pigs/ha			Pigs/ha		
Decrease	264	0.002	0.009	168	0.006	0.01
Increase	228	-0.007		324	-0.006	

Note: This table shows the results of two-tailed t-tests on mean differences of annual growth rates of livestock and crop indicators between the countries that decreased and those that increased N inputs and outputs in the period 2002-14. ***, **, * implies that the difference is different from zero and statistically significant at the 1%, 5% and 10% levels.

Source: Nitrogen input and output was obtained from *OECD Agri-environmental Indicators database* (OECD, 2018^[16]) and data on land use and livestock from FAOSTAT (FAOSTAT, 2018^[21]).

Table 2.2. Differences in livestock density and crop mix for countries that increased versus those that decreased P inputs and outputs

Groups	Inputs			Outputs		
	Obs	Mean	Difference (mean decrease-mean increase)	Obs	Mean	Difference (mean decrease-mean increase)
	Oil crops (ha)			Oil crops (ha)		
Decrease	336	0.027	-0.057***	168	0.013	-0.047***
Increase	144	0.084		312	0.060	
	Fruit and vegetables (ha)			Fruit and vegetables (ha)		
Decrease	336	-0.006	0.01**	168	0.002	0.019***
Increase	144	-0.024		312	-0.018	
	Cereals (ha)			Cereals (ha)		
Decrease	336	-0.006	-0.008	168	-0.008	-0.007
Increase	144	0.002		312	-0.001	
	Livestock heads/ha			Livestock heads/ha		
Decrease	348	0.003	0.005	168	0.007	0.008
Increase	144	-0.002		324	-0.001	
	Cattle/ha			Cattle/ha		
Decrease	348	0.006	0.006	168	0.007	0.004
Increase	144	-0.001		324	0.002	
	Chickens/ha			Chickens/ha		
Decrease	348	0.037	0.016	168	0.048	0.02
Increase	144	0.021		324	0.024	
	Pigs/ha			Pigs/ha		
Decrease	348	-0.004	-0.007	168	0.003	0.01
Increase	144	0.003		324	-0.005	

Note: This table shows the results of two-tailed t-tests on mean differences of annual growth rates of livestock and crop indicators between countries that decreased and those that increased P inputs and outputs in the period 2002-14. ***, **, * implies that the difference is different from zero and statistically significant at the 1%, 5% and 10% levels.

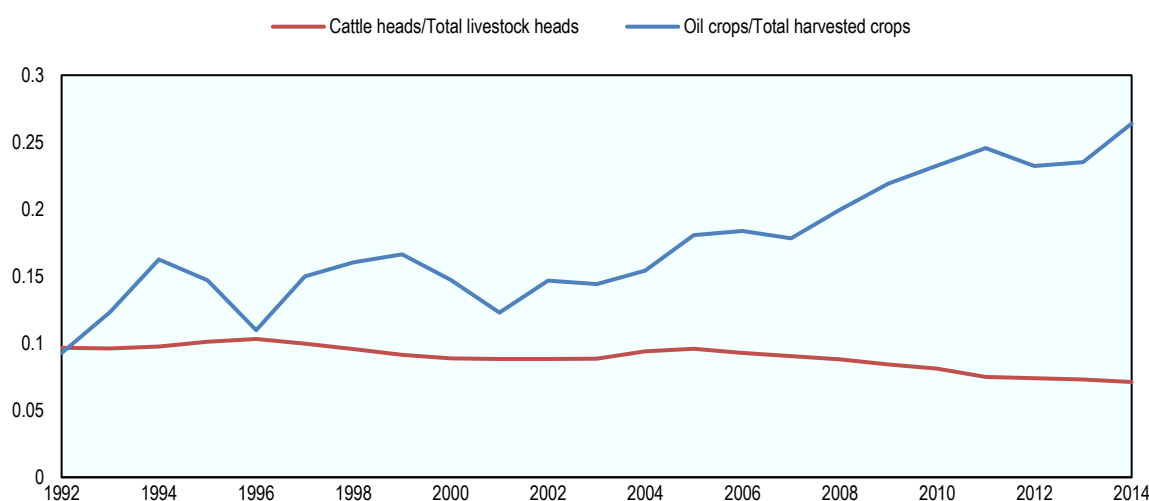
Source: Nitrogen input and output was obtained from *OECD Agri-environmental Indicators database* (OECD, 2018^[16]) and data on land use and livestock from FAOSTAT (FAOSTAT, 2018^[21]).

