Synergies and trade-offs between adaptation, mitigation and agricultural productivity

A SYNTHESIS REPORT

Jussi Lankoski, Ada Ignaciuk, Franck Jésus

JEL Classification: Q18, Q54, Q58
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SYNERGIES AND TRADE-OFFS BETWEEN ADAPTATION, MITIGATION AND AGRICULTURAL PRODUCTIVITY: A SYNTHESIS REPORT

Jussi Lankoski, Ada Ignaciuk and Franck Jésus, OECD

This report develops quantitative and qualitative frameworks to test the possibility of systematically assessing a range of policies and their intended and unintended effects. The analysis spans the three policy objectives of enhanced productivity, climate change mitigation, and climate change adaptation. The preliminary findings and lessons learned are drawn from two applications of a qualitative framework (France and the Netherlands), where information was gathered through a wide-ranging questionnaire, and from two applications of a quantitative modelling framework which was tested using data from Finland and from selected sites in one region of the United States.

Keywords: Productivity, mitigation, adaptation, greenhouse gas emissions, agricultural policy

JEL classification: Q58, Q54, Q18

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Lessons learned

Global agriculture today faces a number of opportunities and challenges. Growth in demand is putting pressure on natural resources and contributing to increased greenhouse gas (GHG) emissions from the agriculture sector, while climate change is expected to increasingly affect productivity growth rates.

A key policy question for many governments is how to design and implement policies that incentivise practices which would stimulate agricultural productivity growth and sustainable resource use, and whether there would be synergies or trade-offs with GHG mitigation and adaptation objectives. Perhaps even more importantly, how do current agricultural and agri-environmental policies perform in this respect? These questions have not yet been explored in any depth.

This paper presents preliminary findings from an attempt to fill gaps in knowledge by experimenting with both quantitative and qualitative approaches, developed to test the possibility of systematically assessing a range of policies and their intended and unintended effects across the three objectives of enhanced productivity, climate change mitigation, and climate change adaptation. The preliminary findings and lessons learned are drawn from two applications of a qualitative framework (France and the Netherlands), where information was gathered through a wide-ranging questionnaire, and from two applications of a quantitative modelling framework which was tested using data from Finland and estimated data from three sub-river basin sites in the midwestern United States. While it is clearly not possible to draw broad conclusions or generalisations, some insights have begun to emerge.

While some countries are explicitly trying to design policies targeting positive impacts across the three objectives, it seems that in practice, several policy instruments appear to be sending signals that may impede the achievement of at least one of the three objectives. For example, a green set-aside payment may have positive effects on productivity and mitigation but negative effects on adaptation. An investment subsidy for adaptive capital may support adaptation but could negatively affect mitigation or productivity.

The quantitative results obtained by applying the model developed for this study to stylised policy instruments also illustrate that the agricultural and environmental conditions may matter a great deal for the potential performance of a given policy instrument across the three objectives. Moreover, the simulations developed were mainly focused on single stylised policy instruments implemented in isolation. In practice policy instruments for productivity enhancement or climate change objectives are implemented as a part of an overall agricultural and environmental policy-mix. The latter can mitigate or reinforce the synergies and trade-offs induced by any given policy instrument.

Thus far, country level ex ante assessments to identify whether current policies are effective in supporting all of the three objectives are non-existent or very limited. Governments could usefully consider introducing inter-institutional dialogue to address
questions of policy consistency and undertaking both ex ante and ex post policy evaluation systems.

While the practical and theoretical situations analysed as part of this project are necessarily limited in scope, the tools developed are assessed as promising. Going forward it is envisaged that the quantitative approach will continue to be developed and applied to a sufficiently diverse range of situations using improved data sources to begin to yield conclusions of a more general nature, as well as helping to identify the structural, agricultural and environmental conditions that affect policy performance, and through that allow improvement of future policy performance. The qualitative framework can help governments initiate inter-institutional dialogue to ensure that questions of policy consistency are addressed in the first place, and ensure that both ex ante and ex post consideration of these issues is more strongly anchored in government processes and procedures. The insights garnered from the qualitative assessment will be used to strengthen the framework for innovation and sustainable productivity growth, including by incorporating analysis of climate change adaptation and mitigation in country specific applications.

As tools for policy makers, these two complementary frameworks may help to raise awareness of the issue, and stimulate efforts to strengthen institutional settings and processes better able to cope with them, while also suggesting analytical avenues to identify and assess policies that generate synergies or trade-offs between the three objectives.
1. A growing interest in coherent policy approaches

Governments are increasingly aware of the need to implement policies that aim to simultaneously achieve productivity improvement, enhance adaptation to climate change and contribute to greenhouse gas (GHG) mitigation (hereafter referred to as the three objectives – productivity, adaptation and mitigation). Policy makers’ interests in initiatives such as Green Growth, Climate Smart Agriculture, and Bio-economy reflect the importance of achieving economic and environmental goals at the same time.

However, efforts to pursue these three objectives simultaneously are limited within current policy settings. Integrating adaptation and mitigation objectives into existing productivity-enhancing policies may not be sufficient if existing policies send conflicting signals to farmers. The agricultural sector (including forestry) is subject to a wide range of national and international regulations, macroeconomic and structural policies, as well as to policies specific to the agricultural sector itself. These policies have intended and unintended effects on the three objectives, which are rarely assessed. Doing so could contribute to understanding if and how policies induce synergies or trade-offs between the three objectives, and identify potential areas for policy alignment or new policy action.

This report explores the use of quantitative and qualitative frameworks developed for a systematic assessment of a range of policies and their intended and unintended effects on the three policy objectives. The document also presents initial applications of a quantitative framework using data from Finland and estimated data from three sub-river basin sites in midwestern United States and applications of a qualitative policy assessment framework in case studies of France and the Netherlands.\(^1\)

These frameworks are designed to complement the OECD initiative on assessing policies to improve sustainable agricultural productivity growth (OECD, 2015a). While OECD (2015a) focuses to a large extent on policies to improve agricultural productivity growth sustainably, the frameworks presented in this document concentrate on the interactions between agricultural productivity growth and the climate change dimension of sustainability (adaptation and mitigation\(^2\)). The frameworks presented here complement the sustainable productivity framework.

Section 2 of this report presents the rationale of promoting synergies between the three objectives given the short and long-term challenges agriculture faces. Section 3 reviews the limited analysis and findings in the literature. Section 4 briefly presents the general set up of the quantitative and qualitative frameworks (detailed description of these frameworks is provided in Annexes B and C, respectively). A preliminary assessment of possible policy impacts is provided in Section 5.

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\(^2\) The quantitative framework has been further developed and currently also includes water quality objectives (nitrogen and phosphorus runoff from field parcels to surface waters).
2. Simultaneously increasing productivity, adapting to climate change and mitigating emissions in agriculture

Global agriculture today faces a number of opportunities and challenges, including responding to the rising demand for agricultural commodities with constrained and deteriorating natural resources necessary for food production. Demand for agricultural products continues to increase because of population growth, changes in incomes and diet, and the need for alternative energy and fibre sources. At the same time, the availability of productive land that is suitable for agricultural expansion is decreasing in many countries (Steenwerth et al., 2014) and the competition for other necessary resources such as water and minerals is increasing.

Several agricultural commodities are facing a slowdown in the growth rate of yields. In many European countries, the growth trend of cereal yields has been declining since the mid-1990s, which can – at least partially – be attributed to increased heat stress during grain filling and drought during stem elongation (Brisson et al., 2010). The OECD-FAO Agricultural Outlook 2015-2024 projects a further decline in yield growth for cereals and oilseeds. In the case of Brazilian wheat, maize and soy as well as of Paraguayan soy, the changes in temperature and precipitation between 1980 and 2008 have also slowed the expected yield increase trends (Marengo et al., 2014). Climate disruptions to agricultural production in the United States have increased in the past 40 years and this trend is likely to continue (USNCA, 2014).

Extreme events already trigger serious economic consequences on agriculture. For example, the 2013 flood in Pakistan caused an estimated USD 1.91 billion in losses to the agriculture sector (Business Insurance, 2013). During the droughts of 2011 and 2012 on the US Great Plains, ranchers liquidated large herds due to lack of feed and water. Many cattle herds were sold to slaughterhouses; others were relocated to other pastures through sale or lease (Shafer et al., 2014). Moreover, the indirect effect of heat stress has increased vulnerability of livestock to diseases, reduced fertility, and reduced milk production. Overall, climate disruptions to agriculture are projected to become more severe over this century (USNCA, 2014).

Climate change will have direct negative effects on agriculture for most regions and crops. This will depend on the intensity of distinct changes in temperature and precipitation but also on their combination. Projected effects of climate change include increased mean temperatures, increased variability in temperature and rainfall patterns, changes in water availability, increased frequency and intensity of extreme weather events, and changes in ecosystems (Beddington et al., 2012; Gornall et al., 2010; Wheeler and von Braun, 2013; USNCA, 2014). Towards the end of the century, climate change is projected to negatively affect the growth rates of yields for most crops, especially at higher levels of temperature rise and at low latitudes (Figure 1). The average yields growth of a majority of crops, in practically all regions, are likely to be negatively affected by climate change. In OECD countries, the yields of maize, wheat and rice are projected to be lower, on average, by 10%, 7% and 6%, respectively by 2050, as compared to a situation where current climate conditions would prevail (Ignaciuk and Mason D’Croz, 2014).
Figure 1. Effects of climate change on growth rates of crop yields are likely to be negative in most regions

Central projection, percentage change in yields under RCP 8.5 in 2050 relative to current climate

Source: IMPACT model, based on the AgMIP study.

Agriculture is also contributing a significant share of the global greenhouse gas (GHG) emissions that are causing climate change – 10-12% directly through agricultural activities and an additional 7% to 14% through changes in land use (Tubiello et al., 2014; Smith et al., 2014). The main direct agricultural GHGs emissions are nitrous oxide emissions from soils, from applications of fertilisers, manure and urine, and methane emissions by ruminants (enteric fermentation) and paddy rice cultivation. Nitrous oxide and methane are two important GHGs in terms of total global warming potential, representing 6.2% and 16% of total global warming potential respectively, with agriculture accounting for 58% of total anthropogenic nitrous oxide emissions and for 47% of total anthropogenic methane emissions (IPCC AR5, 2014). Agriculture is expected to remain the main source of these non-CO2 gases in the coming decades (USEPA, 2013). This trend is particularly concerning given the significantly higher global warming potential of nitrous oxide and methane relative to CO2. In addition, the sector generates substantial emissions indirectly due to changes in land use, including land clearing and deforestation (Smith et al., 2014; Bennetzen et al. 2016, p.764).

The agricultural sector is projected to have structurally lower yield growth rates, will experience substantial direct and indirect damages from climate change, and may face additional costs from stringent economy-wide mitigation policies. In view of these multiple challenges, many governments are exploring policies that can stimulate sustainable agricultural productivity growth by exploiting synergies with climate objectives of mitigation and adaptation.
3. A review of available literature

Analysing synergies and trade-offs across the three objectives – as well as identifying strategies to address them – has received limited attention in the literature. By far, most policy analyses still investigate productivity, climate change adaptation and mitigation aspects in silos looking at one or at most two objectives at a time. Furthermore, most policy practices to address climate change are in their initial phase in the agricultural sector (e.g. identifying vulnerabilities, risk assessments and data collection) and most countries are yet to determine how to appropriately implement climate change policies (Duguma et al., 2014).

The existing literature indicates that policies and policy interactions may involve unintended and adverse effects on objectives other than the one(s) directly targeted. According to Hove (2011), “at both the national and international levels, uncoordinated and at times conflicting policies spanning economic development, climate change mitigation and adaptation, and food security can generate perverse incentives and conflicting goals that hinder a more holistic approach to agriculture”. Similarly, OECD-IEA-ITF-NEA (2015) argues that “government interventions to address climate change necessarily interact with policies in many other areas and this may cause frictions and unintended consequences, if not outright contradictions, as these policy interactions engage”.

As climate challenges have only recently been taken into account in agriculture policies, there is as yet little information available to determine their effectiveness at increasing productivity and achieving climate change adaptation and mitigation objectives. Previous policies have been designed to achieve primarily food security and farm income objectives and have not been monitored against climate change goals.

There are no unified metrics to measure the performance of policies on all three objectives. Environmentally adjusted total-factor productivity (EATFP) – which measures productivity growth by accounting also the use of natural resources and production of undesirable environmental outputs in addition to conventional inputs and outputs – could be used to measure sustainable productivity increase. But the task of estimating agricultural EATFP remains challenging (OECD, 2014). Mitigation via lowering GHG emissions or via sequestered carbon can be assessed using estimates of CO₂ equivalents. While the absolute reduction of emissions is the main goal for addressing climate change, lowering emissions intensity per unit of output is also desirable, as a step in the right direction, and can be used as a secondary measure of progress in emission reductions. There is, however, no consensus on what the metrics of adaptation should be. Ignaciuk (2015) discusses various ways to measure different proxies that can help monitoring progress in adaptation. Due to the particular aspects of adaptation, such measures are hardly comparable between countries.

