AGRICULTURAL POLICIES IN DEBATE

An International Perspective on the Green Deal in EU Agriculture

Modeling economic and ecological impacts of F2F-Options in Non-EU countries with a special focus on Brazil

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APD | DIÁLOGO AGROPOLÍTICO BRASIL · ALEMANHA
AGRARPOLITISCHER DIALOG BRASILIEN · DEUTSCHLAND

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The Agricultural Policy Dialogue Brazil-Germany (APD) is an interchange mechanism for knowledge and information on bilateral and global agri-environmental challenges. Germany has been developing similar initiatives with several countries for more than two decades, and they are essential references for the development of APD in Brazil.

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ABOUT THIS STUDY

This study is used as a reference document for the APD | AGRICULTURAL POLICY DIALOGUE BRAZIL - GERMANY. The content of this study is the sole responsibility of the authors, and any opinions expressed herein are not necessarily representative or endorsed by APD.

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Table of contents

Executive Summary

0.1 Context and TORs of the study

Present food systems are characterized by major market failures, i.e. domestically as well as internationally markets are no longer able to effectively coordinate economic actions in a way that market equilibrium corresponds to societies' maximal well-being. In particular, agriculture and its associated land-use changes are the biggest contributors to climate change, accounting for roughly 21% of anthropogenic greenhouse gas emissions between 2007 and 2016. Further, pressures placed on natural resources by food production have left 25% of the globe's cultivated land area degraded, while deforestation for agriculture and the intensification of agricultural landscapes are major contributors to biodiversity loss. Moreover, the environmental damage caused by the current management of food systems amplifies disruption - extreme weather events precipitate forced migration, exacerbate tensions around the use of scarce freshwater or sh stocks, and can fuel political instability.

As has become clear at the latest food summit, governments all over the globe can no longer ignore these challenges linking agriculture and food value chains to diets, health and planetary ecosystems and urgently seek for practical solutions to fundamentally transform food systems to be in better correspondence with societies' demand for a secure, healthy and environmentally friendly production and consumption of food. What is needed are innovative governmental mechanisms that beyond markets coordinate global, national and local land use activities to guarantee sustainable production of healthy food and fair access to it for every person in the world.

In this regard two central questions arise: First, what are innovative governmental mechanisms that imply a globally efficient use of natural resources? And secondly, how can these innovative mechanisms be effectively implemented? Especially, the latter relates to the question of political feasibility, i.e. beyond identification of innovative political solutions which enable a sustainable use of natural resources, it is important to understand determinants of effective food system transformation policies. Given this background an exchange of ideas and experiences between and across different political leaders can be rather productive and efficient to identify effective and politically feasible transformation paths which then can be used as a common road map. In particular, given the fact that in 2020 the European Commission has suggested the Farm-To-Fork strategy (F2F) as a first major attempt to start an effective transformation of the EU-food system, it is interesting especially for other countries to learn from the experience made in the EU. This applies especially to other relatively large federal states like the United States, India or Brazil, which despite many important differences at least partly have a similar demographic, economic and political structure.

In this context the aim of this report is to prepare a follow-up analysis on existing studies modeling economic and ecological impacts of the F2F-strategy. This report should be used as a background paper for future political dialog and exchange of ideas between relevant governmental leaders and stakeholders in agricultural policy in Brazil and Germany, respectively. In particular, based on the existing study Modeling Economic and Ecological Impacts of the F2F-strategy the following components are relevant:

- Up-dating simulation results of the original study.
- Highlighting important impacts of the F2F-strategy from an international perspective with special focus on Brazil.
- Analyzing stakeholder response to the Commissions F2F-strategy as well as preferred stakeholder positions regarding future policy options to implement the Green Deal in agriculture.

Given this background the study includes the following analysis steps:

I. To generalize analyses of potential economic and economic impact of different F2F-options and to be able to identify optimal policies implementing the Green Deal in EU-agriculture from maximizing total welfare from the perspective of different social groups we derived a set of metamodels for the CAPRI-model applying innovative simulation and Bayesian estimation techniques (Ziesmer et al., 2022).

II. To analyze stakeholder perspective on the F2F-strategy and alternative options to implement the Green Deal we conducted a stakeholder survey including 60 governmental and nongovernmental stakeholder organizations in Germany. Survey data was collected using an online questionnaire tool in March to July 2022.

III. By combing collected stakeholder data with metamodels of the CAPRI-model specific policy beliefs as well as preferred narratives on how different F2F-policies impact on economic and ecological goals could be identified. Based on identified narratives and beliefs political feasibility of different options regarding future F2F-implementations could be assessed.

0.2 Central results

Main results of our analyses can be summarized as follows:

0.2.1 Major conclusion from existing F2F-Study by Henning et al. (2021)

A. **The F2F strategy itself does not yet correspond to a consistent agricultural policy strategy:** Individual F2F measures do rather correspond to specific production restrictions which are not yet providing a consistent agricultural policy framework designed to achieve an effective and efficient implementation of the Green Deal's goals in agriculture. The unsolved key issues are:

1. Leakage Effects: One of the main weaknesses of the F2F strategy is that it is not yet effective to reduce climate change. One major factor corresponds to leakage effects with regard to GHG emissions. In general, leakage effects can be avoided when an internationally coordinated climate policy is implemented within an international governance structure. However, since the establishment of an international climate policy is a difficult undertaking unlikely to deliver results in the foreseeable future, the agricultural adaptation of the Green Deal goals should include second best options in order to minimize leakage effects. Said options can include but are not limited to: (a) promoting technological progress in order to increase and secure a sustainable production within the agricultural sector, (b) promoting technological progress in the processing and consumption of agricultural commodities (reduction of food waste) as well as (c) trade policy interventions in order to avoid shifts of production into non-EU countries.

2. Inclusion of the LULUCF-Sector: Another reason for the limited climate-efficacy of the F2F strategy are the induced land use changes, which amount to 48% of the compensation of the F2F induced reduction of GHG-emissions in agriculture, making them an important factor together with leakage-effects. In contrast to controlling leakage effects, controlling LULUCF-effects in the EU is relatively easy to achieve through respective regulatory measures. In addition to that, proven incentives for land use changes, such as reforestation or rewetting of moors, can be used as an effective measure to control the LULUCF-effects within European agriculture.

3. Minimizing adjustment costs: The imposed actions stated by the F2F strategy are to be considered ad hoc and not validated by a scientific foundation with regard to the type of intervention as well as their scale. In general, the agricultural measures taken should be goal-oriented. With regard to the F2F strategy, the political restriction of the maximum N-balance as well as GHG-emissions seems reasonable, as those directly target the respective ecosystem services provided by agriculture. In contrast to that, restricting agricultural production to specific technologies without any evidence-based foundations that these technologies contribute effectively and efficiently to the achievement of set goals of the Green Deal appears rather ineffective. A good case in point is the extension of organic farming to 25%. This holds especially true if agricultural policy measures are available that provide direct incentives to farmers to produce relevant ecosystem services. For example, this is the case with regard to the nitrogen, phosphorus and potassium nutrient cycles as well as GHG emissions. However, it is more difficult for biodiversity. In this regard further research is definitely needed to identify adequate indicators and incentive schemes that allow an effective and efficient public management of biodiversity.