Countries that experienced increases in both N inputs and outputs reduced the area devoted to fruit and vegetables and increased that devoted to oil crops. Considering these patterns can both generate increases in nutrient inputs and outputs, the effect on the balance is unclear. Livestock changes also seem to play an important role in changing nutrient inputs and outputs. A further investigation into the situation in Canada can help to illustrate these developments. Canada is one of the few countries where nutrient surpluses declined despite increases in fertiliser inputs (Figure 1.4 and Figure 1.5).

The evolution of Canada's livestock composition and crop mix since the 1990s illustrates the relevance and complexity of such drivers. Canada's N surplus per hectare grew by an average 8.2% per year in the 1990s, but fell by 0.5% a year in the 2000s – a difference of 8.7 percentage points – while P surpluses went from an annual growth of 5.3% to an annual reduction of 13.7% over the same period. Most of this decline can be explained by a combination of changes in livestock density, livestock composition, crop mix and improved cultivars. The number of cattle as a share of the total numbers of livestock fell 30% between 1992 and 2014 and harvested oil crops as a share of total harvested crops increased 210% over the same period (Figure 2.1). At the same time, farmers have adopted cultivars with more efficient nutrient uptakes, reducing the need for fertiliser and improving yields (Han

et al., 2015^[22]; Iqbal et al., 2016^[23]; Morrison et al., 2016^[24]; De Bruin and Pedersen, 2009^[25]). Most of those changes occurred in the last decade – in fact over the period 2002-14, livestock density decreased on average 1.6% per year, mainly due to a reduction in cattle heads (Figure 2.1).

Figure 2.1. Canada’s agricultural sector produces more oil crops and less cattle (1992-2014)



Note: Oil crops and total harvested crops are measured in cultivated hectares.

Source: OECD Agri-environmental Indicators database (OECD, 2018^[16]).

2.2. Policy instruments

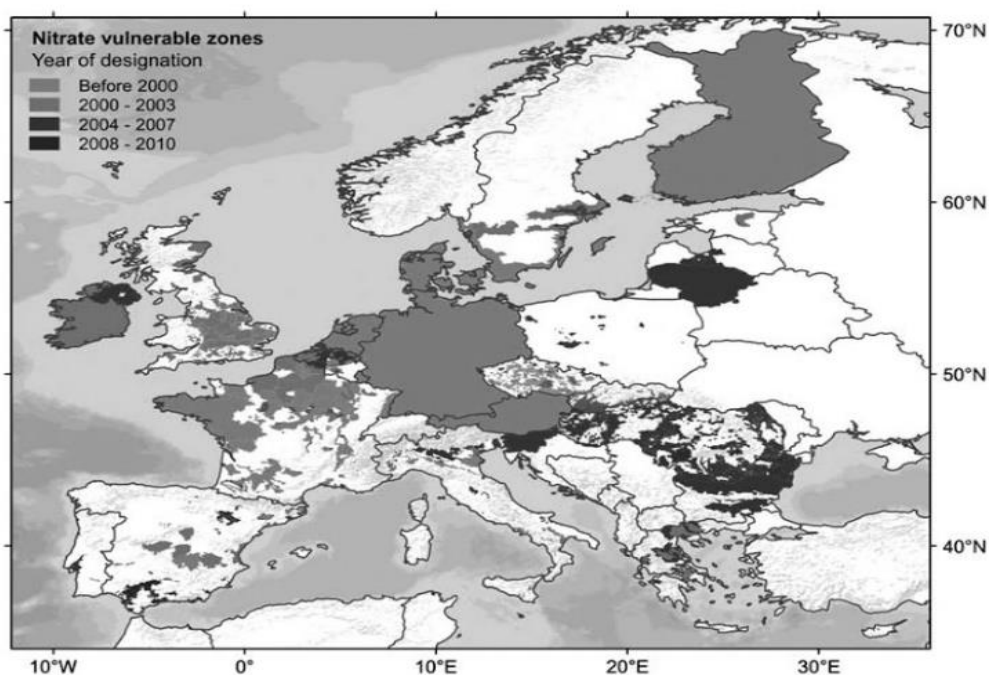
Agricultural policies can affect environmental outcomes by influencing production patterns, farming practices and input use (OECD, forthcoming 2019^[26]). An OECD evaluation of agricultural support policies on the environment found that market price support and payments based on input use appear to consistently increase nitrogen runoff, while payments based on non-current area (cultivated area in previous seasons) and decoupled payments in general seem to have no impact on nutrient balances (OECD, forthcoming 2019^[26]). As well as general forms of support to agriculture, countries have a multiplicity of policies to deal with nutrient surpluses and their impact on water quality including limits on fertiliser application and livestock density, guidelines for manure application, taxes and subsidies, voluntary schemes, information-based policies, water quality trading, co-operative agreements, and natural-capital-based nutrient allocations (OECD, 2012^[27]; OECD, 2017^[28]). Countries also have a diverse policy mix in terms of the types of policies they adopt and their geographical scope, which is not surprising considering nutrient pollution sources from agriculture are difficult to identify (nonpoint) and a mix of policies and regulatory approaches are often more effective than single policies (OECD, 2010^[29]; OECD, 2017^[28]).