Additionally, existing evaluations largely focus on assessing whether programmes have been implemented and do not consider whether climate-change policy outcomes have been affected or achieved.

Further research is needed to address the knowledge gap on intended and unintended effects of agricultural and environmental policies, as well as on the level of coherence between them. Such an assessment would help identify trade-offs, weigh if they are acceptable or if they can be minimised, as well as consider if and how synergies could be exploited.
4. Quantitative and qualitative frameworks to assess synergies and trade-offs across the three objectives

4.1. Quantitative policy assessment framework

The quantitative policy assessment framework proposes a formal theoretical model and empirical applications for identifying potential synergies and trade-offs inherent in various agricultural and agri-environmental policy instruments across the three objectives. The model describes crop production under crop yield risk (increased variability of yields, decreased yield growth, and potentially decreased expected yields in certain locations) impacted by climate change. The theoretical model is a combination of an agronomic model and the expected utility framework. The latter describes the risk-attitudes and risk-behaviour of farmers. The agronomic model is based on heterogeneous land quality, in which the allocation of land between alternative crops, tillage methods, and the entry and exit of arable land are endogenous.

Farmers’ choices regarding input use, investment, tillage method adoption and land allocation under uncertainty are characterised both in the absence and presence of policy instruments. Two versions of the model have been developed: a static and a dynamic model. The latter allows one to analyse climate change adaptation as a dynamic decision problem. The theoretical model can be used to characterise the impacts of policy instruments on the three objectives qualitatively and to provide initial policy recommendations regarding the potential to foster synergies or address trade-offs.

Agricultural crop yields can be enhanced by investment and cultivation method choices. Agriculture’s contribution to GHG mitigation can be obtained by reducing the use of emission intensive inputs (such as nitrogen fertiliser), through soil carbon sequestration, or by providing bioenergy feedstock to replace fossil fuels. The investment in new technology and adoption of new more climate change resilient cultivation methods are included to represent the adaptive capacity of farmers.

Government intervention to address one of the three policy objectives may induce synergies or trade-offs with the two other policy objectives. This depends on whether farmers are risk-neutral or risk-averse, whether the productive input (e.g. nitrogen fertiliser) is risk-increasing or risk-decreasing (variance of yields are increased or decreased), and whether investment in crop yields enhancement is input-increasing (e.g. increases optimal nitrogen fertiliser application) or input-saving (decreases optimal nitrogen fertiliser application). Since farmers’ optimal decisions also depend on how they consider the long-term nature of crop yield risks associated with climate change, the model allows inter-temporal analysis regarding farmers’ choices of input use, land allocation and investment under a given set of policy instruments.

The stylised policy instruments considered in the theoretical model include: i) an investment subsidy to enhance the adoption of crop yield or adaptation improving technologies, ii) a decoupled area payment and a crop insurance subsidy for yield risk to support farm income, iii) an input tax (nitrogen fertiliser), a soil GHG emissions tax, and a payment for green set-aside to address GHG mitigation objectives.

As caveats, theoretical model and its quantitative applications focus on crop production and related environmental effects, but do not consider the livestock sector that plays an important role regarding climate change mitigation in agriculture sector. Also the climate change adaptation options considered in the current modelling framework are quite limited. Considering limitations of available data and uncertainty related to climate change.
change impacts on crop yields (both average yields and variance of yields) and environmental parameters, the quantitative applications of the model aim to illustrate the dynamics at play and shed light on the incentives created by different types of stylised policy interventions, farmers’ responses to these incentives, and the resulting direction rather than exact magnitude of outcomes regarding the considered policy objectives. Annex B provides a formal description of the theoretical model.

4.2 Qualitative policy assessment framework

The qualitative policy assessment framework essentially builds on two existing OECD initiatives: i) The framework Analysing Policies to Improve Agricultural Productivity Growth Sustainably which considers the full range of policy incentives and disincentives with a potential impact on sustainable agricultural productivity and innovation (OECD, 2015a); and ii) The Policy Coherence approach developed by the OECD Policy Coherence for Development unit (2015c), which is a useful lens through which policy effects can be identified and assessed.

The policy assessment framework includes four parts: (I) policy goals; (II) institutions; (III) policies; and (IV) on the ground initiatives. These parts integrate a top-down approach (Parts I to III) and bottom-up approach (Part IV). Part I aims at understanding how the three objectives are captured within the country’s overall policy goals and which of the objectives is prioritised. Part II aims at identifying relevant institutions and assessing institutional coherence challenges. Part III focuses on the identification and assessment of policy effects in terms of whether they generate synergies or trade-offs across the three objectives. Part IV complements the top-down approach of Parts I-III by: i) identifying on the ground initiatives involving synergies or trade-offs across the three objectives, and ii) assessing how these initiatives can inform policy design and implementation. Finally, the framework includes a review of the key trends related to climate change and adaptive capacity of agricultural systems in a given country to help to identify adaptation needs.

Annex C reviews each part of the framework and proposes a set of questions to guide policymakers throughout the assessment. Applying the policy assessment framework may help government to stimulate a dialogue on the institutional coherence on the three policy objectives and identify where synergies and trade-offs are in the given institutional context. As a caveat, this framework is not designed to compare countries but rather to highlight potential policy incoherencies from a country specific perspective. The questions included in this framework aim to identify potential effects of policies on the three objectives, and more importantly to assess how policies might be resulting in trade-offs between the three objectives. The questions included in the framework are not exhaustive, though. Moreover, the relevance of questions and sections may vary across countries.
5. Initial policy assessment applications with quantitative and qualitative frameworks

5.1. A model application on the basis of data from Finland and data estimates from three sub-river basin sites in the Midwestern United States

To identify how different policy instruments might perform with respect to the three policy objectives, the theoretical model is applied using data from Finland and data estimates and crop model simulation results from three sub-river basin sites in the midwestern United States. The detailed description of the data employed, empirical modelling, and the quantitative results for both applications are provided in respective technical background documents.

The following stylised policy instruments are considered in the assessment: (i) a decoupled crop area payment and a crop insurance subsidy for yield risk to support or maintain farm income, (ii) a payment for green set-aside and a nitrogen fertiliser tax to address GHG mitigation objectives, and (iii) an investment subsidy for adaptive capital to enhance adaptation to climate change. More detailed description of these policy instruments for both applications is provided in Annex E.

The following indicators are used to assess and compare the potential impact of stylised policy instruments on the policy objectives:

- For productivity, the indicator used is the total factor productivity (TFP). A divisia index is used to calculate outputs and inputs in each policy scenario relative to the reference scenario (Market solution without government policy intervention) and the outputs are divided by inputs to get relative productivity levels for policy (see Annex D for a more detailed description of how TFP is defined and calculated);
- For climate change mitigation, the indicator used is the net greenhouse gas emissions from the field crop sector (thus GHG emission changes in other sectors, such as livestock, transport or energy are not included in this indicator);
- For adaptation to climate change, the indicator used is an adaptation index.

3. The model application using estimated data from the United States serves only to illustrate the potential direction of stylised policy effects under a specific set of agricultural and environmental conditions and assumptions. Results from this model application should not be interpreted as indicative of actual policy outcomes under real conditions in the United States.

4. The respective technical background documents are COM/TAD/CA/ENV/EPOC(2016)23/FINAL for application on the basis of data from Finland and COM/TAD/CA/ENV/EPOC(2016)16/REV2 for data estimates and crop model simulation results from three sub-river basin sites in the midwestern United States.

5. We evaluate a generic crop insurance subsidy for area yield risk. Such a crop insurance product is not representative of the majority of crop insurance products available to and used by farmers in the Midwestern United States.

6. Adaptation index is a multiplicative power function with constant returns to scale. It has equal weights (elasticity) for the investment in adaptive capital, crop yields under climate change and net-revenue from production under climate change. A situation without policy (Market solution) is a benchmark solution which is normalised to one and results from policy instruments are represented as relative to Market solution.
With this selection of stylised policy instruments and performance indicators, the quantitative analysis aims to illustrate the potential impacts (i.e. the direction rather than the exact magnitude) of outcomes in relation to the three policy objectives. A benchmark scenario without any policy called “Market solution” is used to compare the possible performance of each policy instrument independently.

**Table 1. The illustrative effects of policy instruments on the three policy objectives in the application using Finnish data**

<table>
<thead>
<tr>
<th>Policy instrument</th>
<th>Productivity</th>
<th>Mitigation</th>
<th>Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decoupled crop area payment</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Crop insurance subsidy for yield risk</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Nitrogen fertiliser tax</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Investment subsidy for adaptive capital</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Payment for green set-aside</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: The table presents changes relative to situation without a policy (so called Market solution): + (improves achievement of policy objective), - (weakens achievement of policy objective), and 0 (no change).

The model results from the Finnish application (Table 1.) suggest that all of the assessed policy instruments may create some trade-offs across policy objectives (for more detailed quantitative results, see Table E.1). In other words, each instrument while supporting one or two of the policy objectives may worsen the situation on one or two of the policy objectives when compared to a situation with no policy instrument in place. However, their potential performance differs greatly in this respect:

- The payment for green set-aside and a nitrogen fertiliser tax seem to perform well with respect to all objectives except adaptation to climate change. However, since the negative impact of green set-aside payment on adaptation is rather small (-1%), this measure could be considered to have an overall positive or neutral effect on the three policy objectives.

- The decoupled area payment appears to provide more trade-offs than the other policy instruments as it increases GHG emissions and decreases productivity relative to the policy free benchmark.

- The crop insurance subsidy for yield risk and the investment subsidy for adaptive capital seem to be neutral with respect GHG emissions and promote adaptation but their productivity performance is weaker than the benchmark provided by the market solution without government policy intervention. However, since the impact of crop insurance subsidy for yield risk on productivity is rather small (-1%), this measure may also be assessed as having an overall positive or neutral effect on the three policy objectives.

- The decoupled area payment, crop insurance subsidy for yield risk, and investment subsidy for adaptive capital all perform well with respect to adaptation.

Thus, on the basis of stylised policy simulations, the Finnish application suggests that none of the policy instruments can simultaneously promote all policy objectives, but that payments for green set-aside perform well overall with positive impacts on productivity and mitigation and very limited negative impact on adaptation, as does crop insurance subsidy for yield risk with positive impact on adaptation, and a neutral or very limited negative impact on productivity and mitigation.
Table 2. provides corresponding results using estimated data from three sub-river basin sites in the midwestern United States (see Table E.2 for more detailed quantitative results).

<table>
<thead>
<tr>
<th>Stylised policy instrument</th>
<th>Productivity</th>
<th>Mitigation</th>
<th>Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decoupled crop area payment</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Crop insurance subsidy for yield risk</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Nitrogen fertiliser tax</td>
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<td>+</td>
<td>+</td>
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<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: The table presents changes relative to situation without a policy (so called Market solution): + (improves achievement of policy objective), - (weakens achievement of policy objective), and 0 (no change).

The model results using data estimates from these three sub-river basin sites (Table 2.) suggest that three of the five stylised policy instruments create some trade-offs across policy objectives (for more detailed quantitative results see Table E.2.) The model results suggest the following:

- The nitrogen tax seems to perform well on all three policy objectives considered.
- The impact of the decoupled crop area payment appears to be relatively neutral and does not appear to result in any negative trade-offs across the different policy objectives.
- The investment subsidy for adaptive capital appears to perform well although it slightly reduces productivity (-0.1%).
- Crop insurance subsidy for yield risk is estimated to slightly decrease productivity (-0.1%) and increases GHG emissions (1%) but to be slightly positive with respect to adaptation. Considering that these relative impacts are rather small one may consider that that crop insurance subsidy for yield risk is overall a relatively neutral policy instrument across the three objectives.
- Payments for green set-aside seem to promote productivity (as lowest productivity crop land is allocated to green set-aside) and GHG emissions reduction, but at the expense of adaptation.

Thus, the application of the theoretical model using estimated data from these three sub-river basin sites suggests that the nitrogen fertiliser tax can simultaneously deliver on all three policy objectives. It should be noted, though, that such measure would somewhat reduce production and farm profits (Table E.2). The decoupled crop area payment performs much better in this case than in the Finnish case indicating that agricultural conditions (e.g. profitability of production without government support) and environmental conditions (e.g. environmental sensitivity of land under cultivation) may matter a lot for performance of the given policy instrument.

The results in Table 3. illustrate the relative impact of stylised policy instruments in both applications of the theoretical model. Results are presented as a relative (%) change to the benchmark solution (Market solution without government policy intervention).
Decoupled crop area payments may in some cases induce important trade-offs between the three objectives (Finnish data) or no trade-offs at all (the data estimates for the US sub-river basin sites). This can be explained by the entry-exit margin impact of changes in cultivated agricultural land in the model results. Under agricultural and environmental conditions represented by the data estimates for the sub-river basin sites, agricultural production remains profitable even without agricultural support policies while in Finland low quality land would not be cultivated without agricultural support policies. Given this starting point the introduction of a decoupled crop area payment in the model does not have major impacts under conditions represented by the data estimates for the sub-river basin sites and thus does not result in major trade-offs between different policy objectives. In Finland a decoupled crop area payment creates stronger trade-offs through expansion of cultivated land, especially regarding GHG mitigation. However, this impact can be mitigated if a fixed base area is set for decoupled crop area payments so that those payments are not paid for cultivated land that was previously idled or under some other use.\footnote{In many countries eligibility for decoupled payments is determined by a fixed, historical base, so that cropland expansion does not take place as a result of the policy. Expectations regarding future updates of historical base area may create incentives for cropland expansion in the longer run in countries with available land.}

If one does not account for the small negative effects, the crop insurance subsidy for yield risk seems to be rather neutral across the three objectives in both cases, with even a positive effect on adaptation, especially in the case of Finland.