4. Socially just distribution of adjustment costs: The effective implementation of the Green Deal goals requires a considerable collective effort of the entire European society. Thus, it is of the utmost importance that all cornerstones of the F2F strategy are collectively implemented by all member states. Furthermore, it is also important to realize a fair distribution of costs and benefits resulting from the implementation of the Green Deal goals among the European member states and their individual regions as well as among the relevant socio-economic groups, namely farmers and consumers. The latter includes a fair distribution of cost and benefits between farmers, i.e. animal and crop producers, and lastly among the consumers as well, i.e. between households of different socio-economic statuses and income.

B. Smart and innovative governance mechanisms are required:

1. The effective and efficient implementation of the Green Deal goals does not only require the use of disruptive technology in agricultural production, but rather innovative and smart governance mechanisms which combine the flexibility and incentive compatibility of market mechanisms with the planning security of regulative policy interventions.

2. Furthermore, these effective governance mechanisms should allow a flexible adaption of regional and temporal distribution of the costs and benefits to changing framework conditions, such as technological progress or changing international trade flows.

3. In this context, tradable allowances (emissions-trading-systems), as they have already been established for CO_2-emissions in the non-agricultural sector, present a promising tool and could also be developed for the effective and efficient monitoring of other ecosystem-services such as the N-balance or even biodiversity. In addition to that, allowances-trading-systems allow a flexible and transparent division of the costs to provide each individual ecosystem-service between farmers and consumers as well as between the individual social groups among farmers and consumers.

0.2.2 Identifying optimal F2F-policy options based on metamodels of CAPRI

A. Maximizing the social welfare of total EU-society, i.e. maximizing the average welfare per capita of a EU-citizen including both economic welfare as well as welfare derived from ecosystem services, implies that an optimal policy mix would include the following F2F-measures:

- reduction in nitrogen balance of 75%,
- reduction in pesticide use of 75%,
- share of ecological compensation conservation areas of at least 15%

B. Additionally, agriculture would be included in GHG-emission trading, where a price of 292 USD per t CO_2eq. would be realized.

Maximizing the social welfare of individual EU member states, i.e. maximizing separately the average economic welfare per capita of a citizen in each EU member state including both economic welfare as well as welfare derived from ecosystem services, implies a surprisingly unique optimal policy mix for all individual member states. In particular, member states would completely agree in the following F2F-measures:

- reduction in nitrogen balance of 75%,
- reduction in pesticide use of 75%,
- GHG-emission trading with a price ranging between 273-309 USD per t CO_2eq.

Moreover, maximizing national social welfare all member states would agree in neglecting the two F2F-measures ’increase of organic farming’ as well as ’reducing mineral fertilizer input by 20%’. However, only regarding the implementation of ecological compensation conservation areas members states are divided into two subgroups, one subgroup preferring at least 15% and another preferring to also neglect this measure completely.

C. Compared to the F2F-strategy suggested by the European Commission implementing the optimal F2F-option would imply the following improvements in economic and ecological achievement levels:

- increased reduction in nitrogen pollution from 50% (F2F) to almost 80% (optimal F2F).
- reduction in GHG-emissions (including leakage effects) from 29% (F2F) to over 60% (optimal F2F),
- increase in biodiversity from 15% (F2F) to over 25% (optimal F2F)

Simultaneously, economic welfare would change as follows:

- higher decrease in consumer welfare from -0.14% (F2F) to almost -0.3% (optimal F2F) per capita income.
- increase in farm pro ts from 50% (F2F) to almost 150% (optimal F2F),
- higher decrease in total economic welfare (without ecosystem services) from -0.05% (F2F) to -0.01% (optimal F2F)

Hence, overall in comparison to the Commission’s F2F-strategy the optimal F2F-option implies an increase in total society net-welfare by over 60%. However, from the perspective of individual socio-economic interests groups the following results are observed:

- consumers realize an overall increase in net-welfare by 60% comparing total economic and ecological impacts of Commission F2F to impacts derived under the optimal F2F
- farmers would also realize a similar increase in net-welfare ranging from 60% (F2F) to over 200% (optimal F2F)
- in contrast, agribusiness industry would realize a total economic welfare loss (without ecosystem services) increasing from -25% (F2F) to over 40% (optimal F2F)

0.2.3 Assessing stakeholder responses

A. German stakeholders significantly agree in overall Green Deal goals, but disagree with F2Fstrategy as well as in optimal F2F-policy options.

- regarding policy goals almost all governmental and non-governmental organizations agree in accepting Green Deal goals, i.e. increasing eco-system services delivered by EUagriculture. However, a second relevant identified goal dimensions corresponds to global food security. Regarding this dimension two clusters can be identified, one focusing on a positive impact of the F2F-strategy on global food security and a second group for which environmental goals are clearly prioritized vis-a-vis food security. Interestingly, the first includes most agribusiness and farm organizations, while most environmental organizations can be found in the second cluster.

- In contrast to policy goals, stakeholders are far less in agreement regarding optimal policyoptions to implement the Green Deal goals in agriculture. On the one hand almost none of the interviewed stakeholders agrees with the F2F-strategy suggested by the European commission as an effective option to implement the Green Deal in agriculture. However, on the other hand, the conducted factor analysis of preferred policy options as stated by stakeholders implies that there are two opposing groups. One favoring a focus on organic farming, i.e. preferring F2F-measure corresponding to (1) an increase of organic farming of at least 37.5% as well as (2) an increase of ecological compensation conservation areas of at least 15% and decrease chemical farm inputs, e.g. (3) reduce mineral fertilizer input by 30% as well as the use of pesticides by 75%. We denote this policy option as F2F-eco. Alternatively, a second stakeholder group prefers moderate F2F-options (F2F-soft), e.g. (1a) a reduction of nitrogen loss by only 20%, (2a) a reduction in pesticide use by only 20% , (3a) an ecological compensation conservation area of only 5% and a C02 price of only 50 USD per t CO_2eq. Most environmental organizations are in cluster 1 favoring the F2F-eco option, while most agribusiness and also farm organizations are in cluster 2 favoring the option F2F-soft, while political parties as well as group of state and federal ministries subdivide between the two groups according to their political ideology.

- A more comprehensive analysis of political beliefs and narratives held or proclaimed by stakeholders in the public political debate reveals the following. First, especially agribusiness organizations strategically support the narrative that an effective implementation of the Green Deal would seriously endanger global food security as well as induce extremely high adaption costs on the consumer side especially for low-income households, while the main driver of their political opposition vis-a-vis F2F and an effective implementation of the Green corresponds to their realistically expected pro t losses induced by an Green Deal implementation. In contrast, farm organizations share the critical view on F2F-strategy as well as an effective implementation of the Green Deal with agribusiness industry. However, the main driver of their political opposition results form their biased policy beliefs, that any effective implementation of the Green Deal goals in agriculture implies high losses in farm incomes. Analogously, most environmental organizations as well as green dominated governmental organizations favor the F2F-eco strategy because they hold biased policy beliefs regarding the positive impact of organic farming as well as a reduction in mineral fertilizer on delivered ecosystem services. As the biased farmer beliefs also the latter beliefs heavily contrasts with scientific models, e.g. existing economic-ecological models like the CAPRI-model.

0.2.4 Assessing overall welfare of total EU-population and political feasibility of future F2F-options

Based on conducted economic and political analyses the following conclusions regarding the overall society welfare impacts and political feasibility of different F2F-options can be drawn:

A. By far the most favorable F2F-option to implement the Green Deal goals corresponds to the identified optimal F2F-option.