While there is no “one-size fits all” policy, some attributes of policies can improve the effectiveness of the policy mix, such as monitoring and enforcing the policy, or appropriate targeting (OECD, 2010^[29]; OECD, 2017^[28]; OECD, 2017^[30]). Targeting addresses questions about who a regulation should apply to and to what degree. Poorly targeted policy instruments are likely to be ineffective at tackling nutrient balance surpluses, which are mainly locally generated.

One example of a targeted policy is the Nitrate Vulnerable Zones (NVZs) policy mandated by the European Union (EU) Nitrates Directive (OECD, 2017^[28]) and, by definition, confined to EU countries. NVZs are those land areas that drain into polluted waters or water sources at risk of nitrate pollution if no action is taken. EU Member States are required to declare NVZs and revise and update them every four years. States that implement a national action program covering all its territory to tackle nitrogen pollution are not required to designate NVZs. Austria, Denmark, Finland, Germany, Ireland, Lithuania, Luxembourg, Malta, the Netherlands and Slovenia, as well as the region of Flanders and Northern Ireland have implemented national action programs. Farmers in NVZs have to comply with measures included in the Codes of Good Agricultural Practice, which each individual EU Member State defines but which have to at least include “measures limiting the periods when nitrogen fertilisers can be applied on land in order to target application to periods when crops require nitrogen and prevent nutrient losses to waters; measures limiting the conditions for fertilizer application (on steeply sloping ground, frozen or snow covered ground, near water courses, etc.) to prevent nitrate losses from leaching and run-off; requirement for a minimum storage capacity for livestock manure; and crop rotations, soil winter cover, and catch crops to prevent nitrate leaching and run-off during wet seasons” (European Commission, 2018^[31]). The application of both fertiliser and livestock manure is limited in NVZs; in the case of fertiliser based on crop needs and all N inputs into the soil, while manure is limited to 170 kg nitrogen/hectare/year including both manure spreading and direct application by grazing animals.

NVZs have been progressively adopted over time (Figure 2.2), although in some cases there have been delays in the implementation of policies (Gruère, Ashley and Cadilhon, 2018^[32]).

Figure 2.2. Designated nitrate vulnerable zones as submitted by EU Member States



Source: Sessa (2012^[33]), Sustainable Water Ecosystems Management in Europe, p. 22.

In order to empirically relate nutrient balances to agricultural policies (both general and targeted at addressing N pollution), as well as livestock and cropland types, an econometric analysis was carried out to correlate agriculture, economic and policy variables with N and P balances (Table 2.3). The analysis considered two types of policy variables: those specifically addressing nitrogen issues and those affecting all agriculture. Policies directly addressing N are represented by indicator variables that take a value of one for the period when a given country applied a national program to tackle nitrogen pollution “NVZ (whole country)” or a particular region an NVZ “NVZ (partial region)”. Agriculture support figures were obtained from Anderson and Valenzuela (2008^[34]) and are divided into distortionary policies (labelled “Coupled support”) and decoupled policies (labelled “Decoupled payments”). The former include market price support and subsidies linked to input or production, while the latter represent support not linked to current production, inputs or area of production.¹ Livestock and cropland mix variables were included to control for the composition of the sector. To assess the impact of the level of development of a given country, per capita gross domestic product (GDP) was also included as an explanatory variable.

The analysis estimated two econometric specifications (models) for each nutrient balance: Specification (1) includes only economic and policy controls and Specification (2) adds livestock and cropland composition explanatory variables. The main results (highlighted in the table) suggest that:

For countries that declared NVZs, both NVZ variables (whole country and partial regions) are associated with decreased nutrient balances per hectare. However, only the whole-country NVZ approach is statistically significant in both specifications (declaring a whole-country NVZ is associated with a 22% decrease in N balance and a 30% decrease in P balance).² Considering only EU countries have NVZ policies, the NVZ finding does not imply that other forms of policy interventions that non-EU countries may have enacted were not effective; to the extent that other countries’ N policies are omitted from the analysis, the fact that the NVZ coefficient is statistically significant reflects that NVZ policies tend to stand out compared to other countries’ policies.³ Interestingly, while NVZs mostly target N, they also seem to affect P, possibly to the fact that regulations in NVZs, are also likely to impact P surpluses

Distortionary forms of agriculture support are positively associated with increases of both surpluses in a statistically significant way (a 1% increase in this form of support is associated with a 0.07% increase in N balance and a 0.12% increase in P balance), **decoupled support has no statistically significant association with balances.**

¹ While the OECD *Producer Support Estimate* database is more accurate and can be divided in different categories of support, it was not possible to use it for this exercise as EU support is reported as an aggregate, so all the variability needed to identify the effects of other policies would have been lost.