The simulated effects of payments for green set-aside are similar in both case, with positive effects on productivity and mitigation and negative effect on adaptation.

### Table 3. The effects of stylised policy instruments on the three policy objectives

<table>
<thead>
<tr>
<th>Stylised policy instrument</th>
<th>Productivity</th>
<th>Mitigation</th>
<th>Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US sites</td>
<td>US sites</td>
<td>US sites</td>
</tr>
<tr>
<td></td>
<td>Finland</td>
<td>Finland</td>
<td>Finland</td>
</tr>
<tr>
<td>Decoupled crop area payment</td>
<td>0.0</td>
<td>0.0</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>-11.3</td>
<td>14.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Crop insurance subsidy for yield risk</td>
<td>-0.1</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>-0.6</td>
<td>0.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Nitrogen fertiliser tax</td>
<td>0.4</td>
<td>-15.9</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>3.1</td>
<td>-10.9</td>
<td>-7.7</td>
</tr>
<tr>
<td>Investment subsidy for adaptive capital</td>
<td>-0.1</td>
<td>-1.8</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>-2.9</td>
<td>0.0</td>
<td>22.1</td>
</tr>
<tr>
<td>Payment for green set-aside</td>
<td>1.9</td>
<td>-65.9</td>
<td>-6.2</td>
</tr>
<tr>
<td></td>
<td>12.6</td>
<td>-9.4</td>
<td>-1.2</td>
</tr>
</tbody>
</table>
The nitrogen fertiliser tax seems to foster mitigation and productivity improvements in both cases, but with strikingly opposite effects on adaptation between the two situations considered. The investment subsidy for adaptive capital appears to support adaptation but with negative effects on either mitigation or productivity depending on the case.

The overall agricultural and environmental policy package may affect the performance of the policy instruments evaluated above in isolation. Data from Finland was used to test how these stylised policy instruments perform as a part of the larger policy package consisting of several policy instruments (for example, a combination of the decoupled crop area payment, the agri-environmental payment and the crop insurance subsidy for yield risk). In this case, when an agri-environmental payment with environmental compliance criteria (e.g. fertiliser application constraints) was part of the policy-mix then trade-offs induced by decoupled crop area payments could be reduced. Similarly, a combination of decoupled crop area payment with a fertiliser tax reduces trade-offs induced by decoupled crop area payment.

**Initial conclusions from the quantitative applications of the model**

- The illustrative quantitative results suggest that existing policy measures in agriculture could in some cases send signals that could impede the achievement of some of the three objectives. However, as some of the trade-offs created were relatively minor in magnitude, a compound indicator, such as social welfare could be useful to reveal overall social welfare performance of the given policy instruments (Social welfare performance is reported in Tables E.1. and E.2.).
- Most of the quantitative applications presented here are focused on single stylised policy instruments implemented in isolation. However, in practice policy instruments for productivity enhancement and climate change goals are implemented as a part of an overall agricultural and environmental policy mix. In the test of potential effects of the stylised policies within a policy mix using the Finnish application of the model, results suggested that the latter can mitigate or reinforce synergies and trade-offs created by any given policy instrument.
- Thus in a complex policy context such as will be likely in any effort to implement at the Paris Climate Change agreement while at the same time ensuring food security, countries will need to make specific assessments of policy effects on the three objectives to account for the differences in situations.

**5.2 Key findings from qualitative case studies of France and the Netherlands**

The qualitative case studies of France and the Netherlands using the qualitative policy assessment framework presented in Section 4.2 assess whether existing policies in the two countries foster synergies or induce trade-offs between the three objectives.

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8. The main reason for this is that the nitrogen tax has strong negative effect on profitability of production in the Finnish case, and since the net-revenue from production is one of the three elements in the adaptation index it has relatively strong impact on adaptation.

**French case study**

France’s institutional framework reflects a recent shift towards promoting the integration of economic, environmental and climate considerations in agriculture, with government agencies and initiatives increasingly focused on the need to consider climate change together with specific agricultural priorities. Recent agricultural orientations and strategies seek to give stronger, if not equal, weight to climate change considerations and to encourage mitigation and adaptation along with competitiveness and productivity. France has also designed national climate-change mitigation and adaptation plans that include actions specific to the agriculture sector. These changes are mirrored by an institutional shift toward collaboration both within and between the ministries responsible for the policy areas.

Improving economic and environmental performance of agricultural and agri-food value chains is, notably, an overarching goal of France’s 2012 agro-ecology project10 as well as its 2014 Law for the Future of Agriculture, Food, and Forests (LAAF) (MAAF, 2013). A hallmark of this law is the creation of Economic and Environmental Interest Groups (GIEE), which are platforms for individual farmers to undertake collective efforts that are officially recognised and may receive support for projects that advance economic and environmental interests simultaneously (MAAF, 2014a). Another example of the French commitment to enhance carbon storage and to increase resilience of agriculture is the 4 per mille initiative.

Recent national climate-change mitigation and adaptation plans include actions specific to the agriculture sector. In support of the national goal to reduce emissions by 40% by 2030 and by 75% by 2050 compared with 1990 levels, the National Low Carbon Strategy sets a non-binding target of 12% emissions reduction from agriculture compared with 2013 levels by 2028 and 50% by 2050 compared with 1990 (MEEM, 2015a). While the inclusion of targets for agriculture is an important step, sectoral mitigation targets are not legally binding. This approach still allows for France’s Expert Committee for Energy Transition to periodically review and potentially revise the carbon budgets of the agriculture and other sectors, leaving flexibility to address trade-offs that may arise (MEEM, 2015b). The National Climate Change Adaptation Plan emphasises research, innovation, and knowledge transfer, decentralised incorporation of adaptation objectives in agricultural policies at the regional level, and efficient management of water and other natural resources (MEEM, 2011). The recent adoption of these mitigation and adaptation plans is indicative of a considerable shift towards the integration of climate objectives across sectors, including agriculture.

France has focused on adopting a wide variety of different policy tools to address the many aspects of agriculture related to climate change adaptation or mitigation. In particular, France favours the use of soft policies in its policy mix as an alternative or

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10 In French agricultural policies, agro-ecology refers to public policies designed to promote and sustain agro-ecological production systems, including organic production, which combine economic, social performance, environment and health. This concept emphasises the self-sufficiency of farms with an aim to improve their competitiveness by maintaining or increasing economic efficiency, improving the value added of production and reducing the consumption of energy, water, fertilisers, plant protection products, and veterinary drugs, particularly antibiotics. Agro-ecological systems are based on biological interactions and the use of ecosystem services and the potential offered by natural resources, in particular water resources, biodiversity, photosynthesis, soil, and air. These systems aim to contribute to the mitigation and adaptation to climate change in agriculture.
supplement to regulations. A recent survey by the French ministry in charge of agriculture noted an increased awareness and acceptance by farmers of the agro-ecology project; an umbrella project for public policies designed to promote and sustain agro-ecological production systems that incorporate a number of public-awareness increasing tools.

Agricultural policies in France are determined, to a large extent, at the European level by the Common Agricultural Policy (CAP). The current iteration of the CAP incorporates climate change adaptation and mitigation measures and places a stronger emphasis on environmentally sustainable agricultural practices. Pillar I programmes, for example, incorporates Good Agriculture and Environmental Condition (GAEC) requirements and green payments, to address environmental and climate change objectives. While the aim of the “new” CAP is still to encourage farm investments to increase competitiveness and productivity, the addition of these measures addresses climate concerns more than the former CAP, and provides a platform for integration of climate and productivity considerations in agriculture. For Pillar II, depending on the way of accounting, an estimate of 30% to 66% of the budget targets climate change. These include agro–environmental and climate measures (AECM), less favoured areas (LFA) forestry measures and investments (MAAF, 2015). For the programming period 2015-2020,

Many recently-developed policies, as well as some reforms made to existing policies, support at least two of the three objectives of productivity growth, adaptation, and mitigation. Some new policies try to achieve synergies between the economic and climate change objectives. For instance, the Energy Methanisation and the Nitrogen Autonomy Plan (EMAA) shows potential to create synergies between productivity and mitigation by encouraging investments in more energy-efficient production and improved efficiency of nitrogen use. Synergies between adaptation and productivity are supported by the EcoPhyto Plan, which aim to reduce use of phytosanitary products and decrease the reliance of crops on pesticide use and encourages biodiversity and soil health improvement.

The livestock sector production, targeted by support coupled to production, namely suckler (beef) and dairy cattle, plays a major role in GHG emissions; emissions from enteric fermentation and livestock manure alone account for about 43% of emissions from agriculture in France (MAAF, 2014b). Support to such production, represents 93% of coupled payments under the current CAP in France (MAAF, 2015). Support to the livestock sector is done through a diverse set of instruments. It includes measures coupled to production (approximately EUR 1 million for France), some of which promote more environmental-friendly practices, and decoupled measures, including measures with clear climate goals and measures to support permanent pasture lands. Pasture lands, if properly managed, can serve to sequester carbon and offset some of the GHG emissions of livestock production.

11. Under Pillar I of the CAP, 30% of payments are tied to environmental goals (conditions for farmers to receive green payments) many of which address climate goals, such as maintenance of permanent grassland or ecological focus areas. The remaining 70% are subject to GAEC that do not always target climate change, but often, indirectly.

12. It includes measures coupled to production (approximately EUR 1 million for France), some of which promote more environmental-friendly practices, and decoupled measures, including measures with clear climate goals and measures to support permanent pasture lands. Pasture lands, if properly managed, can serve to sequester carbon and offset some of the GHG emissions of livestock production.
cattle (Haspel, 2015). France is also looking to mitigate emissions from the livestock sector through policies such as the Energy Methanisation and Nitrogen Autonomy (EMAA) and the Plant Protein Plan and development of pasture lands (MAAF, 2015). Emissions from livestock decreased by 11.3% between 1990 and 2012.

French farmers, among other sectors, benefit from a reduced rate of internal consumption tax (TIC) on their fuel. The reduced cost of fuel resulting from the measure incentivises its use and supports agricultural production at the expense of increased emissions. Similarly, irrigators are also exempt from certain fees on water use, which may stimulate inefficient water use, contribute to more emissions (Levraut, 2013) and make climate change adaptation difficult.

Reducing GHG-emitting by-products of agricultural production to achieve climate change goals is also not always incentivised by government policy. For example, French policy on manure is only partially successful at reducing GHG emissions, because the policy’s focus is on subsidising the disposal of manure, while farms that produce surplus manure are not penalised (Le Goffe, 2013).

**Dutch case study**

With regard to climate change issues, agricultural policies in the Netherlands aim to stimulate synergies between competitiveness and GHG mitigation, while the agri-food sector (with the exception of water resource management) is seen as primarily responsible for adaptation efforts. Emission-reduction targets have been presented to the private sector as an opportunity rather than a threat to productivity, and drive innovation in the agri-food chain.

The Dutch agri-food sector currently accounts for approximately 9.3% of total national greenhouse gas (GHG) emissions (RIVM, 2015), and is expected to contribute to national mitigation targets. The Netherlands has committed to a 30% reduction of emissions compared with 1990 levels for the period of 2013 to 2020 (Coalitieakkoord, 2007). Climate-change mitigation efforts for agriculture in the Netherlands focus particularly on the livestock and the greenhouse-horticulture sectors, which together comprise about 90% of Dutch GHG emissions from agriculture. These two most GHG-intensive agri-food sectors have already achieved their 2020 emission reduction targets: 3.3 Mt of CO\textsubscript{2} (compared to 1990 emission levels) was reduced by the greenhouse horticulture sector and 5.6 Mt CO\textsubscript{2}-eq by livestock farmers.

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13. However, France considers that there is a global carbon leakage risk of producing livestock outside of the country with likely worse climate performance (i.e. shift of the production to places where more GHG would be emitted to produce a similar product, or grassland turned into crop in the case that livestock is abandoned) and the synergy with other environment aspects such as biodiversity or water must be taken into account. Additionally, the diversification of livestock production, by promoting pasture lands, is considered a significant way of enhancing agriculture adaptation to climate change.