B. Assuming national governments of all EU member states would be benevolent dictators maximizing the social welfare of their country it turns out that the optimal F2F-option corresponds to a win-win situation, i.e. in essence all EU-members states would unanimously prefer this optimal F2F-option. However, in political reality democratically elected governments can rarely be considered as social welfare maximizing, but rather policy preferences of electoral supportseeking governments are determined by the political will of their electorate. The latter is dominated by simple narratives and biased policy beliefs that are formed in complex political communication processes. Empirical analyses imply that these processes at least in Germany are dominated by two narratives implying two dominant policy options, F2F-eco and F2F-soft, respectively. Accordingly, forecasting future policy decisions it appears most realistically that a compromise between these options and the original F2F-proposal will finally be implemented in EU-member states.

C. Given the fact that our analyses clearly indicated that both options, F2F-soft, F2F-eco and the original F2F-proposal, are extremely inefficient when compared to the scientifically identified optimal F2F-option a fatal dilemma between society welfare and political feasibility results.

D. A potential solution of this dilemma corresponds to an effective and interactive science-society communication, where scientists effectively communicate true policy impacts and stakeholders adapt their policy beliefs and narratives to scientific knowledge. However, as our analyses also show, the latter is not only a technical matter, as at least the selection and proclamation of narratives are always at least partly also strategically motivated.

E. Finally, these results support the importance of political dialogues between science and society as well as between stakeholders of different countries, like the one that initiated this project report.

0.2.5 International Perspective on future F2F-options

In general, the implementation of Green Deal goals in EU-agriculture has economic and ecological spillover effects via induced changes in international agricultural commodity prices as well as induced changes in agricultural production patterns as well as associated ecosystem services. Regarding economic welfare spillover effects a reasonable indicator corresponds to induced changes in international prices, where in- or decreased international prices might have positive or negative welfare effects in other countries depending on the net-export position of the country. However, while induced changes in GHG-emissions are explicitly modeled within the CAPRI-model (except induced changes in the LULUCF-sector), spillover effects for other ecosystem services are not explicitly modeled, but can rather be roughly estimated based on induced changes in production patterns. Accordingly the report focused on induced price changes on international markets, especially in Brazil and estimated corresponding welfare implications from net-export positions of Brazil for different commodities.

Main results are the following:

A. All F2F-options induce an increase in international prices for both crop and animal products. Especially in Brazil the implementation of the F2F-strategy would increase prices for pigs as well as poultry followed by beef and milk, while for oilseeds and vegetable and fruits induced price increases are comparatively low. However, compared to induced increases in EU-prices international price increases induced by F2F-implementation are rather low ranging between less than 1% and 8% in Brazil. Interestingly, induced price increases are significantly higher if the optimal F2F-option would be implemented with an increase of 10% for beef and even 15% for pork meet, while for the implementation of the F2F-eco as well as F2F-soft option international price effects are almost neglectable.

B. Given the fact that Brazil is one of the largest, if not the largest, producer and exporter in the world for beef, pork and poultry meat as well as soy, induced price increases especially for these products c.p. imply positive economic welfare effects for Brazil. However, analogously to the EU these induced welfare effects are asymmetrically distributed across farmers and consumers, where the latter c.p. realize losses due to increase food prices.

C. In contrast, to the discussed five F2F-measures a particular measure corresponds to the ban of soy imports into the EU. In contrast, to all other F2F-measures soy ban has a negative impact on international soy prices and hence on economic welfare realized by Brazil. However, analysis of the impact of soy ban reveals that induced price decrease in oilseeds prices are still relatively modest ranging between -3% to -5%.

D. Overall, our analyses imply that from a social welfare perspective of Brazil the implementation of the optimal F2F-option would be most preferable, while the F2F-strategy suggested by the European Commission as well as the F2F-eco and the F2F-soft option are far less favorable to Brazil. However, these conclusions do not yet include induced changes in local ecosystem services, e.g. changes in biodiversity and nitrogen pollution in Brazil. Given the fact that F2Foptions induced production shifts from EU to Brazil the picture might change taking negative spillover effects in local ecosystem services into account. Analogously, a soy ban obviously will imply a reduction in soy production in Brazil, which, ceteris paribus, would decrease negative environmental damages induced by soy production in Brazil. Hence, for a final evaluation of F2F-impacts on total welfare in Brazil a more detailed analysis would be required.

1. Background and outline of the study

Present food systems are characterized by major market failures, i.e. domestically as well as internationally markets are no longer able to effectively coordinate economic actions in a way that market equilibrium corresponds to societies' maximal well-being. In particular, agriculture and its associated land-use changes are the biggest contributors to climate change, accounting for roughly 21% of anthropogenic greenhouse gas emissions between 2007 and 2016. Further, pressures placed on natural resources by food production have left 25% of the globe's cultivated land area degraded, while deforestation for agriculture and the intensification of agricultural landscapes are major contributors to biodiversity loss. Moreover, the environmental damage caused by the current management of food systems amplifies disruption - extreme weather events precipitate forced migration, exacerbate tensions around the use of scarce freshwater or sh stocks, and can fuel political instability.

As has become clear at the latest food summit, governments all over the globe can no longer ignore these challenges linking agriculture and food value chains to diets, health and planetary ecosystems and urgently seek for practical solutions to fundamentally transform food systems to be in better correspondence with societies' demand for a secure, healthy and environmentally friendly production and consumption of food. What is needed are innovative governmental mechanisms that beyond markets coordinate global, national and local land use activities to guarantee sustainable production of healthy food and fair access to it for every person in the world.

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In this context a comprehensive study on potential economic and ecological impacts of implementation of the F2F-strategy has been conducted by Henning et al. (2021). The analyses were conducted based on the CAPRI-model, which is a regional partial equilibrium model focused on the agricultural sector including environmental and land-use effects induced by farm production. To include international trade flows and corresponding agricultural price effects, the CAPRI sector model is linked to an international trading model. Based on the new trade theory, the trading model assumes that traded agricultural commodities are not perfectly homogeneous goods, but rather imperfect substitutes. Therefore, agricultural trade involves a non-linear transaction cost and trade flows that respond only in a limited way to changed terms of trade (TOT), i.e. changed price relation on domestic and international markets.

The F2F Strategy will initially focus on the implementation of the Green Deal's agricultural main goals, which are defined as the following technical production restrictions and target values:

1. Reduction of mineral fertilizer use by 20% (fertilizer in the following)
2. Reduction of pesticide use by 50% (pesticides)
3. Reduction of the Nitrogen-balance surplus by 50% (nutrients/nsurplus)
4. Share of high diversity landscape features of at least 10% (landscape/national)
5. Share of organic farming of at least 25% (organics)

The aim of this report is to prepare a follow-up analysis on existing studies modeling economic and ecological impacts of the F2F-strategy. This report should be used as a background paper for future political dialog and exchange of ideas between relevant governmental leaders and stakeholders in agricultural policy in Brazil and Germany, respectively. In particular, based on the existing study Modeling Economic and Ecological Impacts of the F2F-strategy the following components are relevant:

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III. By combing collected stakeholder data with metamodels of the CAPRI-model specific policy beliefs as well as preferred narratives on how different F2F-policies impact on economic and ecological goals could be identified. Based on identified narratives and beliefs political feasibility of different options regarding future F2F-implementations could be assessed.

2. Environment and EU Agriculture: Baseline and Outlook

This chapter details the baseline in its three components (a) greenhouse gas emissions (b) nitrogen balance and (c) biodiversity, all of which are heavily influenced by the new Green Deal implementations. If not explicitly mentioned otherwise, all of the provided data can be assumed to be EU-27 data.