² The lack of a statistically significant coefficient on NVZ (Partial region) should not be considered as a reason to argue against the effectiveness of the partial territory approach, as it may be explained by the fact that the dependent variable is a crude whole-country measure of the nitrogen balance and it could be masking improvements in specific regions within countries that have declared regional NVZs.

³ To test the robustness of these findings, the specifications were estimated only for EU countries and the results did not change the main conclusions.

Oil crops are positively associated with N balance and this association is statistically significant at the 10% level: a 1% increase in the oil-crop cultivation area is associated with a 0.13% increase in N balance; while they are also positively associated with P balance, the coefficient is not statistically significant.

Livestock density, particularly cattle density, has a strong and positive association with N balances (a 1% increase in cattle density is associated with a 0.3% increase in N balance), **while poultry density affects P balances** (a 1% increase in poultry density is associated with a 0.7% increase in P balance). Livestock density is highly associated with the intensification of livestock operations, which has been on the rise globally, contributing to an increase in animal production (Liu et al., 2010_[35]). Highly intensive livestock operations rely on concentrated feed and are less dependent on open-range feeding (Bouwman, 2013_[7]). While intensive operations tend to lead to more efficient nutrient uptake by individual animals, at the livestock system scale, once the cultivation of feed crops has been taken into account, the efficiency gains from those systems are not clear (Bouwman, 2013_[7]). These systems face additional challenges such as the handling of large amounts of manure and, when established in areas with limited amounts of agricultural land, few possibilities for its reuse.

Table 2.3. The role of livestock, crop mix and agricultural policies on nutrient balances

Controls	N per ha		P per ha	
	Model 1	Model 2	Model 1	Model 2
GDP per capita	0.144 (0.129)	0.107 (0.139)	1.176* (0.618)	0.491 (0.610)
Nitrogen Vulnerable Zone (Whole country)	-0.280*** (0.058)	-0.224*** (0.048)	-0.443*** (0.145)	-0.300** (0.135)
Nitrogen Vulnerable Zone (Partial region)	-0.013 (0.059)	0.036 (0.051)	-0.138 (0.135)	0.028 (0.126)
Coupled support	0.112*** (0.024)	0.078*** (0.025)	0.206*** (0.056)	0.122** (0.055)
Decoupled payments	-0.007 (0.017)	0.005 (0.012)	0.015 (0.048)	0.023 (0.037)
Cattle (heads per hectare)		0.308** (0.139)		0.354 (0.329)
Poultry (heads per hectare)		0.080 (0.074)		0.653*** (0.219)
Pigs (heads per hectare)		0.161 (0.102)		0.356 (0.260)
Cereals (hectares)		0.174 (0.193)		0.683 (0.430)
Fruit and Vegetable (hectares)		-0.124 (0.124)		0.062 (0.240)
Oil crops (hectares)		0.133* (0.067)		0.163 (0.100)
Trend	0.004 (0.007)	-0.004 (0.005)	-0.050*** (0.018)	-0.062*** (0.018)

Year fixed effect	Yes	Yes	Yes	Yes
Country fixed effect	Yes	Yes	Yes	Yes
Observations	566	545	524	504
R-squared	0.332	0.410	0.495	0.554
Number of countries	35	34	34	33

Note: All variables were transformed to logarithms, except for NVZs, which are dummy variables that take a value of 1 when a given country declared NVZs. Due to data availability for policy variables, the sample covers 1990-2011. Coefficients were estimated using a fixed effects model and robust standard errors are presented in parenthesis. *, ** and *** represent statistically significant coefficients at the 10%, 5% and 1% levels, respectively.

Sources: N and P balances were obtained from the OECD Agri-environmental Indicator database (OECD, 2018_[16]). Coupled and decoupled support variables were obtained from Anderson and Valenzuela (2008_[34]), livestock and cropland composition variables were downloaded from FAOSTAT (FAOSTAT, 2018_[21]), and GDP per capita from the World Bank Development Indicators Database (World Bank, 2018_[36]). NVZs dummies were constructed from the information provided by the Nitrates Directive (European Commission, 2018_[31]).

2.3. Improved farm management practices

The reduction in P surpluses observed in the majority of OECD countries in the last two decades (Figure 1.3) can be partly associated with higher rates of soil testing in farms. Through soil testing in areas such as Western Europe, which have historically had persistently high rates of P applications, farmers have recognised that they can reduce P application rates without compromising yields, (Schoumans, 2015_[37]).