14. The Plant Protein Plan seeks to encourage production of plant proteins for use as animal feed.

15. This translates to a target ceiling of 150 mega ton CO\textsubscript{2} equivalent ceiling (Coalitieakkoord, 2007). All sectors under the EU Emissions Trading Scheme (ETS), including greenhouse horticulture, must realise this target proportionally. These target reductions in the Netherlands fall under EU-wide emissions limits. EU standards for emissions levels also apply to non-ETS–sectors, namely agriculture (Milieubalans, 2008).
The Dutch government creates favourable conditions for the agri-food sector to develop cost-effective actions in support of climate change mitigation, and to encourage uptake of climate-friendly measures. The Dutch government tries to actively reduce barriers for the uptake of sustainable technologies (including emission-reducing measures), and has designed various programmes to remove the obstacles in regulation and legislation and acts when it appears likely that the fixed emissions targets agreed with the sector will not be met.

Dutch policy makers favour designing public-private agreements (covenants) that outline government’s emission reduction targets and allow a degree of freedom on how the private sector may achieve those targets. The provisions laid down in the covenants are legally binding and enforceable. A number of very successful covenants were applied in the Netherlands. They stimulate innovation as they push the agri-food sector to sustain its competitive position while at the same time reducing emissions. If the private sector fails to achieve the agreed targets, the government enforces regulations, which are often already contained in the agreements. For instance, the growth of the dairy sector following the abolition of the EU milk quota resulted in the sector’s inability to curb its emissions. Because there is a serious threat that the sector will not be able to meet the agreed targets, phosphate rights regulations are implemented, which at the end will likely result in a decrease of a number of livestock and consequently cut GHG emissions.

The European legislation has been the main driver of the Netherlands’ efforts to reduce emissions from the livestock sector. The most influential piece of legislation that drives national policies to reduce manure surplus and associated emissions is the 1991 EU Nitrate Directive. The pork and poultry sectors have managed to increase their productivity without additional emissions by investing in bioenergy and increasing manure exports. The same results have not been seen in all sectors; the dairy sector has been less successful in containing its emissions.

The energy market liberalisation and the, until recently, high prices of fossil fuels are behind the notable success of the greenhouse sector in reducing its emissions. In 2011 the greenhouse sector used 52% less energy per unit of production compared with 1990. This was achieved through the implementation of combined heat and power installations that both decreased the energy use per unit of production and generated income from electricity sales. The government has also played a role in the successful transition to more efficient energy use in the greenhouse sector. The ministry had provided some seed money in the past to stimulate energy development, and decreased the tax rate the sector has to pay on its gas bill, as it did for other energy-intensive sectors. Research activities on energy savings are also funded up to 60% by public support.

The recent abolition of the EU milk quota induced trade-offs between productivity and emissions reduction objectives. The abolition of milk quotas, as of 1 April 2015, including the soft landing dairy quota system\(^\text{16}\), allowed the Dutch dairy sector to grow\(^\text{17}\), resulting in an increase of manure production exceeding the sector’s agreed limits; this

\(^{16}\) Over the period 2009-2014, the milk quotas were increased annually by 1% by the European Union.

\(^{17}\) While the Dutch dairy farm sector achieved continuous productivity growth, the change in milk quota regime changed its dynamics. The total factor productivity growth, before the phasing out of the milk quota, was almost entirely driven by a decline in input use. However, currently the main driving force of TFP growth in the Dutch dairy farm sector became the expansion of milk output (Kimura and Sauer, 2015).
increased direct GHG emissions. It also affected the use of manure from the pork industry. Although arable farmers are paid less for utilizing a tonne of cow manure than pig manure, they prefer to use cow manure, as they earn more money, in total, on using cow manure (pig manure contains about three times more phosphates than cow manure).\textsuperscript{18} Pork farmers, in turn, have to search for alternative solutions to using pig manure.

The Common Agricultural Policy (CAP) has limited impact on the livestock and greenhouse horticulture sectors (except on extensive dairy sector) in the Netherlands. The shift away from production support to income support has stimulated the sector to adjust its production in reaction to the market. The Dutch livestock sector receives relatively limited support under the current CAP; mostly in the form of Pillar I direct income support per hectare. With the further decoupling of CAP, the shift to a hectare based direct income support and the national convergence of the per-hectare premiums means that the veal, beef, and the intensive dairy sectors will face reductions of the previous direct payments during the transition to 2019. The government will financially support the transition towards measures aimed at strengthening the sustainability and the future viability of the sectors as part of the Pillar II measures\textsuperscript{19}. For extensive livestock farmers, i.e. for most dairy farmers, direct income support is higher as it is linked to support per hectare. The greenhouse horticulture sector does not receive any direct income payments. As for the Pillar II, the government has chosen not to explicitly include specific measures on promoting resource efficiency and the transition to a low-carbon economy. In line with the Dutch position that innovation is key to strengthen the competitiveness of a sustainable sector, a portion of Pillar II funds is designated to this objective, including livestock farmers and greenhouse horticulture\textsuperscript{20}.

\textbf{Conclusions from the application of the qualitative framework}

Looking forward, the qualitative framework has shown potential to help governments initiate an inter-institution dialogue towards identifying whether the impact of agricultural and agri-environmental policies on the three objectives are considered, what contradictions might exist, and how the government could better structure its institutional setting to identify such contradictions and to address them. The insights garnered will be used to strengthen the application of the framework for innovation and sustainable productivity growth, while more generally climate change, both adaptation and mitigation, will be mainstreamed in applications of the framework.

\textsuperscript{18} Cow manure contains less nitrogen and phosphorus, therefore a larger amount of cow manure can be utilised per hectare.

\textsuperscript{19} The veal sector will receive EUR 10 million per year and the beef sector EUR 500 000 per year under the RDP.

\textsuperscript{20} About EUR 800 million is dedicated to productive and non-productive investments under RDP that enable farms to respect regulations via further innovation, but it is unclear how much is dedicated to improve innovation within the livestock sector.
References


Marengo et al. (2014), “Climate Change in Central and South America: Recent Trends, Future Projections, and Impacts on Regional Agriculture”, Working Paper, No. 73. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).


Annex A.

Impacts of a selection of land management practices on productivity, climate change mitigation and adaptation

Table A.1 summarises the impacts of some land management practices on farm productivity, climate adaptation, and GHG mitigation. Practices were sourced from Bryan et al. (2011) and should not be seen as an exhaustive list of potential synergetic practices. The extent of the impacts on productivity, climate adaptation and greenhouse gas mitigation will depend largely on local conditions. Effects are therefore defined qualitatively rather than quantitatively.
Table A.1. Examples of land management practices, and their impacts on productivity, climate change adaptation, and greenhouse gas mitigation

<table>
<thead>
<tr>
<th>Examples management practice</th>
<th>Productivity impacts</th>
<th>Climate adaptation benefits</th>
<th>Greenhouse gas mitigation potential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cropland management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved crop varieties or types (early-maturing, drought resistant, etc.)</td>
<td>Increased crop yield and reduced yield variability</td>
<td>Increased resilience against climate change, particularly increases in climate variability (prolonged periods of drought, seasonal shifts in rainfall, and the like)</td>
<td>Improved varieties can increase soil carbon storage</td>
</tr>
<tr>
<td>Changing planting dates</td>
<td>Reduced likelihood of crop failure</td>
<td>Maintained production under changing rainfall patterns, such as changes in the timing of rains or erratic rainfall patterns</td>
<td>Unknown, although higher yields are likely to increase soil carbon</td>
</tr>
<tr>
<td>Improved crop/fallow rotation/rotation with legumes</td>
<td>Increased soil fertility and yields over the medium to long term due to nitrogen fixing in soils; Short-term losses due to reduced cropping intensity</td>
<td>Improved soil fertility and water holding capacity increases resilience to climate change</td>
<td>High mitigation potential, particularly crop rotation with legumes</td>
</tr>
<tr>
<td>Use of cover crops</td>
<td>Increased yields due to erosion control and reduced nutrient leaching; Potential trade-off if cover crops replace grazing area in mixed crop–livestock systems</td>
<td>Improved soil fertility and water holding capacity increases resilience to climate change</td>
<td>High mitigation potential through increased soil carbon sequestration</td>
</tr>
<tr>
<td>Appropriate use of fertiliser and manure</td>
<td>Higher yields due to appropriate use of fertiliser/manure</td>
<td>Improved productivity increases resilience to climate change; Potential greater yield variability with frequent droughts</td>
<td>High mitigation potential through reduced nitrous oxide emissions when nitrogen fertiliser has been over-applied relative to crop needs.</td>
</tr>
<tr>
<td>Incorporation of crop residues</td>
<td>Higher yields due to improved soil fertility and water retention in soils; Trade-offs exist if crop residues would have otherwise been used as animal feed</td>
<td>Improved soil fertility and water-holding capacity increases resilience to climate change</td>
<td>High mitigation potential through increased soil carbon sequestration</td>
</tr>
<tr>
<td>Reduced or zero tillage</td>
<td>Increased yields over the long term due to greater water-holding capacity of soils; limited impacts in the short term; Potential trade-offs in terms of weed management and potential waterlogging</td>
<td>Improved soil fertility and water-holding capacity increases resilience to climate change</td>
<td>Some mitigation potential through reduced soil carbon losses</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>Uncertain impacts on yields: Yields could increase on adjacent cropland due to improved rainwater management and reduced erosion; Potential reduced yields if smaller crops compete with trees for light, water and soil nutrients</td>
<td>Increased resilience to climate change due to improved soil conditions and water management; Benefits in terms of livelihood diversification</td>
<td>High mitigation potential through increased soil carbon sequestration</td>
</tr>
<tr>
<td><strong>Soil and water management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation and water harvesting</td>
<td>Higher yields, greater intensity of land use</td>
<td>Reduced production variability and greater climate resilience when systems are well designed and maintained</td>
<td>Low to high depending on whether irrigation is energy intensive or not</td>
</tr>
<tr>
<td>Management of livestock or grazing land</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td></td>
</tr>
<tr>
<td>Diversify, change, or supplement livestock feeds</td>
<td>Higher livestock yields due to improved diets</td>
<td>Increased climate resilience due to diversified sources of feed</td>
<td>High mitigation potential because improved feeding practices can reduce methane emissions</td>
</tr>
<tr>
<td>Destocking</td>
<td>Potential increases per unit of livestock; Total production may decline in the short term</td>
<td>Lower variability over the long term, particularly when forage availability is a key factor in livestock output</td>
<td>High mitigation potential because reduced livestock numbers lead to reduced methane emissions</td>
</tr>
<tr>
<td>Rotational grazing</td>
<td>Higher yields due to greater forage availability and quality; Potential short-term trade-off in terms of numbers of livestock supported</td>
<td>Increased forage availability over the long term, providing greater climate resilience</td>
<td>Positive mitigation potential due to increased carbon accrual on optimally grazed lands</td>
</tr>
<tr>
<td>Improved breeds and species</td>
<td>Increased productivity per animal for the resources available</td>
<td>Increased resilience of improved species or breeds to withstand increasing climate extremes</td>
<td>Varies, depending on the breeds or species being traded</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Restoring degraded lands</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Revegetation</td>
<td>Improved yields over the medium to long run; improved yields on adjacent cropland due to reduced soil and water erosion</td>
<td>Reduced variability due to reduced soil and water erosion</td>
</tr>
<tr>
<td>Applying nutrient amendments</td>
<td>Improved yields over the medium to long run</td>
<td>No known benefits for adaptation</td>
</tr>
</tbody>
</table>

Adapted from Bryan et al. (2011).
Annex B.

A theoretical model for identifying potential synergies and trade-offs induced by policy instruments across three objectives

Input use and investment

**Crop production under risk**

Let us consider agricultural production under heterogeneous land quality. The land is divided into field parcels which are of the same size and homogeneous in land quality. Land quality differs over field parcels and it can be ranked by a scalar measure \( q \), with the scale chosen so that minimal land quality is zero and maximal land quality is one, i.e. \( 0 \leq q \leq 1 \). Let \( G(q) \) denote the cumulative distribution of \( q \) (acreage having quality \( q \) at most), while \( g(q) \) is its density. It is further assumed that \( g(q) \) is continuous and differentiable. The total amount of land is thus \( G = \int_0^1 g(q) dq \).

The production function is usually expressed using a productive input (such as fertiliser, pesticide or irrigation water) as an argument, so that production, \( y \), is \( y = f(x,q) \), where \( x \) is the productive input and \( q \) refers to land quality. Crop production functions indicate how crop yields increase with increasing use of productive inputs. While the above formulation of crop production function reflects certainty, every farmer faces yield uncertainty caused by weather conditions and other factors. These risks can be captured using a simple but helpful approach suggested by Just and Pope (1978), who present production function in the following additive form:

\[
y = f(x; q) + h(x; q)\varepsilon,
\]

where \( \varepsilon \) denotes the yield risk. For the theoretical analysis, it is useful to assume that \( \mathbb{E}[\varepsilon] = 0 \) and \( \text{Var}(\varepsilon) = 1 \). Hence, the first term of equation (1) gives the expected yield as a function of productive input. The latter term indicates how the use of productive input impacts risk. This formulation allows us to distinguish between risk-increasing and risk-decreasing inputs. When \( x \) refers to fertiliser input, it is regarded as a risk-increasing input in this analysis, so that \( h'(x) > 0 \) and its use increases the variance of the production.\(^{21}\) When \( x \) refers to the use of herbicides and pesticides, since they are

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\(^{21}\) When variance is taken as the sole measure of risk, nitrogen application usually increases the variance of yields and profits and thus risk-averse farmers would tend to apply less nitrogen fertiliser. However, risk-averse farmers may also be inclined to apply more fertiliser to ensure that expected yield outcomes are met (at a potential cost to water-quality and GHG emissions). These weather-related drivers suggest differing farmer-risk responses, and it is unclear which driver is predominant. Empirical evidence is mixed regarding whether nitrogen fertiliser is risk-increasing or risk-reducing input.
typically regarded as risk-reducing inputs, then \( h'(x) < 0 \) indicating that increasing the use of \( x \) decreases the variance and thus risk of production. The empirical model is flexible and allows selecting nitrogen fertiliser to be risk-increasing, risk-decreasing or risk-neutral input depending on the underlying empirical evidence for a given application.