2.1. Greenhouse gas emissions

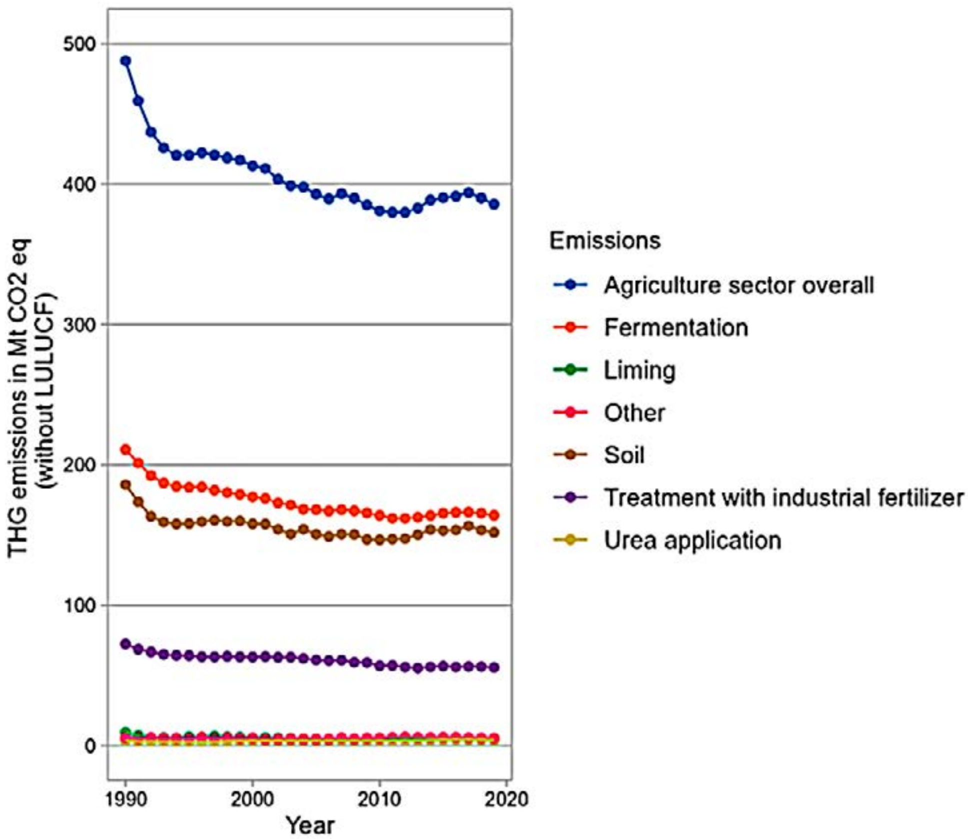
Anthropogenic climate change can largely be attributed to the emission of greenhouse gases. According to Section A of the Kyoto Protocol (UNFCCC Secretariat, 1997), those include:
Carbon Dioxide (CO_2)
Methane (CH4)
Nitrous Oxide (N_2O)
Partially halogenated Fluorine-carbohydrates (H-FCHn)
Perfluorinated Carbohydrates (P-FCHn)
Sulfur Hexafluoride (SF6)
Agriculturally related greenhouse gases include methane released by fermentation as well as nitrous oxide and carbon dioxide released through agricultural cultivation.

Compared to the reference year of 1990, those emissions should be reduced within the EU by 20% in 2020 and 40% in 2030, respectively. In 1990, greenhouse gas emissions within the EU-27 were as high as 4857 Megatons (Mt) CO_2eq with the overall goal being greenhouse gas-neutrality until 2050 (equaling a reduction of 80-95%). According to the European Environmental Protection Agency, the 2020 goal of reducing greenhouse gas emissions by 20% will be reached, however, with the current and additional measures in place only a reduction of 30-32% is predicted to be reached by 2030 (EEA, 2019). Even if the emission goals for 2030 would be reached, the long term goal of CO_2 neutrality would require the following reduction values between 2030 and 2050:

80% reduction compared to 1990: 114 Megatons (Mt) CO_2eq
95% reduction compared to 1990: 157 Megatons (Mt) CO_2eq

This is only feasible through extensive transformations within the agriculture- and food sector, meaning that agricultural greenhouse gas emissions must be reduced significantly. Figure 1 illustrates the current development of agricultural greenhouse gas emissions within the EU-27 based on Eurostat data, which show an overall reduction of agricultural emissions from 488 Mt CO_2eq in 1990 to 386 Mt CO_2eq in 2019.

Figure 1 – Greenhouse gas emissions within the agricultural sector (in Mt CO_2eq)

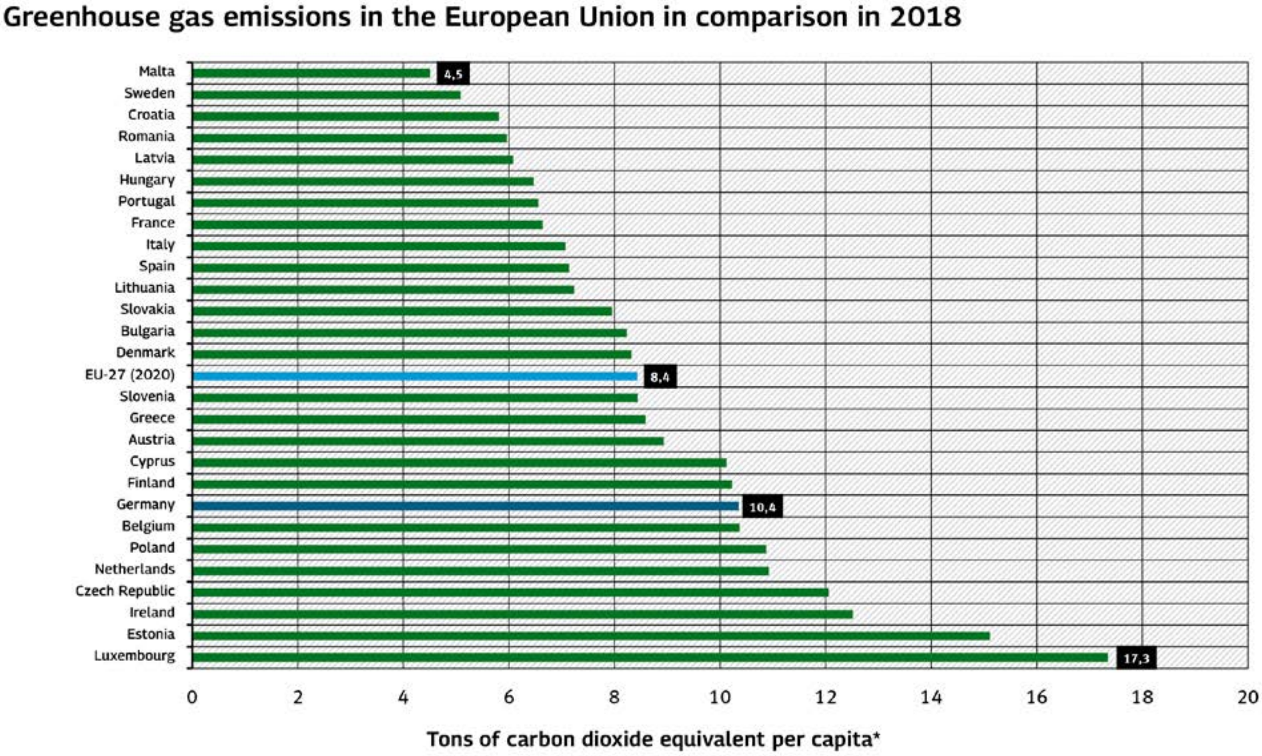


Source: Eurostat – GHGEmissions by soure sector (Code: env_air_gge).