Soil testing is part of a group of practices branded “improved farm management practices” or “best management practices” (BMPs), which aim to decrease the environmental and health impacts from agricultural activities while maintaining farm productivity. There are a large variety of BMPs, from practices that require significant effort, like introducing conservation tillage and crop rotation, to simple actions like avoiding the application of manure when rain is forecast (Sharpley et al., 2006_[38]). Consequently, the economic cost of implementing different BMPs can vary substantially, depending on their scope and complexity. Big structural changes, like implementing manure storage systems, are usually more expensive than more basic measures, such as choosing the right time for manure application (Sharpley et al., 2006_[38]); establishing livestock watering systems away from stream corridors can be comparably more costly than creating grass or forest buffers (Shortle et al., 2013_[39]). Moreover, the implementation of BMPs will also vary according to the type of farm and the geographic condition where the farm is located (Shortle et al., 2013_[39]).

Best management practices for applying fertiliser are usually linked to the 4R Principles: right rate, right timing, right source and right placement. The International Plant Nutrition Institute (2007_[40]) summarises these principles as follows:

- **Right rate:** assess and make decisions based on soil nutrient supply and plant needs.
- **Right timing:** assess and make decisions based on the dynamics of crop uptake, soil supply, nutrient loss risks and field operation logistics.
- **Right source:** ensure a balanced supply of essential nutrients, considering both naturally available sources and the characteristics of specific products.
- **Right placement:** Address root-soil dynamics and nutrient movement, and manage spatial variability within the field to meet site-specific crop needs and limit potential losses from the field.

Soil testing is crucial for reducing nutrient application rates and it is directly related to the “right rate” principle. Other BMPs such as conservation tillage, conservation crop rotation and cover crops can also reduce nutrient surpluses (OECD, 2016^[41]). Numerous previous studies have found positive impacts from BMPs in reducing nitrate leaching and improving water quality. For instance, pre-sidedress nitrate tests⁴ have significantly reduced post-harvest residual soil nitrates (NO₃) in corn fields (Durieux et al., 1995^[42]; Justes et al., 2012^[43]). Similarly, conservation tillage practices have resulted in reduced NO₃ leaching when compared with conventional tillage (Randall and Iragavarapu, 1995^[44]; Weed and Kanwar, 1996^[45]). Other studies have shown that the use of cover crops during the inter-growing season has led to lower residual soil NO₃ and reduced leaching in corn and other field crops (McCracken et al., 1994^[46]; Mary et al., 1999^[47]; Justes et al., 2012^[43]). New technologies emerging in the agriculture sector can facilitate BMPs and, therefore, affect nutrient balances (Box 2.1).

Other technological developments include enhanced efficiency N fertilisers (EEFs) which release N at a slower rate than conventional fertilisers or delay the N transformation processes by using inhibitors or coating materials. These can improve crop uptake of N and reduce the risk of N leaching, but their performance depends on the type of crop and the biophysical conditions of the farm, as well on management practices. EEFs can be categorised into four types (Li et al., 2018^[48]): 1) urease inhibitors, which delay urea hydrolysis thus lowering ammonia emission potential; 2) nitrification inhibitors, which reduce the activities of nitrifying bacteria, thereby reducing the risks of nitrate leaching as well as nitrous oxide emission; 3) double inhibitors, which are designed to lower ammonia, nitrate and nitrous oxides emissions losses by combining urease and nitrification inhibitors; and 4) polymer-coated fertilisers, which use partially permeable coating material to control N release. According to a meta-analysis of studies conducted from 1970 to 2016, urease inhibitors and polymer-coated fertilisers were the most effective EEFs for reducing ammonia emissions (Pan et al., 2016^[49]). Double inhibitors were most effective increasing yields and improving nitrogen uptake when applied on grassland, while EEFs were, in general, less effective in wheat and maize systems (Li et al., 2018^[48]). While EEFs can potentially increase yields and reduce environmental risk, their effectiveness is highly dependent on farm management practices (Li et al., 2018^[48]).

⁴ A soil nitrate test used to determine if additional fertiliser nitrogen is needed for corn.