**Enhancing agricultural crop yields**

The farmer can invest in new technology (for example, precision farming equipment) to improve crop yields. We let the investment be continuous, \( k \), but it can be treated as a discrete investment as well. We assume for simplicity that investment does not impact the variance of yields\(^{23}\). We allow for a choice between current conventional tillage and new (e.g. no-till) cultivation methods (denoted by \( i = 1,2 \)), with the assumption that the new cultivation method is more climate-resilient than current practices. Hence, the expected crop yield function under these tillage methods can be expressed as a function of inputs \( x \) and \( k \):

\[
y^i = f^i(x, k; q) .
\]

By assumption the investment improves crop yields under both cultivation methods (current and climate resilient). It is natural to assume that the first partial derivative is \( f^i_1 > 0 \) and second partial derivative is \( f^i_{kk} < 0 \), that is, investment has diminishing marginal returns. The investment \( k \) relates to the use of productive input \( x \) in three possible ways defined as follows:

- **Input-increasing investment**: the investment increases crop yields and promotes higher use of input. Mathematically, \( f^i_{x,k} > 0 \), indicating the investment increases the marginal product of input.

- **Input-saving investment**: the investment increases crop yields with a reduction in the use of input. Mathematically, \( f^i_{x,k} < 0 \), and the investment decreases the marginal product of input.

- **Input-neutral investment**: the investment increases yields and does not change input use. Mathematically, \( f^i_{x,k} = 0 \), and investment has no impact on the marginal product of input.

Government can promote productive investments, for example, by providing investment subsidies (e.g. cost-share investment subsidy) to farmers.

---

\(^{22}\) As regards agricultural productivity theoretical model mainly focuses on crop yields and crop yield enhancement through investment.

\(^{23}\) Productivity enhancing technology is assumed to improve expected mean crop yields but not to affect crop yield variability caused by climate change. However, productivity enhancing technology which is assumed to increase the efficiency of nitrogen use might as well decrease the variability of crop yields and not only improve mean crop yield. Moreover, technology investments serve multiple purposes including productivity and efficiency of input use (such as fertiliser, pesticide or irrigation water).
Optimal choices of input use and investment

Recall, $i$ denotes two alternative cultivation methods, the current method and a new climate-resilient cultivation method (e.g. no-till)\(^{24}\). In each field parcel the farmer chooses the cultivation method that provides the highest profits, and optimises the use of inputs and investment within the cultivation method. Thus, farmer’s decision choices entail both discrete technology choices and continuous production choices. The model is solved in a recursive manner: production is optimised under both cultivation methods and the one providing the highest profit is chosen. Since land quality is homogenous within each field parcel there is a corner solution and the whole field parcel is cultivated with the method providing highest profits. However, profitability of cultivation methods differs over heterogeneous land quality and thus there are two unique critical land productivities that define: (i) land allocation between cultivated cropland and idled land and (ii) cropland allocation between different cultivation methods. That is, a minimum quality of land below which land is not allocated to crop production and a critical quality of land denoted $q^c$ at which the land allocation switches from one tillage method (or crop) to another (see, for example, Lichtenberg 2002). Thus, there exists a land quality level for each cultivation method, denoted $q_i$, for which the profit is zero. Without a loss of generality it can be assumed that this marginal land quality is lower for traditional cultivation method (1) than for new cultivation method (2). Second, we assume that output of cultivation method 2 per unit land area is more responsive to increases in land quality than output of cultivation method 1, that is $f_2^i(x_i; q) < f_1^i(x_i; q), \forall q$. Third, it is assumed that at land quality $q = 1$ cultivation method 2 has a higher profit than method 1.

Let the price of crop be $p$, cost of productive input be $c$, per hectare cultivation costs be $M_i$, unit price of investment be $w$ and the decoupled area payment be $A$. Cultivation costs $M_i$ include among other things labour (measured in working hours). We assume that capital investment reduces labour input, thus, $M_i'(k) < 0$. Let $E$ denote the working lands agri-environmental (A-E) payment that compensates income forgone and extra costs incurred due to participation in A-E scheme (including compliance requirements, such as fertiliser application constraints and buffer strip establishment and management). To make the exposition simpler the upper limit on fertiliser application is translated to an equivalent nitrogen tax, $t$. Furthermore, $\overline{m}$ denotes the mandatory buffer strip and $h(\overline{m})$ the costs of establishing the mandatory buffer strip. Then the stochastic profits of the risk-averse farmer participating in a working lands agri-environmental programme are,

$$\tilde{\pi}^i(\varepsilon) = (1 - \overline{m})\left[ p(f^i(x_i; k; q) + h(x_i)\varepsilon) - (c + t) x_i \right] - M_i - wk + E - h(\overline{m}) + b(m) + A \quad (2)$$

The farmer can hedge against the risks by taking insurance, like crop yield insurance, where the farmer buys coverage for the yield risk. We evaluate a generic crop insurance subsidy for area yield risk. Such a crop insurance product is not representative of the majority of crop insurance products available to and used by farmers in the midwestern United States. Typically, insurance companies supply a set of coverages for a given set of premiums. Hence, the choice of insurance is a discrete 0-1 choice and determined by the requirement that a farmer must be better off with the insurance contract than without it. Nevertheless, once insured, the farmer’s choices may be impacted by the insurance

\(^{24}\) Powlson et al. (2014) argue that there is abundant evidence that no-till is beneficial for the functioning and quality of soil in many situations (though not all) and resulting soil conditions offer potential for increased resilience to weather variability and climate change.
contract and this requires a separate analysis. A typical crop yield insurance compensates based on the chosen coverage, δ, and yield loss, defined as the difference between agreed normal yield, \( \bar{y} \), and actual yield, where yield is below normal. Thus, the compensation is \( p \delta (\bar{y} - y) \), but it is zero if \( \bar{y} < y \). Furthermore let \( v \) be indemnity and \( n \) the premium. To examine other potential policy instruments, we consider that the government may subsidise crop yield insurance by a subsidy \( s_1 \) and investment for adaptive capital (such as improved subsurface drainage) by a subsidy \( s_2 \) (equation 3).

Another policy instrument to explore is a payment for green set-aside (or land retirement with conservation cover). Due to the climate and water quality benefits associated with green set-aside, a government may want to provide a payment for green set-aside establishment and management. When a given field parcel is allocated to long-term green set-aside, the depleted carbon content of soil starts gradually increasing via carbon sequestration. This process is finite in terms of both quantity and time of soil carbon sequestration. Let the annualised average value of sequestered carbon per year be \( b \). Let \( B \) denote government payment for green set-aside reflecting the climate benefits from sequestered carbon when the costs of green set-aside maintenance and establishment is denoted by \( z_\delta \). It is natural to assume that low quality field parcels (that is, field parcels with low opportunity costs) are most likely to be allocated to green set-aside.

The stochastic profits subject to all these policy instruments and over all land productivities can be expressed as

\[
E^i(\varepsilon) = \begin{bmatrix} \delta & 0 \end{bmatrix} \left\{ F(s,k,q) + h(x) \right\} + v(x) \left(p \delta (\bar{y} - y) \right) - n(\delta)(1-s_k) - w(1-s_k)k \}
- M(k) + E
- h(M) + A) z_\delta + (B - z_\delta)(1 - L_i) g(q) dq
\]

where \( L_i \) denotes the share of land allocated to crop production and \( L_2 = (1 - L_1) \) denotes the share of land allocated to green set-aside (or land retirement with conservation cover).

A risk-averse farmer maximises the expected utility from stochastic profits,

\[
EU(\pi^i) = E[U(\bar{\pi}^i(\varepsilon))].
\]

The first-order conditions characterising the optimal choice of inputs and land allocation are

\[
x_i : E \left[ U'(\bar{\pi}^i)(pf_x^i + h'(x) - v'(p \delta (\bar{y} - y)) \left( \frac{\partial y}{\partial x_i} - c \right) \right] = 0
\]

\[
k : E \left[ U'(\pi^i)(pf_k^i - w(1-s_k) - M'(k)) \right] = 0
\]

\[
q^c : E \left[ U'(\pi^i)^B \right] = 0
\]

Starting with equation (5b), as marginal utility is always positive, it must hold that \( pf_k^i - w - M'(k) = 0 \). Investment increases up to the point where the value of marginal product equals the unit price of investment plus the reduction in cultivation costs. The choice of productive input is more interesting. Assume first that no insurance is present. Then (5a) becomes a product of two uncertain variables and can be expressed as,

\[
pf_x^i - c + \frac{cov(U'(\pi^i), h'(x_i) \varepsilon)}{E[U'(\pi^i)]} = 0
\]

\[
(6)
\]

\[
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\]
The first two terms indicate the choice of a risk-neutral farmer. Reflecting risk-aversion, the third term is the risk-adjustment term. The covariance is negative, as high ε is associated with high π and the marginal utility is decreasing. Therefore, derivative \( h'(x_i) \) determines the sign of the risk term. If the input is risk-increasing, \( h'(x_i) > 0 \), the risk-adjustment term is negative indicating that the use of input is lowered relative to the case of risk-neutrality. If we instead have \( h'(x_i) < 0 \), when more input reduces the risk, input intensity is increased above what it would be under a risk-neutral situation. Adding insurance modifies the choice leading to an increase in use of risk-increasing input and decrease in use of risk-reducing input.

A green set-aside competes with crop production on lower quality field parcels. By (5c), there is a critical land quality \( q^* \) that makes the expected utility from crop production and green set-aside equal. Thus, field parcels with quality equal or higher than the critical quality \( q^* \) are allocated to crop production and below that to green set-aside. The mandatory buffer strip does not impact the choice of productive input but affects the size of profits or utility.

Comparative statics helps to trace out how policy instruments impact farmers’ choices. A feature associated with risk-averse behaviour is that the size of profits (wealth) matters. An increase in an exogenous lump sum income (such as decoupled area payment) may impact optimal choices of inputs and investment as well as land allocation. When a farmer exhibits decreasing absolute risk-aversion, an increase in the lump sum income payment makes the farmer better-off and decreases risk aversion. Thus, the farmer increases input use and input-increasing agricultural investment but decreases input-decreasing investment. The impact of the wealth effect of, for example, the decoupled area payment or working lands agri-environmental payment on land allocation is to shift more land to cultivation from green set-aside (if these payments are not paid for land under green set-aside) and the opposite way when payment to green set-aside is increased. An increase in the size of the mandatory buffer strip causes a negative wealth effect and shifts land to green set-aside. Moreover, a risk-averse farmer shifts land from crop cultivation to green set-aside because there is greater risk associated with crop cultivation than with a non-stochastic payment for green set-aside.

**Farmers’ inter-temporal choices under climate change**

There is a need to account for impact of climate change in the long-run, that is, climate change results in lower yields in the future in many areas, and through these changes the profitability of cultivation methods. The prior static model is expanded by introducing a second period. This second period allows incorporating a decreasing trend in yields to represent the effect of climate change.\(^{25}\) It implies following technical condition \( f_i'(x_i, \bar{K}) > f_i'(x_i', \bar{K}) \). Thus, the use of a similar amount of inputs produces lower yields during the second period. Also, it is assumed that the current cultivation method (conventional tillage) performs worse in the second period than the new more climate-resilient cultivation method (e.g. no-till). In addition to the downward trend in yields, the choice of cultivation methods depends on farmers’ learning process, which is reflected in the crop yield function during the second period as a multiplicative term, \( \sigma, n \), where \( n \) refers to the number of farms having adopted the new method; \( \sigma_i \) is a dummy variable,\(^{25}\)

---

\(^{25}\) This assumption of the theoretical model depends naturally on the available literature for a given empirical application.
\( \sigma_i = 1 \) for new cultivation method and \( \sigma_i = 0 \) for current method. Furthermore, investment made during the first period is assumed to increase productivity during the second period relative to the case without investment.