On average, this equates to greenhouse gas emissions of approximately 8 t CO_2eq per capita in the EU. However, inner-European emission values are distributed unevenly as, for example, Malta has an emission rate of 4.5 t CO_2eq per capita, while Luxembourg has 17.3 t CO_2eq. With an emission rate of 10.4 t CO_2eq per capita Germany ranks among the highest emitters in the EU (figure 2) and as of 2016 places 6th internationally only behind China, the US, India, Russia and Japan. With a usage of 15.5 t CO_2eq per capita, the US alone greatly exceeds the consumption levels of Germany or even the EU in general.

The main catalysts of agricultural greenhouse gas emissions, based on total volume emitted, are fermentation and land cultivation with 164 Mt CO_2eq (42.5%) and 152 Mt CO_2eq (39.4%) emitted in 2019, respectively (figure 1).

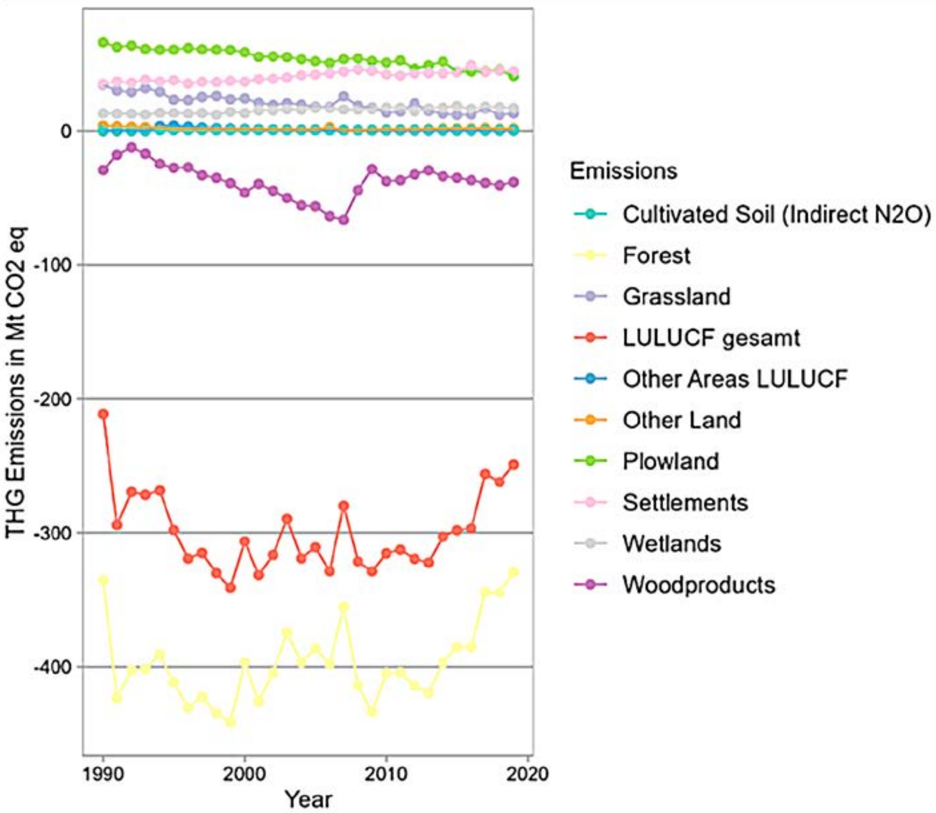
Figure 2 – Greenhouse gas emissions for each member state (in t CO_2eq per capita)



*without emissions from land use

Source: European Environment Agency (EEA), EEA greenhouse gas - data viewer
Land Use Change and Forestry (LULUCF)
https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer (08.25.2020)

Figure 3 – Greenhouse gas enclosure and emissions LULUCF (in Mt CO_2eq)



Source: Eurostat – GHGEmissions by soure sector (Code: env_air_gge).

Apart from reducing active CO_2 emission, lowering natural CO_2 sources poses another important element to reach greenhouse gas neutrality. In contrast to other sectors, changes to land usage and forestry (LULUCF) are the most powerful tools to achieve a net reduction of CO_2 emission. As shown in figure 3, woodland areas and wetlands (e.g. swamps) mostly compensate the emissions of other areas of land usage. Compared to the -329 Mt CO_2eq saved by woodland areas, the remaining LULUCF sectors produced CO_2 emission of 118.5 Mt CO_2eq annually. And while a general increase in emission savings since 1990 could be observed, the most recent trends between 2011-2019 showed a decrease of the overall savings through woodland areas from -404 Mt CO_2eq in 2011 to only 329.4 Mt CO_2eq in 2019. Meanwhile, (positive) emission rates from the other sectors have remained fairly constant over those years (figure 3). According to the UBA (2019), an increase of woodland areas from 37.2% (2015) to 40.7% would therefore be necessary in order to achieve greenhouse gas neutrality.

2.2. Nitrogen balance

Despite its vast abundance in our everyday lives nitrogen (N) does pose a high environmental risk as excess nitrogen can pollute ground, water and air. The following nitrogen compounds pose the highest risk of damage (UBA, 2014):

Direct and indirect Nitrous Oxide (N_2O) emissions
Ammonia (NH3)
Nitrate (NO3) and Nitrite (NO2) pollution of groundwater

One of the Green Deal goals is the reduction of nitrogen-pollution by 50%.
Due to its usage of certain technical inputs agriculture holds the main share of balanced nitrogenexcess (EEA, 2019). Such inputs include:

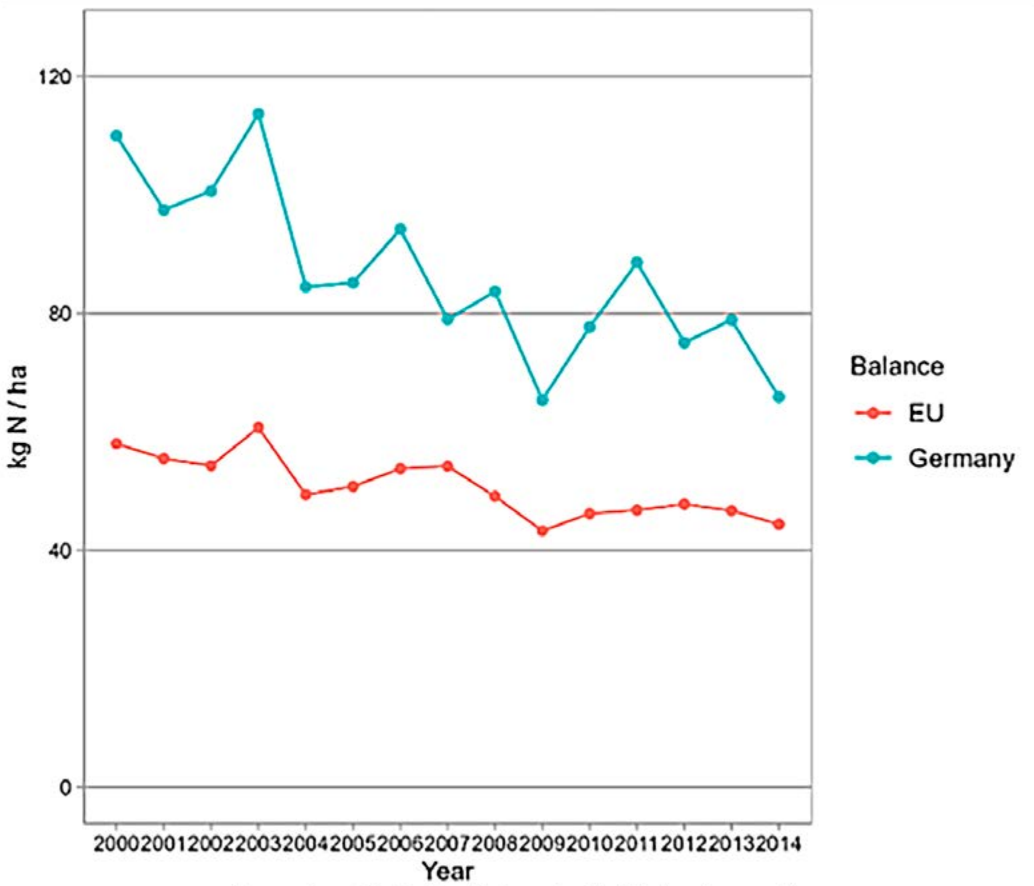
liquid manure
mineral fertilizer
others such as crops