Box 2.1. The potential impact of precision agriculture on nutrient pollution

Precision agriculture aims to monitor and improve the financial performance of farms at within-field resolution by providing detailed information on site-specific yield, nutrient recovery and income (Wong, Asseng and Zhang, 2005^[50]). Recovery of nutrients can be used to evaluate and manage environmental risk such as nitrate leaching (Ortega et al., 2003^[51]). Some of the most important groups of technologies used in precision agriculture are:

1. **geographical information system (GIS)**: software to manage spatial data
2. **global positioning system (GPS)**: provides topographical information used by GISs
3. **remote sensors**: cameras on satellites and airplanes to identify the characteristics of a given area
4. **in situ sensors**: electronic devices to measure soil properties, pests, crop health, etc.
5. **yield monitoring**: measures the crop yield during harvest, providing a yield map with information on production and variability
6. **variable rate technology**: it applies inputs according to specific needs at a precise location. (JRC et al., 2014^[52]; OECD, 2016^[41]; OECD, forthcoming 2019^[53])

GIS and GPS technology

Field studies have shown that site-specific in-season adjustments of fertiliser inputs to account for climatic conditions and varying yield potential differences increase fertiliser nitrogen use efficiency up to 368% compared with common farming practices (Diacono, 2013^[54]). When sensors are used with GPS, and GIS is used to produce prescription maps (e.g. for guiding variable fertiliser or irrigation applications), the extra cost savings can be over 10-20%, depending on the inherent variability and need for variable inputs in a given field (Diacono, 2013^[54]). Research has also shown that the use of GPS (“autosteer”) in farm machinery can increase the efficiency of nutrient use by 5-10% (Craighead and Yule, 2001^[55]). GPS-based guidance systems with automatic controls allow farmers to precisely apply inputs by both modulating the quantities and by reducing nutrient usage in no-application areas and can therefore generate positive environmental effects (Bongiovanni and Lowenberg-Deboer, 2004^[56]).

Variable rate technologies

Thoele and Ehlert (2010^[51]) analysed the potential impact of using a mechanical crop biomass sensor (“crop meter”). They found that its use improved N efficiency by 10-15%, and reduced N fertiliser applications without reducing crop yields. Other studies (Anselin, Bongiovanni and Lowenberg-DeBoer, 2004^[57]; Meyer-Aurich et al., 2010^[58]) concluded that site-specific management of nitrogen fertiliser leads to improvements on N efficiency by 10-15%. Applying at variable rates may not necessarily result in lower fertiliser application rates, however (Dillon and Kusunose, 2013^[59]). A similar mixed picture can be found among country experiences with variable rate applications of nitrogen (Lawes, 2011^[60]; Boyer et al., 2011^[61]; Olesen et al., 2004^[62]; Biermacher et al., 2009^[63]).

Remote sensors

Mounted in satellites or aircraft, sensors have the potential to produce relevant data for improving the environmental performance of agricultural activities (OECD, forthcoming 2019^[53]). The most relevant applications for agriculture are monitoring crop yield, biomass, crop nutrient and water stress, and detection of pests and soil properties (Mulla, 2013^[64]). These technologies have the potential to improve the effectiveness of agri-environmental policies and the quality and scope of agri-environmental indicators (OECD, 2018^[65]; OECD, forthcoming 2019^[53]).

3. Eliminating distortionary policies and developing a coherent set of policies can effectively tackle nutrient surpluses

This section delves further into the role policies play in decreasing nutrient inputs into soils by describing the approaches of two OECD countries. Korea and Denmark were considered to be the best examples to illustrate the role of policies on those trends.

3.1. Korea

Removing some of the most distortionary agricultural subsidies not only creates efficiency gains but can also help reduce environmental pressures. Korea experienced the largest decrease in N fertiliser inputs from 2002 to 2014 in the OECD (Figure 1.4). Decoupling farmers' payments from input use was one of the main reasons behind this change. Nevertheless, Korea still faces significant challenges in dealing with high input levels from manure.

The Korean government has implemented a variety of measures to reduce the overuse of chemical fertilisers. In 1990, it liberalised the sale of agricultural chemicals by progressively reducing domestic subsidies.⁵ Although some restrictions on domestic sales of formulated products by foreign companies remained, these were removed at the end of 1999 (OECD, 1999_[66]). Since the 2000s, Korea has framed its policies within specific targets. Through the Environmentally Friendly Agriculture Fostering Act, enacted in 1997, the Korean government has established policy plans every 5 years, starting in 2001, to promote “environmentally friendly agriculture”, which is defined as a type of agriculture that does not use “chemical materials, such as synthetic agricultural chemicals, chemical fertilizers, antibiotics and antimicrobials, or minimizes the use of such materials, and maintaining and preserving the agricultural ecosystem and environment by recycling by-products of agriculture, fisheries, stock breeding or forestry” (Ministry of Agriculture, Food and Rural Affairs, 2015_[67]).