The profit function of a risk-neutral farmer can be expressed as a present value of profits over the two periods, \( \Pi' = \pi^1_i + (1 + r)^{-1} \pi^2_i \) where \( r \) refers to the discount rate. Hence, under the instruments we have:

\[
\Pi' = \int_0^1 \left[ (1 - \overline{r}) \left[ p(f^i(x_{1i}, k; g) + h(x_{1i})w) - (c + t)x_{1i} + n(p\delta(y - x_{1i})) - n(\delta)(1 - x_{1i}) - w(1 - x_{1i})k \right] - M_{1i}(k) + E \\
- h(\overline{r}) + A)L_1 + (B - z_c)(1 - L_1)g(q)dq + \right]
\]

\[
(1 + r)^{-1} \int_0^1 \left[ (1 - \overline{r}) \left[ p(f^{i2}(x_{1i}, k; \sigma, n, q) + h(x_{1i})w) - (c + t)x_{1i} + n(p\delta(y - x_{1i})) - n(\delta)(1 - x_{1i}) - M_{12i}(k) + E \\
- h(\overline{r}) + A)L_1 + (B - z_c)(1 - L_1)g(q)dq \right]
\]

Differentiating the profits with respect to input and investment yields,

\[
x_{1i} : pf^{i1}_x - (c + t) = 0 \quad (8a)
\]

\[
k : pf^{i1}_k - w(1 - s_2) - M_{1i}'(k) + (1 + r)^{-1} pf^{i2}_k - M_{12i}'(k) = 0 \quad (8b)
\]

\[
x_{2i} : pf^{i2}_x - (c + t) = 0 \quad (8c)
\]

The use of inputs is determined by the usual condition: the value of marginal product is equal to the effective input price. The first-order condition of investment is much different from the static case, because now the farmer accounts also for future returns to the investment. Simply, the sum of current and future value of marginal product of investment must be equal to the effective unit-cost of investment. Hence, relative to the static model, investment is increased.

**Adoption of new technology and learning**

Incorporating optimal input use and investment in the inter-temporal profit function allows one to compare the relative profits of current and new cultivation methods:

\[
\pi^1_i(x^1_i, k^*) + (1 + r)^{-1} \pi^2_i(x^2_i, k^*) > (\leq) \pi^1_i(x^2_i, k^*) + (1 + r)^{-1} \pi^2_i(x^1_i, k^*) \quad (9)
\]

Relative to comparisons in static analysis, we now have new factors impacting the choice between cultivation methods. Recall that due to climate change crop yields during the second period are lower than for the first period, and by assumption new climate-resilient cultivation methods (e.g. no-till) perform better in these circumstances. Hence, the case for the new cultivation method is strengthened. Also, there is a positive externality present via learning since the marginal impact of each new adopter on productivity increases.

**Impact of monetary policy**

An increase in the real interest rate decreases the use of first period input (\( \partial x_i^1/\partial r < 0 \)) if investment is input-increasing but increases it for input-saving investment (\( \partial x_i^1/\partial r > 0 \)). While this seems very surprising, it can be explained by what happens to investment. Investment is unambiguously decreased (\( \partial k/\partial r < 0 \)) by higher interest rate, so that reduction in the use of input reflects reduction in input-increasing investment and in a
similar vein, the increase in input use reflects a reduction in input-saving investment. As input choice is the only continuous decision variable during the second period, we have that \( \frac{\partial x_2'}{\partial r} = 0 \).

**Adaptation through research and development**

Suppose that government invests in research and development to produce crop varieties that are better suited to the changing climate. These can include for instance crop varieties that are resistant to drought. Let \( Q \) denote research and development effort, which increases crop yield resilience and impacts the per hectare (or acre) costs during the second period. They are exogenous to the farmer who cannot affect research and development. To see how research and development impacts the farmer’s profits, suppose that research and development enters the second period yield function as follows

\[
p(x_2, k, \sigma, \mu; q).
\]

Then, by comparative statics we find that \( \frac{\partial x_{ii}}{\partial Q} < 0 \) if investment is input-saving and \( \frac{\partial x_{ii}}{\partial Q} > 0 \) if investment is input-increasing. For investment the effect is negative if investment is input-increasing but ambiguous if investment is input-saving.
Annex C.

Policy assessment framework

Annex C reviews each part of the policy assessment framework and proposes a set of questions to guide policy makers throughout the assessment. This framework can be used by governments if they wish to explore synergies and trade-offs between three policy objectives of agricultural productivity enhancement and climate change mitigation and adaptation. As a caveat, this framework is not designed to compare countries but rather to highlight potential policy incoherencies from a country specific perspective. The questions included in this framework aim to identify potential effects of policies on the three objectives, and more importantly to assess how policies might be resulting in trade-offs between the three objectives. The questions included in the framework are not exhaustive, though. Moreover, the relevance of questions and sections may vary across countries.

The first step: Identification of key trends, including socio-economic and climate change trends

Identifying key trends can help determine goals that should be prioritised, and areas where policy action is most needed. Policy makers need to consider key trends related to climate change, agricultural systems and farmers, namely: (i) climate related hazards; ii) levels of exposure, vulnerability, and adaptive capacity of agricultural systems and farmers; iii) potential risks and impacts on agricultural systems and farmers; and (iv) potential impacts of agricultural systems on climate. Information on these trends will be key to assessing whether current policies are contributing to sustainable and climate-friendly agriculture production in the future.

There are large uncertainties associated with climate change impacts on agricultural systems and farmers, as the above factors and their combination are locally specific. Climate change impacts may be positive or negative, and the causality between climate change and weather events is not always clear. Uncertainty in terms of the impacts of agricultural systems on climate is also a common issue; this is due partly to the generally fluctuating and diffuse nature of emissions within agricultural production, as well as to the complex relations between production and other stages of the agricultural value chain and between the sector and other sectors.

Furthermore, knowledge and information regarding climate trends might not always be available or adequate. More specifically, key trends (identified through meteorological tools, weather stations, seasonal weather forecasts, early warning systems and impact assessments, amongst others) could show if, how and where droughts, temperature increases, extreme events or natural disasters could impact agricultural and human systems. Lack of information might be obstructing the integration and prioritisation of climate objectives. In these situations, policy could potentially play a role by promoting investments in knowledge creation (through the development of adequate tools) and
management, specifically in relation to climate change. A variety of questions, can guide countries in identifying the key trends mentioned above (Box 1).

**Box 1. Identifying key trends**

- What are the key trends in terms of climate change hazards and risks? Including: the probability of occurrence and frequency of weather events, as well as emergent risks involving non-climate stressors; including the management of water, land, and energy.
- What are some key trends in terms of productivity (TFP), levels of vulnerability and adaptive capacity of agricultural systems and farmers, with regard to climate change?
- Are climate change impacts on agricultural systems, productivity levels, and farmers already observable?
- What are the expected impacts of climate change on agricultural systems, productivity levels and farmers?
- What are the trends in terms of GHG emissions generated by the agricultural sector, disaggregated by agricultural activities (including forestry)? How have the above trends been identified?
- Has the public sector disseminated information with regard to these key trends?

**Part I. Policy goals: How the three objectives are captured within the country’s policies**

This section clarifies what are the three objectives and guides policy makers in assessing how the objectives are (or not) integrated into country’s policies.

**Objective 1: Agricultural productivity**

Improving productivity is a key factor on which growth of an economy is influenced (OECD, 2015a). Agricultural productivity is the ability of the sector to convert inputs (such as capital, labour, land and other natural resources) into commodities. It is commonly defined as a ratio of a volume measure of output to a volume measure of input use. Productivity improves if the same use of inputs (e.g. capital, labour and land) produces a larger volume of output or, alternatively, if the same volume of output is achieved by means of less inputs. When agricultural productivity increases, resources (including labour and capital) can be released from food production to expand the non-agricultural sectors of the economy; natural resources such as land and water can also be used for environmental purposes. If populations continue to grow and natural resource stocks continue to be depleted at the current rate, growth in agricultural productivity without adversely affecting the natural resources will become increasingly important (OECD, 2014). Agricultural productivity growth can contribute to: (i) improving food security; (ii) poverty reduction; (iii) sustaining agricultural employment and livelihoods, (iv) increasing national revenues and economic growth and (v) increasing environmental services. The extent to which increased agricultural productivity will influence the above mentioned elements depends in part on the country characteristics.
Objective 2: Climate change adaptation

Countries increasingly stress the importance of adaptive actions against locally-specific climate change related risks and vulnerabilities. Moreover, managing climate change risks, as well as pursuing adaptation to the adverse effects of climate change and increasing the resilience of agriculture (among other sectors) prevails on most national adaptation strategies (Ignaciuk, 2015). However, interpretations on how to achieve these overarching goals differ. For instance, in the case of the Netherlands, increasing the overall sustainability and resilience of the agricultural sector, is the priority (Martijn Root, Coherent Policies for Climate Smart Agriculture Workshop).

Adaptation actions in agriculture, as defined by the IPCC, should be aimed primarily at increasing the adaptive capacity of agricultural systems and securing long-term agricultural productivity. When levels of risk and vulnerability are extremely high, and impossible or costly to address, adaptation can involve considering alternative production systems, alternative products, non-farm income sources or the geographical relocation of communities. Actions aiming at responding to climate change impacts in the short term but increasing vulnerability and potentially affecting productivity in the long run, would be better termed as “coping strategies” rather than adaptation measures. Such actions may lead to maladaptation – resulting in increased environmental and climate degradation and in increased vulnerability in the long term.

Objective 3: Climate change mitigation

Mitigation actions aim at reducing GHG concentration through reduction of emissions and enhancement of carbon stocks. Reducing GHG emissions in agriculture can be achieved, for instance, through policies to promote (i) switching from emission intensive inputs to GHG-neutral substitutes; (ii) increasing the efficiency of input use; or (iii) changing soil management and tillage practices. Currently, most of low- and medium income countries do not include mitigation actions in their agricultural policy objectives. High-income countries stress the need to include mitigation efforts by the agricultural sector, but beyond emission reduction through more efficient resource use, limited actions have been undertaken. Setting policy targets for planned mitigation in agriculture can be challenging, notably for two reasons: (i) it is generally argued that reducing emissions from the sector should not compromise the ability of the agricultural sector to sufficiently provide food and other products; and (ii) emissions from the sector are generally diffuse and fluctuating in nature.

Assessing the integration of objectives in the policy making process

The process of integrating the three objectives within the national policy making process is challenging. In recent years, various countries, have gradually introduced sustainable productivity and climate change adaptation in policy design and implementation. The extent and levels of integration vary across countries. Integration can be i) reflected in the legal, policy and institutional framework, for instance through national adaptation plans or sectoral plans ii) limited to programme or project design and implementation; or iii) both. Integration of objectives should take place at different levels: national, local or sectoral plans and programmes. Integrating these objectives, might represent progress in

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26. Maladaptation refers to actions or inaction that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future.
addressing climate change challenges for the agricultural sector, nevertheless the particularities of the integration process should be assessed.

Policy makers should assess not only if and to what extent they have integrated the three objectives but also if the prioritisation of objectives corresponds to their international commitments, national development priorities and climate related risks and impacts.

Moreover policy makers should determine if and when some trade-offs between the three objectives are acceptable (given that double or triple wins are not always possible). Synergies and trade-offs between policy objectives might be present, for instance, in situations where productivity is prioritised over adaptation or mitigation, i.e. when policies put in place environmentally harmful subsidies to increase short term productivity). Prioritising one or two of the three objectives, however, does not necessarily mean that the other objective(s) are not taken into consideration. Box 2 is designed to guide the assessment of the integration of objectives in the policy making process.

**Box 2. Assessing integration of objectives within national goals**

- Are the three objectives of agricultural productivity, climate change adaptation and climate change mitigation policy priorities?
- Have these objectives been formally included in the country legislation, national, rural and sectoral development plans?
- How do the legal framework, policy framework and budget allocation reflect the prioritisation of objectives and objectives?
- Have these objectives been included in (public) programme and project design and implementation?
- If yes, what are the specific objectives and targets set for and within each objective?
- Does the government prioritise one objective over others? Which one(s)?
- What is the rationale identified by governments behind the integration and prioritisation of objectives? (e.g. international agreements, national priorities, key trends related to climate change and socio-economic characteristics).

**Part II. Institutions: Assessing institutional setting coherence between the three objectives**

Even when the three objectives have been integrated in the policy making process, they are generally addressed by different institutions and funded through different mechanisms. Therefore, countries should assess institutional setting coherence and coordination challenges at the international, regional, national and local levels. This requires assessing (i) if institutions are working in coordination with each other, and through which intra and inter-institutional mechanisms and (ii) if and how institutional setting coherence and coordination issues are or could be identified, monitored and addressed.

Identifying key institutions and stakeholders responsible for addressing the three objectives, and analysing institutional effectiveness and coordination (for the design, implementation, monitoring and evaluation of policies, programmes and projects) are
essential to determining how the objectives and the associated strategies and funding mechanisms are integrated and distributed between and within various institutions. The lack of co-ordination and co-operation and a segmented institutional approach might result in trade-offs between and within objectives. Identifying institutional coherence challenges, could ultimately contribute to creating synergies between different objectives. Box 3 is designed to guide the assessment of institutional coherence.