Usage of mineral and organic fertilizer thereby acts as the primary source of pollution inputs. Opposed to those inputs are certain output sources such as nutrient removal through plant crops or harvesting and grazing, which ultimately, however, are unable to fully compensate the inputs.

The corresponding excess values are registered by the nutrient balance. Figure 4 illustrates the development of the European Nitrogen-balance provided by Eurostat between 2000 and 2014. Most notably, there has been a steady decrease in annual nitrogen excess from 58 kg N/ha in 2000 to 44 kg N/ha in 2014. The highest annual N-load during the measurement period was registered in 2003 with 60.7 kg N/ha. For 2030, the EEA (2019) has projected a 2.6% decrease in average nitrogen-excess compared to 2008 (which, as seen in figure 4 had registered a value of 49.1 kg N/ha).

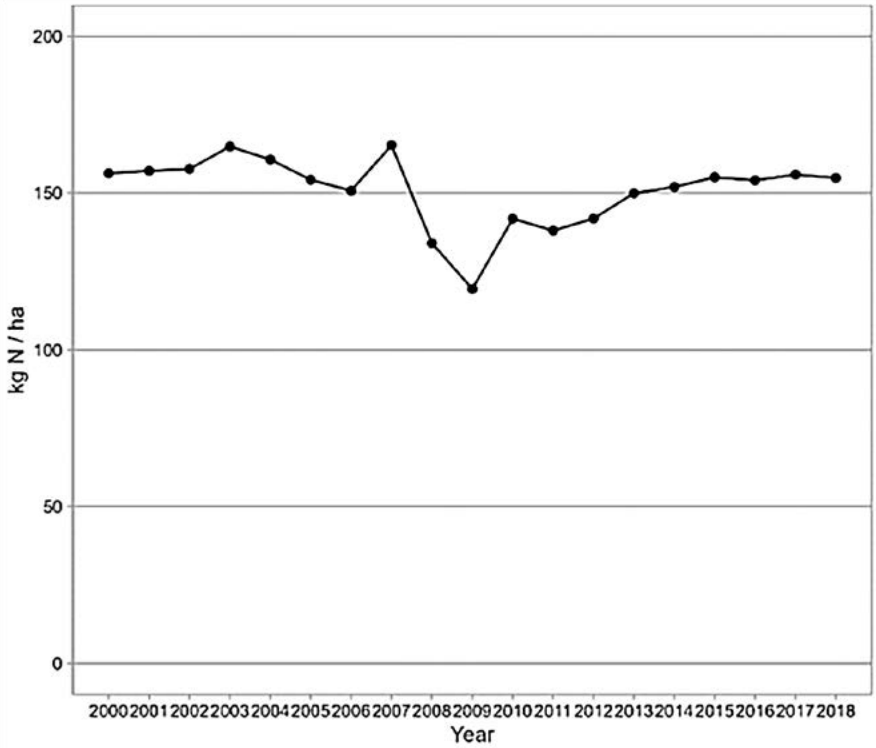
Since fertilizer use has been identified as the main source of agriculturally induced nitrogen-production, it would be advisable to investigate the temporal development of its use, which is captured in figure 5. At the beginning of the recording in 2000, the annual fertilizer use was 156.3 kg N/ha, while the highest (165.25 kg N/ha) and lowest values (119.42 kg N/ha) were recorded in 2007 and 2009, respectively. However, since 2009, when the lowest use values were recorded, fertilizer use has been steadily increasing and has reached a net value of 154.84 kg N/ha in 2018, equaling the initial value from 2000.

Figure 4 – Net Nitrogen balance (in kg N/ha LA)



Source: Eurostat - Nutrient balance brutto (Code: aei_pr_gnb).

Figure 5 – Fertilizer Usage (in kg N/ha LA)



Source: World Bank - Fertilizer consumption (kilograms per hectare of arable land).

A detailed study conducted by Henning et al. (2019) demonstrated that the problem of high N-balances is mainly rooted in manure usage, as they were able to demonstrate through model simulations using the German state of Schleswig-Holstein as an example that the N-balance could be reduced by 70-75% by using organic fertilizer if those were attributed the same N-efficiency as mineral fertilizer, meaning that no waste nor reduced herbal N-sources would be considered.

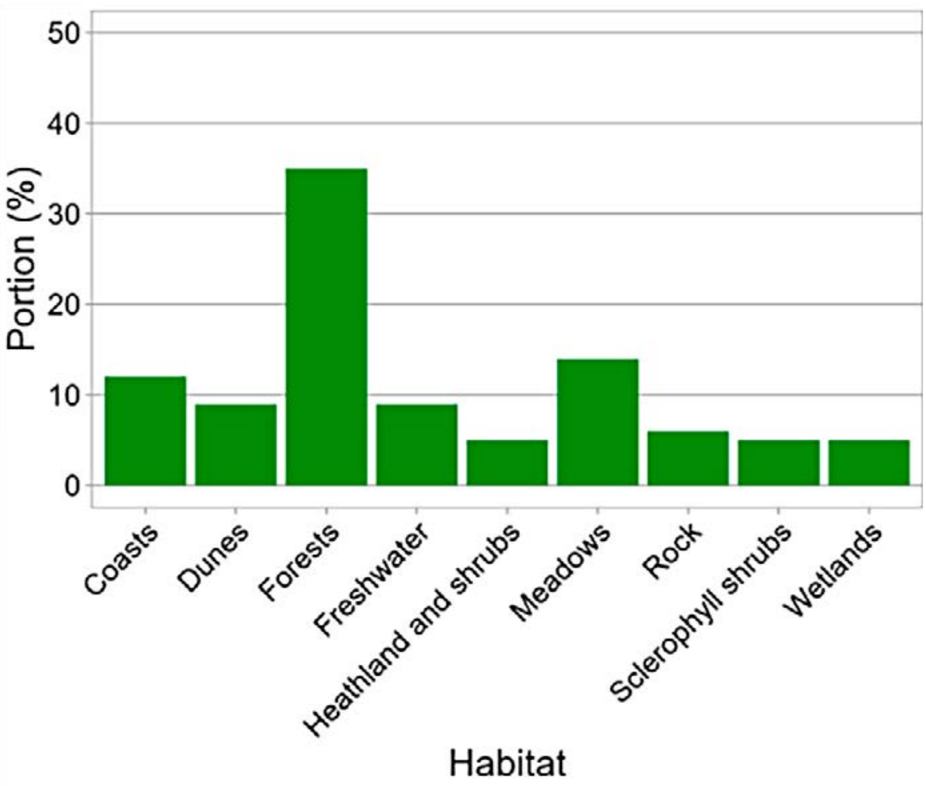
2.3. Biodiversity

Another main goal of the Green Deal is the preservation and expansion of biodiversity and to protect Earth's diverse flora and fauna. Apart from its ecological advantages, an intact and diverse fauna holds many economic and social advantages such as health and welfare (EEA, 2019). In order to focus on preserving biodiversity, the Green Deal implemented its EU-Biodiversity Strategy for 2030 , which includes goals such as protecting:

- *at least 30% of all land areas;*
- *at least 30% of sea surface.*

Of those protected areas, at least one third are due to receive special protection. Despite ongoing urbanization, industrial agriculture poses the main threat for biodiversity (EEA, 2019): Agriculturally induced biodiversity losses are mainly due to fertilizer usage (see N-balance mentioned above), manure and general greenhouse gas emissions. In addition to that, the expansion of agricultural land area through the clearing of woodland areas resulted in a loss of nesting and feeding sites for birds, which in turn results in a depletion of their population. Moreover, pesticide usage is affecting insect population and seed growth as well, resulting in reduced food sources and thereby aggravating the loss of bird population.

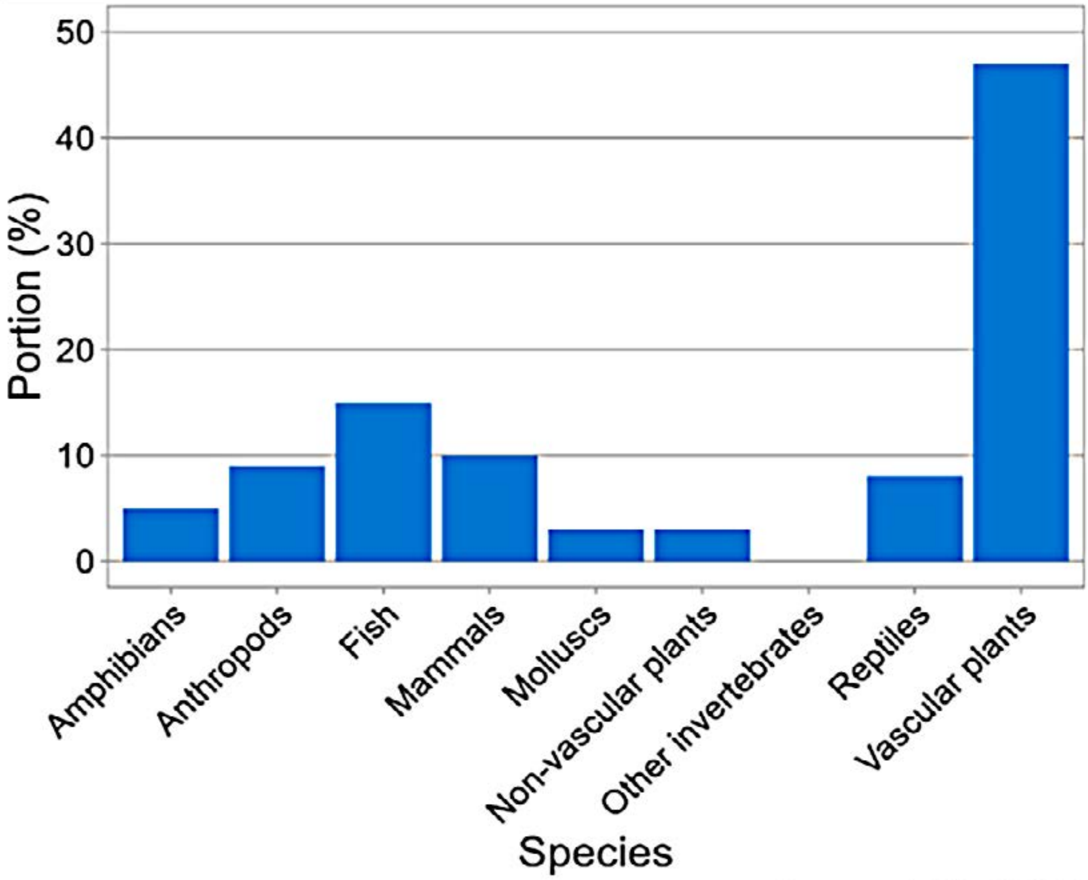
Figure 6 – Habitats below habitat guidelines (in %)



Source: EEA (2020)

Most at-risk habitats include meadow land, heath land, shrubbery as well as fresh water (EEA, 2020). The latest EFA-report on the state of European nature reserves identifies the shares of habitat- and species-categories according to habitat-guidelines between 2013-2018. The main share of all protected habitats falls on woodland areas with 35% (figure 6), followed by meadow land (14%) and coastal areas (12%). With a share of 5% each, moors, swamps, marsh, and hardleaf bushes as well as heath- and bush land display the lowest share of all habitat categories.

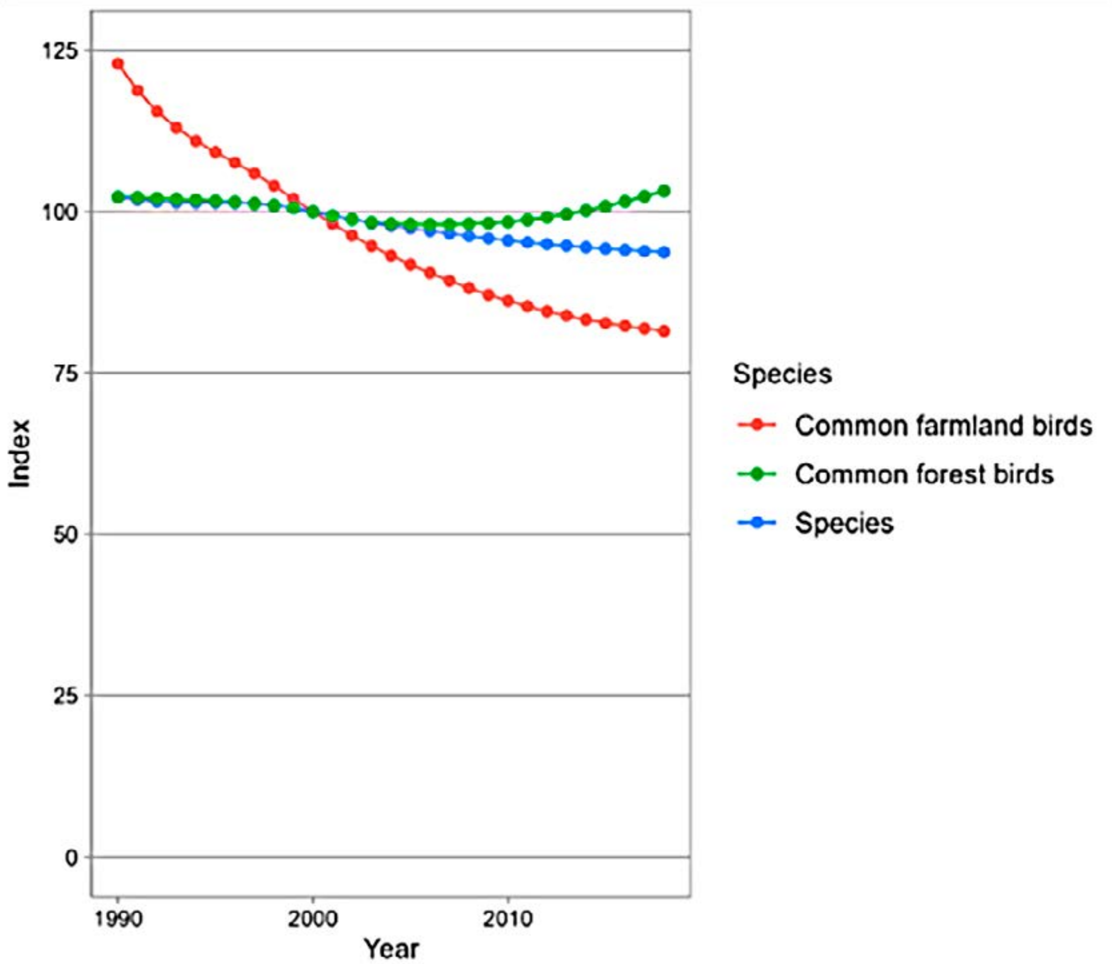
Figure 7 – Species below habitat guidelines (in %)