In particular, the plans focus on promoting the safe and appropriate use of agricultural chemicals, setting maximum limits for chemical residues and effluent from livestock excretion, encouraging compliance with fertiliser application rates for each crop, banning the dumping of agricultural waste, and establishing requirements for converting animal excretion into solid and liquid manure. The act also defines a framework for certifying environmentally friendly agricultural products and establishes direct payments to compensate for the reduced yields from adopting environmentally friendly farming practices (OECD, 2008_[68]). For example, one of the policy objectives in the most recent 5 year plan (2016-20), is to reduce the quantity of chemical fertilisers and pesticides by 9% relative to 2014 levels.

Since 1996 the Korean government has been decreasing subsidies for chemical fertilisers and has now completely eliminated them. This policy change was the main reason for the reduction in chemical fertiliser use in the last decade (Korean Fertilizer Association,

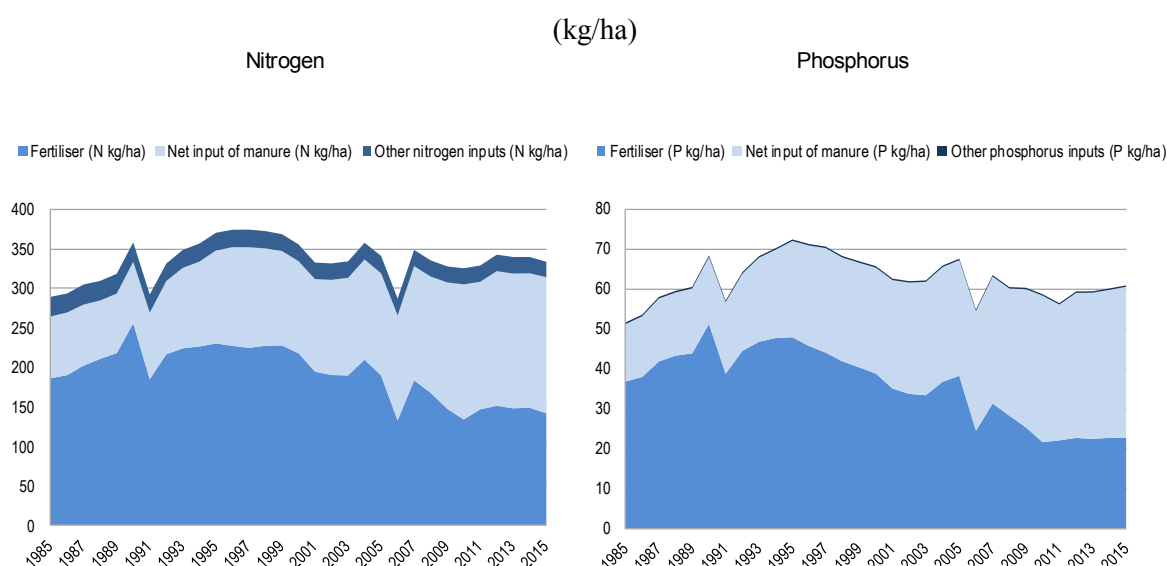
⁵ In the case of pesticides, subsidies were supplied through the National Agricultural Co-operatives Federation (NACF). As for fertilisers, from 1982 to 1994, the government subsidised their prices through the Agricultural Chemicals Account (OECD, 1999_[66])

2015^[69]). As a consequence, manure has overtaken fertiliser as the main nutrient input to soils (Figure 3.1).

However, over the last five decades, the Korean agriculture sector has experienced a rapid transformation that has been mainly driven by new patterns of food consumption: meat consumption increased from 5.2 kg per person in 1970 to 46.8 kg in 2015, and consumption of dairy products increased from 1.6 kg per person in 1970 to 75.7 kg in 2015 (OECD, 2018^[70]). As a consequence, the livestock sector experienced the sharpest growth in the country's agriculture sector from 1970 to 2013; the value of livestock products increased from 15% of total agricultural production to 46% over that period (OECD, 2018^[70]). To cope with the increasing demand for meat and dairy products, livestock density has increased, leading to greater environmental pressures per unit of land.

While Korea has successfully lowered fertiliser use, mainly by eliminating fertiliser subsidies, manure management remains a challenge and it is now the largest contributor to nutrient inputs to soils. Korea has the largest nitrogen surplus per hectare among OECD countries (Figure 1.2) and the second largest phosphorus surplus per hectare (Figure 1.3). Since the size of the livestock industry keeps growing while the total area of crop land keeps declining, the management of an excess supply of manure is a pressing issue. The Livestock Excretion Management and Use Act passed in 2007 promotes the recycling of manure, mainly to produce and use solid/liquefied fertiliser and energy (Gruère, Ashley and Cadilhon, 2018^[32]). While the programme got off to a slow start, chemical fertiliser is increasingly being replaced by recycled manure to deal with the environmental pressures derived from livestock waste.