**Box 3. Identification and assessment of institutional coherence**

- What are the main institutions responsible for designing and implementing policies in relation to the three objectives? (At the international, national, local and sectoral levels)
- What are the main funding mechanisms with regard to the three objectives? (At the national, local and sectoral levels)
- Have there been studies to identify inter and intra-institutional coordination issues between relevant institutions?
- Do institutions address the planning, implementation and funding of the three objectives separately or jointly? What are the implications of addressing these objectives separately or jointly?
- Have formal mechanisms been established to improve inter and intra-institutional coordination and policy arbitration, with regard to the three objectives?
- What mechanisms exist to balance the interests of diverse institutions and stakeholders?
- Do these mechanisms define clear mandates and responsibilities? Are they able to formulate national positions on policy options and to resolve conflicts between the views and responsibilities of various institutions and stakeholders?

**Part III. Policies: Identifying whether policies generate synergies or trade-offs between the three objectives**

This section helps to identify and assess a range of policies that may affect the three objectives in direct and indirect ways. First, a broad map of various policies is presented. Second, each of the main policy areas is discussed separately and a range of guiding questions are proposed in order to help assess the impacts of various policies on the three objectives. Third, based on a literature review, four examples are presented, each detailing a preliminary assessment for one specific policy.

**Identifying relevant policies**

A wide range of international and national regulations, economy-wide policies and sector-specific policies create a diverse set of incentives and disincentives to achieve progress across the three objectives in the agricultural sector. As such, poorly designed policies might not only be ineffective in achieving their explicit objective(s), but they might also generate unintended negative effects on the other objectives.

Although the effects of a particular policy and of policy interactions will vary across countries, it is possible to identify policies that often have significant effects on the three objectives. Table C.1. lists a range of policies at the international, national, local and sectoral levels are likely to impact at least one of the three objectives. While not an
exhaustive list, the table provides a starting point for policy makers to identify policies they may need to evaluate in their domestic context.

**Table C.1. Examples of policies with potential effects on the three objectives and their objectives**

<table>
<thead>
<tr>
<th>International and regional</th>
<th>Trade &amp; economic cooperation agreements</th>
<th>WTO regulations and agreements Bilateral, regional and multilateral trade agreements Regional Agricultural Policies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Climate frameworks, agreements &amp; coalitions</td>
<td>United Nations Framework Convention on Climate Change Kyoto Protocol Global Climate Change Alliance Global Alliance for Climate Smart Agriculture COP 21- Intended Nationally Determined Contributions (INDC)</td>
</tr>
<tr>
<td>National</td>
<td>National development plans</td>
<td>National Adaptation Funds</td>
</tr>
<tr>
<td></td>
<td>National adaptation plans</td>
<td>National Regulations</td>
</tr>
<tr>
<td>Local</td>
<td>Rural development plans</td>
<td>Public investments on rural development priority areas (infrastructure, education, health) Taxes on incomes and property</td>
</tr>
<tr>
<td>Sectoral</td>
<td>Land</td>
<td>Legislation and policies outlining the allocation of national land resources: land rights, distribution, acquisition, management, use, forms of tenure</td>
</tr>
<tr>
<td></td>
<td>Non Agricultural (Energy, infrastructure, water, mining and trade)</td>
<td>Blending mandates Tariffs or import barriers to promote domestic production of biofuels or fossil fuels Support for investment, tax credits, exemptions or reductions related to mine exploration and development Water and energy support for irrigation</td>
</tr>
<tr>
<td>Social protection</td>
<td>Insurance mechanisms</td>
<td>Cash transfers</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Tax reductions, exemptions or credits for farmers Market price support Income support: coupled or decoupled payments Environmental payments Input subsidies Investments in research and development Advisory and extension programmes</td>
<td></td>
</tr>
</tbody>
</table>

**Assessing the effects of policies on the objectives**

This section discusses the effects of policies on the three objectives for four main policy areas: i) international and regional policies, ii) national and local policies, iii) sectoral policies beyond agriculture and iv) agricultural policies. The section also guides policy makers in assessing the impacts of various policies on the three objectives.

It is impossible to distill the exact impact of a particular policy initiative on the three objectives because there are many other factors that are influencing and hence diluting the signals. These socio-economic and behavioural and other influences will have an effect on how a particular policy is implemented, and how a policy affects behaviour and thus the impacts of the policy on the economy.

**International and regional policies**

International trade and economic co-operation agreements, as well as climate frameworks, agreements and coalitions will have intended and unintended effects on the three objectives. For instance, international phytosanitary standards, import tariffs, import quotas, and commodity prices in international markets, affect domestic production and productivity trends. These may also have an effect on GHG emission patterns.
International climate policies or commitments, such as the Kyoto Protocol or the Intended Nationally Determined Contributions (INDC), may set specific targets for emission reductions at the national and sectoral level.

Countries should identify and assess the effects and coherence of international and regional policies with regard to the three objectives. There may be incoherencies among different international and regional agreements, as well as between these and domestic policies. Such incoherencies may potentially lead to trade-offs between the objectives. For instance, an INDC might set specific targets for emission reductions for the country while existing sectoral policies are incentivising practices that increase GHG emissions, for example through subsidising energy consumption for irrigation or providing tax cuts or other incentives that promote the use of fossil fuels. Box 4 is designed to guide the assessment of the international and regional policies.

**Box 4. International and regional policies: Assessing policy effects**

- What are the most relevant trade, co-operation and climate agreements with potential effects on the three objectives?
- Have the effects of trade, co-operation and climate agreements with regard to the three objectives been identified? If yes, what are they?
- Is there coherence amongst signed or ratified international and regional agreements, in terms of the productivity or production, climate change adaptation or mitigation goals they aim to achieve?
- Is there coherence between international and regional agreements on the one hand and national, local and sectoral plans and policies on the other hand with regards to the three objectives?
- How are international and regional agreements integrated in the domestic policy setting? What is their influence on the three objectives?

**National and local policies**

National development, adaptation and rural development plans provide evidence on the extent to which the three objectives have been formally integrated in the national priority areas. National regulations may encourage productivity, mitigation and adaptation in areas such as the use of land and natural resources, emission standards and targets, and the use of fertilisers and fuels in the sector. Box 5 helps policy makers to assess whether and how existing regulations are affecting synergies and trade-offs in agricultural productivity, adaptation and mitigation.
Box 5. National and local policies: Assessing policy effects

- Do national, rural and local development, adaptation and mitigation plans set specific objectives and strategies for the agricultural sector?
- How do urban policies (e.g. policies related to urban development or policies regulating drinking water quality) affect the agricultural sector?
- Are there national regulations that include specific provisions or restrictions on the allocation of national land resources: land rights, distribution, acquisition, management, use, forms of tenure? What are the visible or potential implications for the three objectives?
- Have certain policies effectively incentivised regulations directly promoting specific types of production over others: forestry production or conservation; agricultural production of certain crops for food, energy or fiber; specific management practices or technologies; livestock production; or urbanisation?
- Are there national regulations that include specific provisions or restrictions on the use of inputs, such as fertilisers or fossil fuels, among others? What are the implications of these regulations on the three objectives?

Sector policies beyond agriculture

Policies for other sectors of the economy such as: industry, energy, infrastructure, housing, and transports, can have an impact on agricultural productivity, climate change adaptation and mitigation. As such, sectoral policies may create incentives and disincentives by for example affecting farmer’s incomes or affecting availability, prices and cost of natural resources. In that sense, some sectoral policies could potentially generate trade-offs between the three objectives. Box 6 helps policy makers assess whether and how non-agricultural sectoral policies can affect climate change adaptation, mitigation, and productivity of agriculture.

Box 6. Sectoral policies beyond agriculture: Assessing policy effects

- What are the effects of sectoral (forestry, industry, energy, infrastructure, housing, telecom and transports) and rural development policies on the three objectives?
- Have policies promoted the supply of inputs, such as water and energy below their marginal cost? If yes, has this encouraged the enhanced use of these resources? What has been the intended or unintended impact of these policies in terms of productivity, adaptation and mitigation?
- What are the effects of certain tax arrangements, beyond the agricultural sector, on agricultural productivity, climate change adaptation and mitigation?

Agricultural policies

Agricultural policies can impact the three objectives in synergetic or conflicting ways. Agricultural support may affect land use or farmer incentives to adopt specific crops or production measures. For instance, policy instruments that distort input and output markets reduce producers’ incentives to use production factors efficiently and can encourage the adoption of agricultural practices that increase climate change vulnerability or GHG emissions. Policies coupled to production may provide strong incentives to
increase input use intensity of environmentally harmful inputs, such as fertilisers or pesticides, or they may drive land allocation towards more intensive crops or expand agriculture into sensitive areas, i.e. such incentives may reinforce environmental market failures. Moral hazard may be exacerbated by under-pricing insurance and affect the resilience of agricultural production. Nevertheless, the impact of agri-environmental policies on production and productivity needs to be better understood. Peltonen-Sainio et al. (2015) is a good example of a forward-looking study aiming at identifying the impact of agri-environmental policies, namely the Finnish agri-environmental program (AEP) on cereal yields and quality.

In contrast, depending on their design and under certain circumstances, policy instruments such as agri-environmental payments, agricultural insurances, support to access credits and other financial services, could encourage more sustainable or profitable investments, as well as the adoption of adaptation and mitigation measures. Moreover, policies that facilitate access to financial services based on compliance with environmental standards could also incentivise farmers to adopt agricultural practices with positive effects in terms of adaptation and mitigation. However, if poorly designed, some agricultural support policies may not be efficient or cost-effective and might have unintended effects on one or more of the three objectives.

It is also important to consider whether some of the above mentioned policies create disincentives for farmers to increase or sustain productivity levels. Effectiveness of these measures in increasing productivity will depend on the objectives set to these instruments (such as social protection, poverty reduction or economic growth). Furthermore, the explicit objective of the agricultural policies is not always clear.

**Box 7. Agricultural policies: Assessing policy effects**

- What agricultural policy instruments are in place (e.g. tax incentives, income support measures, market price support, fertiliser subsidies, water and energy subsidies for irrigation, support for accessing insurance (crop or index) schemes or credits)?

- What is the importance of these instruments (as reflected in budget allocation) compared to other public investments in the sector?

- What is the explicit objective of these instruments? Who do they target? Has the effectiveness and impacts of these instruments been assessed? What are the visible or potential impacts of these instruments on the three objectives?

- Have these instruments been effective in promoting increased productivity (in terms of crop responses and increased incomes)? If yes, what are the visible or expected implications (in the short term and the long term) for climate change adaptation and climate change mitigation?

- Have measures such as environmental payments and insurance subsidies been effective in promoting the uptake of adaptation and mitigation measures? What is the visible or potential impact on productivity related objectives?

- Has the implementation, reform or removal of certain agricultural support policy instruments resulted in an increase or decrease in productivity levels? If yes, in which way and how have they impacted agriculture adaptation or mitigation?
Policy makers should identify and assess the effects and interactions of various agricultural support policy instruments with regard to the three objectives. Based on this assessment, policy makers should concentrate on addressing the negative effects, through policy reform or further policy action. In fact, policy failures should be removed first and then the remaining market failures should be addressed by targeted policies.

**Research and Development**

Research and development (R&D) activities, such as the generation and dissemination of high-quality information and knowledge awareness on climate change and agriculture related trends, may help prepare farmers to prevent or address climate impacts. R&D plays an essential role in the identification and development of new technologies and processes of production. If agricultural R&D simultaneously integrates productivity growth, climate change adaptation and mitigation objectives, it can contribute towards achieving increased synergies. But if R&D prioritises some objectives at the detriment of others, or if farmers are exposed to asymmetric or incorrect information, this may result in trade-offs between objectives.

Policy makers should identify the main trends in agricultural R&D to assess if and how the three objectives are being prioritised and integrated into R&D programmes. This assessment can help identify trade-offs between the three objectives and barriers to the integration of climate objectives into agricultural R&D (including coordination, financial, knowledge infrastructure amongst other barriers).

**Box 8. Agricultural R&D: Assessing policy effects**

- Are productivity, climate change adaptation and mitigation set as R&D priority areas? Does R&D integrate productivity, climate change adaptation and mitigation objectives?
- Does R&D prioritise one or two of the three objectives? If yes, what are the visible or expected implications for the other objectives?
- Are there mechanisms to increase collaboration between public, private, or international researchers with regard to integrating the three objectives?
- Are R&D results available and accessible for farmers?
- Are there any examples in which lack of coordination and cooperation between research institutions or limited access to information resulted in the provision of asymmetric or incorrect information? What are the visible or expected effects on the three objectives?
- How does knowledge generation translate into (on the ground) increased uptake of productivity, adaptation and mitigation measures?

**Capacity Building: Extension and Advisory Services**

Extension and advisory services can play an important role in providing farmers with training, tools, information on key trends, as well as in promoting the adoption of available innovative synergetic measures and technologies. Nevertheless, trade-offs across objectives may arise according to: the nature and structure of these services, and the way in which objectives are integrated into these services; the lack of coordination within and between institutions and stakeholders in charge of planning, funding, implementing and monitoring and evaluation of extension and advisory services; amongst
others. Therefore, policy makers should assess the nature, structure and availability of extension and determine if and how the three objectives are being integrated and prioritised in that domain.

**Box 9. Extension and Advisory Services: Assessing policy effects**

- What is the role of the public sector in providing advisory and extension services?
- What are the main institutions and stakeholders involved in the provision of advisory services?
- What is the explicit objective(s) of these services? Who do they target?
- Are extension and advisory services widely available and used?
- Do these services integrate the three objectives? What objectives do they prioritise? How?
- If they prioritise one or more objectives over others, what are the visible and expected implications for the other objectives?
- Have these services promoted the adoption of agricultural productivity improving technologies or practices? Which measures or practices? What are the visible or potential implications for adaptation and mitigation?
- Have extension and advisory services promoted the adoption of climate change adaptation technologies or practices? Which measures or practices? What are the visible or potential implications for productivity and mitigation?
- Have extension and advisory services promoted the adoption of certain climate change mitigation technologies or practices? Which measures or practices? What are the visible or potential implications for adaptation and productivity levels, or for both?

**Part IV. Assessing how on the ground initiatives can inform policy design and implementation**

Many on-the-ground initiatives that focus on promoting alternative production systems have been developed to exploit synergies between agricultural productivity, climate change adaptation and mitigation related objectives. Generally, these initiatives integrate and promote specific production and management practices such as integrated cropland and livestock management, agro-forestry practices and restoration of degraded lands. Some specific examples of land management practices and their potential effects on the three objectives are included in Annex 1.

On-the-ground initiatives aiming at synergies between the three pillars rarely achieve synergies across all geographic locations. The consequences, and therefore the success of synergetic initiatives depend, among other factors, on local conditions, therefore describing measures generically as synergetic should be done with caution. Environmental, climate, water and soil conditions determine the effectiveness of production systems and how they affect the triple objectives. For example, policies to stimulate no-till or reduced till cropping can improve land productivity through increased soil moisture capture. Additionally, soil conservation practices seem to have lower labour requirements (OECD, 2015b) and are therefore likely to only have a positive impact on the three objectives in dry areas. Inversely, if policies target an increase of cover crops,
that could be beneficial as these crops store carbon in soils, they may in some cases have negative effects on productivity, for instance, if the cover crops compete for water with cash crops in water stressed areas. A whole range of technical, social, cultural and financial conditions could also hamper or facilitate the effective development and adoption of adequate measures.

The success of on-the-ground initiatives also depends on the scale of implementation and assessment. For instance, improved grassland management can sequester carbon and increase soil fertility by increasing the share of leguminous crops, which has a positive impact on yields; however, if the increased grassland productivity results in higher grazing intensity, greenhouse gas emissions from livestock may well increase (Ghahramani and Moore, 2015). Therefore, while the potential for on-the-ground synergies between the three objectives in agricultural systems should be recognised and in principle stimulated, the generalisation of the adequacy of practices in a wider context should be done with care.

**Box 10. Identifying and assessing on the ground initiatives**

- What are the examples of on the ground initiatives that aim at promoting synergies between the three objectives?
- What is the explicit objective(s) of such initiatives?
- Who is responsible for the funding, implementation, monitoring and evaluation these interventions? Is the public sector involved?
- How are agricultural productivity, adaptation and mitigation measured within the on the ground initiative?
- Considering the three objectives and locally specific conditions what visible or potential synergies and trade-offs do these initiatives and practices involve at different implementation levels (farm, landscape, national, international)?
- Can on the ground performance (in terms of uptake and impacts of production and productivity measures) be traced back to policy?
- How could these initiatives and their impacts inform public policy design?
- Are there any data collection, monitoring and evaluation efforts to identify best practices and lessons learned at a farm and landscape level? Is this knowledge informing and directing future policy design?

Looking at bottom-up approaches, however, might still be useful to inform policy design and implementation. Policy makers should identify on the ground initiatives and assess the synergies or trade-offs they involve, as well as the factor(s) that stimulate or impede the adoption of certain practices. Such an exercise can inform policy design and implementation. Different on the ground initiatives promote the uptake of different agricultural production methods and practices, which in turn involve different interactions between productivity, adaptation and mitigation and at different levels (farm, landscape, national, international). In certain cases, a (reverse) chain analysis – from identified initiatives and practices to the ‘impulses’ that led to their adoption could contribute towards; increasing knowledge of what is working and not working on the ground; tracing the causal link between on the on the ground performance and policy intervention;
directing and re-directing public investments in a more efficient manner; and identifying areas for policy reform or further policy action. It is important to note here that the adoption of practices may result from market impulses rather than from a policy impulse or a specific on the ground initiative.
Annex D.

Definition and calculation of TFP

Total factor productivity is estimated by using Törnqvist approximations for Divisia indices. Divisia index of total factor productivity (TFP) growth can be defined as the growth in scalar output \( y = f(x,t; \alpha) \), which cannot be explained by the growth in the input quantity index (vector \( X \)) over time \( t \). A simple index method is used because it is otherwise difficult to provide meaningful definitions of real input or real output due to the heterogeneity of outputs produced and inputs used in different time periods or under different policy scenarios. However, it is possible to provide meaningful definitions of input growth and output growth between any two periods of time or between policy scenarios using index number theory. A separate quantity index is calculated for inputs and outputs, and TFP is measured by calculating the ratio between produced output quantity and input quantity.

A Törnqvist index is a discrete approximation to a continuous Divisia index. A Divisia index is a weighted sum of the growth rates of the various components, where the weights are the component’s shares in total value. For a Törnqvist index, the growth rates are defined to be the difference in natural logarithms of successive observations of the input (output) components (i.e. their log-change) and the weights are equal to the mean of the factor shares of the components in the corresponding pair of periods (years, if productivity changes are measured over time) or policy scenarios (if productivity changes are measured between policy scenarios).

The estimated input (output) index over time:

\[
\ln \left( \frac{Q_t}{Q_{t-1}} \right) = \frac{1}{2} \sum_{j=1}^{k} (S_x + S_y) (\ln q_x - \ln q_y)
\]

where

- \( Q_t \) = Divisia quantity index at time \( t \)
- \( S_x \) = output share of input \( j \) at time \( t \)
- \( q_x \) = quantity of the input \( j \) at scenario \( t \)
- \( j = 1,2,\ldots,k \)
- \( k \) = the number of outputs

We used constant prices for all inputs and outputs over time and policy scenarios.
Annex E.

Quantitative modelling: A description of the stylised policy instruments and selected quantitative results

Description of the policy instruments

To analyse individual stylised policy instruments, a benchmark scenario, or “Market solution” is used to compare the performance of each policy instrument independently.

The benchmark solution and policy instruments for the Finnish application are defined as follows:

- **Market solution** without government policy intervention
- **Decoupled crop area payment** (decoupled crop area-based payment, EUR 190/ha)
- **Payment for green set-aside** (EUR 120/ha for the establishment and management of green set-aside)
- **Crop insurance subsidy for yield risk** (shallow loss crop yield insurance for barley and wheat; total insurance premium EUR 38-59/ha; EUR 38/ha in a reference scenario and EUR 59/ha in the climate change scenario). Decoupled crop area payment is reduced by EUR 21.4/ha in a reference scenario and EUR 38.8/ha in the climate change scenario to reflect the government subsidy share of total insurance premium.
- **Nitrogen fertiliser tax** (11% climate damage tax on CO₂-eq emissions from N fertiliser application and calculated as a basis of social damage estimate of EUR 32/ton of CO₂-eq)
- **Cost-share investment subsidy for adaptive capital** (40% cost-share subsidy for improved subsurface drainage)

The benchmark solution and stylised policy instruments for the application using estimated data from three sub-river basin sites in the midwestern United States are defined as follows:

- **Market solution** without government intervention
- **Decoupled crop area payment** (uniform decoupled income support payment per acre of USD 44.08/acre, equivalent to a premium subsidy for crop yield insurance for corn at 75% coverage level)
- **Crop insurance subsidy for yield risk** (for corn; total premium USD 75.07/acre of which government subsidy covers USD 44.08/acre)

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27 These figures reflect rainfed corn cultivation in Iowa and are derived from the web-based “The Crop Insurance Decision Tool”, CIDT.
- **Payment for green set-aside** (average USD 240.0/acre and varies plus or minus 30% according to opportunity costs of removing land from production, that is, profitability of crop production)
- **Nitrogen fertiliser tax** (12% climate damage tax to reflect CO\textsubscript{2}-eq emissions from nitrogen fertiliser)
- **Cost-share investment subsidy for adaptive capital** (10% cost-share subsidy for adaptive capital investments including investment in nutrient precision application, which increases nitrogen use efficiency)

Table E.1 provides aggregated results for Finnish application of the model for 18 differential cases (soil type-soil quality-tillage method) including total crop production; farmers’ profits; net-GHG emissions (emissions – soil carbon sequestration) from agriculture sector; nitrogen equivalent runoff; adaptation indicators; total factor productivity (TFP); and social welfare (SW).

<table>
<thead>
<tr>
<th>Policy scenario</th>
<th>Total production, t Land use shares (%)(w:b:r:s:i)</th>
<th>Farm profit, (EUR/ha)</th>
<th>Net-GHG emissions, t/ha (average)</th>
<th>Nitrogen-equ runoff, kg/ha (average)</th>
<th>Adaptation index</th>
<th>TFP (value)</th>
<th>SW, EUR/ha</th>
</tr>
</thead>
</table>
| Market solution w=20.4,b=33.7, r=1.4 27-57-7-0-10 | 129.5 6.4 15.9 1.00 1.004 | 322.5 7.3 17.8 1.033 0.891 | Table E.1 provides aggregated results for Finnish application of the model for 18 differential cases (soil type-soil quality-tillage method) including total crop production; farmers’ profits; net-GHG emissions (emissions – soil carbon sequestration) from agriculture sector; nitrogen equivalent runoff; adaptation indicators; total factor productivity (TFP); and social welfare (SW).

- **Nutrient management strategies**
  - **Payment for green set-aside** (average USD 240.0/acre and varies plus or minus 30% according to opportunity costs of removing land from production, that is, profitability of crop production)
  - **Nitrogen fertiliser tax** (12% climate damage tax to reflect CO\textsubscript{2}-eq emissions from nitrogen fertiliser)
  - **Cost-share investment subsidy for adaptive capital** (10% cost-share subsidy for adaptive capital investments including investment in nutrient precision application, which increases nitrogen use efficiency)

Table E.2 provides aggregate results for the application of the model using estimated data from three sub-river basin sites in the midwestern United States. Total corn and soybean production, farmers’ profits, net-GHG emissions (emissions – soil carbon sequestration) from agriculture sector, adaptation index, nitrogen runoff, phosphorus runoff, total factor productivity (TFP), and ex-post social welfare (SW).
Table E.2. The application using estimated data from three sub-river basin sites in the midwestern United States

<table>
<thead>
<tr>
<th>Stylised policy scenario</th>
<th>Total production (corn and soy), Mt</th>
<th>Farm profit, USD Billion</th>
<th>Net-GHG emissions, Mt</th>
<th>Adaptation index</th>
<th>Nitrogen runoff, 1000 tons</th>
<th>Phosphorus runoff, 1000 tons</th>
<th>TFP</th>
<th>SW, USD Billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market solution</td>
<td>135.0</td>
<td>22.3</td>
<td>-1.70</td>
<td>1.00</td>
<td>320</td>
<td>18.0</td>
<td>1.658</td>
<td>8.21</td>
</tr>
<tr>
<td>Nitrogen fertiliser tax</td>
<td>134.5</td>
<td>21.8</td>
<td>-1.97</td>
<td>1.036</td>
<td>296</td>
<td>17.1</td>
<td>1.664</td>
<td>8.34</td>
</tr>
<tr>
<td>Decoupled area payment</td>
<td>135.0</td>
<td>24.7</td>
<td>-1.70</td>
<td>1.042</td>
<td>320</td>
<td>18.0</td>
<td>1.658</td>
<td>8.20</td>
</tr>
<tr>
<td>Crop insurance subsidy for yield risk</td>
<td>135.0</td>
<td>22.3</td>
<td>-1.69</td>
<td>1.002</td>
<td>325</td>
<td>18.1</td>
<td>1.656</td>
<td>8.17</td>
</tr>
<tr>
<td>Cost-share investment subsidy</td>
<td>135.0</td>
<td>22.3</td>
<td>-1.73</td>
<td>1.067</td>
<td>316</td>
<td>17.9</td>
<td>1.657</td>
<td>8.22</td>
</tr>
<tr>
<td>Payment for green set-aside</td>
<td>117.7</td>
<td>20.6</td>
<td>-2.82</td>
<td>0.938</td>
<td>247</td>
<td>14.1</td>
<td>1.690</td>
<td>7.30</td>
</tr>
</tbody>
</table>

Note: Climate Change 2020-60, risk-averse farmer: total production (corn + soybean), farm profit, net-GHG emissions (CO2-eq) from agriculture, adaptation index, nitrogen runoff, phosphorus runoff, total factor productivity (TFP), and ex post social welfare.