Figure 3.1. Evolution of nitrogen and phosphorus inputs in Korea (1985-2015)



Source: OECD Agri-environmental Indicators database (OECD, 2018^[16]).

3.2. Denmark

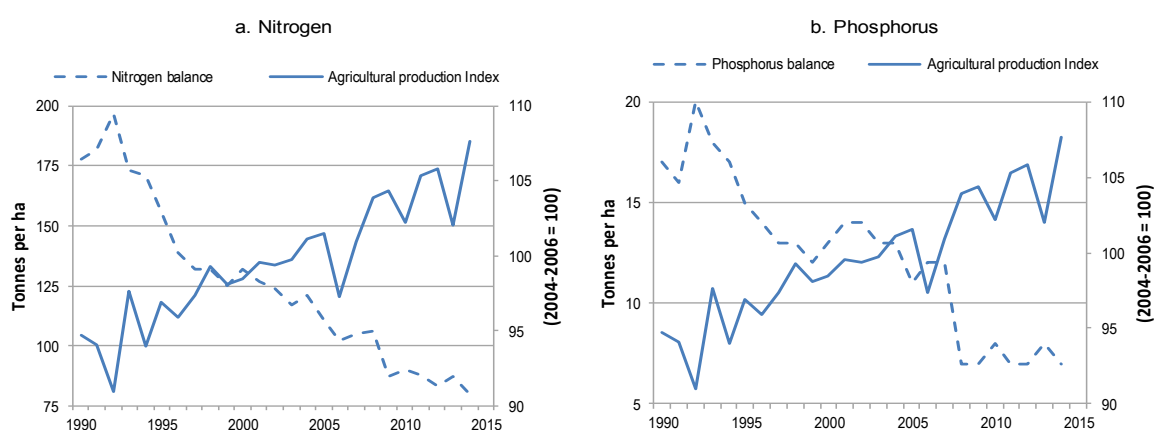
Acting early, defining clear nutrient pollution reduction targets, constant monitoring and evaluation of policies, and a coherent policy mix can yield sustained reductions in nutrient

surpluses while improving the performance of agriculture. Denmark is one of the few OECD countries which has simultaneously experienced an expansion in agricultural production and a decline in nutrient balance surpluses since the 1990s. Underlying this success is a long history of adopting, monitoring and evaluating regulations, as well as combining a wide range of command-and-control, market-based, voluntary and information regulations.

Denmark's nitrogen and phosphorus balances per hectare have consistently fallen since the 1990s while agricultural production has exhibited steady growth (Figure 3.2). Denmark and the Netherlands are the only OECD countries which have achieved significant nutrient balance reductions and steady agricultural production growth in the last two decades. Moreover, despite having one of the most developed environmental regulation systems in the world (Grinsven et al., 2012^[71]) agricultural exports account for more than double its domestic consumption (FAO, 2014^[72]) and more than 60% of Denmark's land area is used for agriculture.

Denmark acted early to monitor and combat nitrogen pollution. High nitrogen concentrations were detected in groundwater used for household consumption during the 1980s, and surveys and monitoring of oxygen concentrations in the Danish marine waters indicated an increase in the frequency of oxygen depletion events (Kronvang et al., 2008^[73]). Since the early 1980s, multiple regulations have been implemented via the Action Plans for Aquatic Environment (1987, 1998, and 2004), Sustainable Agriculture (1990 and 1996) and Green Growth (2009) policies. The Danish policy mix falls into three categories (Dalgaard et al., 2014^[74]): command and control measures, market-based regulations, and information and voluntary action. In particular, the policy mix often includes targets for both reductions of N and P discharges, includes fertiliser accounting systems, N quota systems which regulate the use of fertilisers, bans on manure application on bare fields, fertiliser taxes for non-agricultural uses, taxes on phosphorus content in feed, agri-environmental schemes, and advisory services (OECD, 2018^[70]).

Figure 3.2. Agricultural production and nutrient balances in Denmark (1990-2015)



Source: Nitrogen and phosphorus balance were obtained from OECD Agri-environmental Indicators database (OECD, 2018^[16]); agricultural production index from FAOSTAT (FAOSTAT, 2018^[21]).

While Denmark has a multiplicity of regulatory instruments in place, they all contribute to the achievement of clear and well-established targets defined in the action plans. More importantly, even though targets are not always reached, constant monitoring and

evaluation of plans and policies have been key to improving the effectiveness of policies (OECD, 2018^[70]; Tan and Mudgal, 2013^[75]). Since the 1990s, with the implementation of environmentally sensitive areas (ESAs), Denmark has also started to move towards geographically targeted regulations, which tend to be more cost-effective.

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