Source: EEA (2020)

With regard to species protection, vascular plants hold the biggest share with 47%, followed by fish at 15% and mammals with 10% (figure 7).

Figure 8 – Indices for common field and wood bird species (Index, baseline year 2000)



Source: Eurostat – Indices of common species according to estimates (Code: env_bio3).

Figure 8 depicts the development of common field and wood bird species. The index for field bird species amounts to 39 and 34 for wood birds. In 2018, the index value for wood bird species was 103.18, which is slightly higher than the initial value of 102.26 in 1990. However, the index values between 2001 and 2013 were all lower compared to the baseline value in 2000. The trend for field bird species, however, has been continuously negative and has been sinking from 122.92 in 1990 to 81.5 in 2018.

3. Economic and ecological impacts of the F2F-strategy of the European Commission: Summary of Results of the Henning et al. report

In this chapter we summarize main results of the study of Henning et al. (2021) on the economic and ecological impact of the F2F-Strategy.

3.1. Production

The F2F Strategy would lead to a significant decline in production and a respective price increase within the EU, with the reduction of the N-balances by 50% generating the strongest effects. In practice, the decrease in production ranges from **-20% for beef, -6.3% for milk** as well as **21.4% and -20 % for cereals and oilseeds, respectively**, throughout the EU. The number of animals would be even further reduced with a decline of **-45% for feeder cattle and -13.3% for milk cows and young cattle** while **cereal and oilseed areas** would only be reduced by -2.6% and -6%, respectively. When compared to the N-balance reduction of 50%, all other Farm to Fork Strategy (F2F) measures would lead to more moderate production adjustments which generally lie below 10%.

The strong decrease in production would imply a price increase within the EU. The strongest price effects could be observed for **beef with an increase of +58%, followed by pork with a +48% increase followed by raw milk with approximately +36% increase.** Price increases for crops would vary between **+15% for fruits & vegetables** (including permanent crops and wine), **+18% for oilseeds and +12.5% for cereal.** In parallel to the production impacts, the strong price effects could also be attributed to the N-balance reduction of 50%, while the price effects of the other F2F measures would yield a moderate increase of +5%, with the exception being the reduction of pesticides, which would lead to a price increase of +10% for oilseeds and fruits & vegetables.

Figure 9 – Production Volume [in ha and heads], % change to baseline

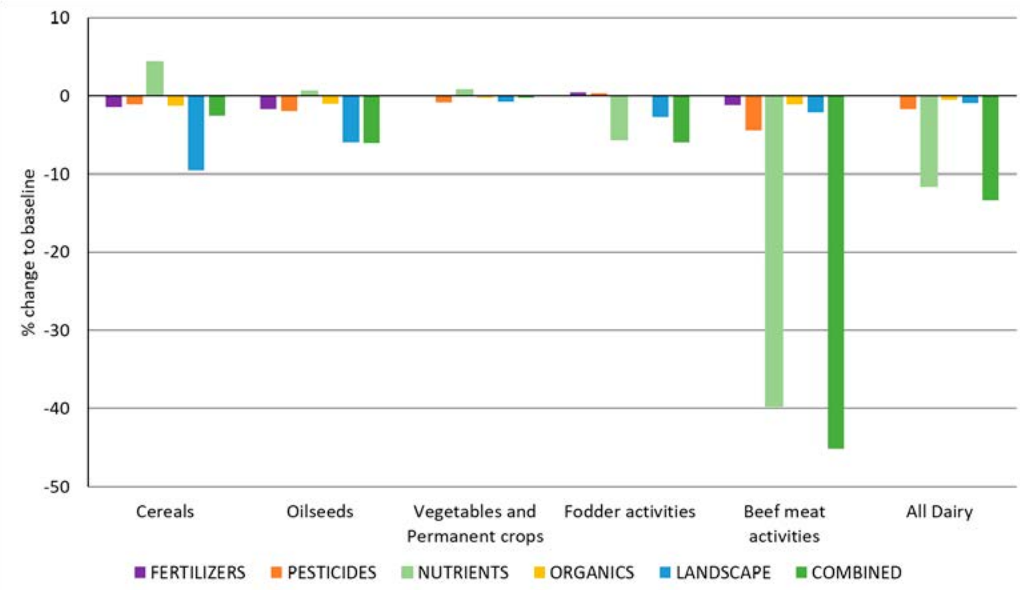
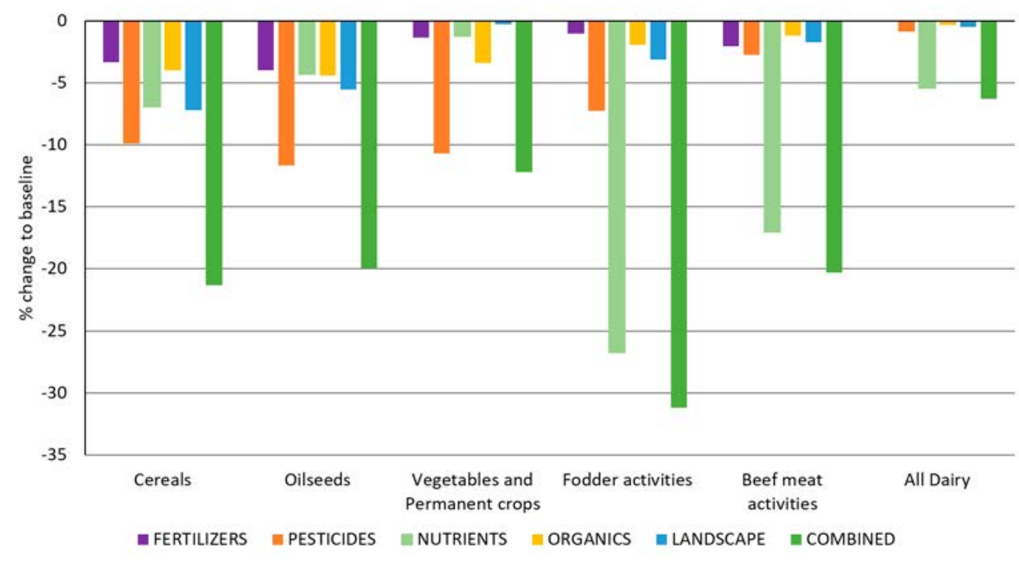


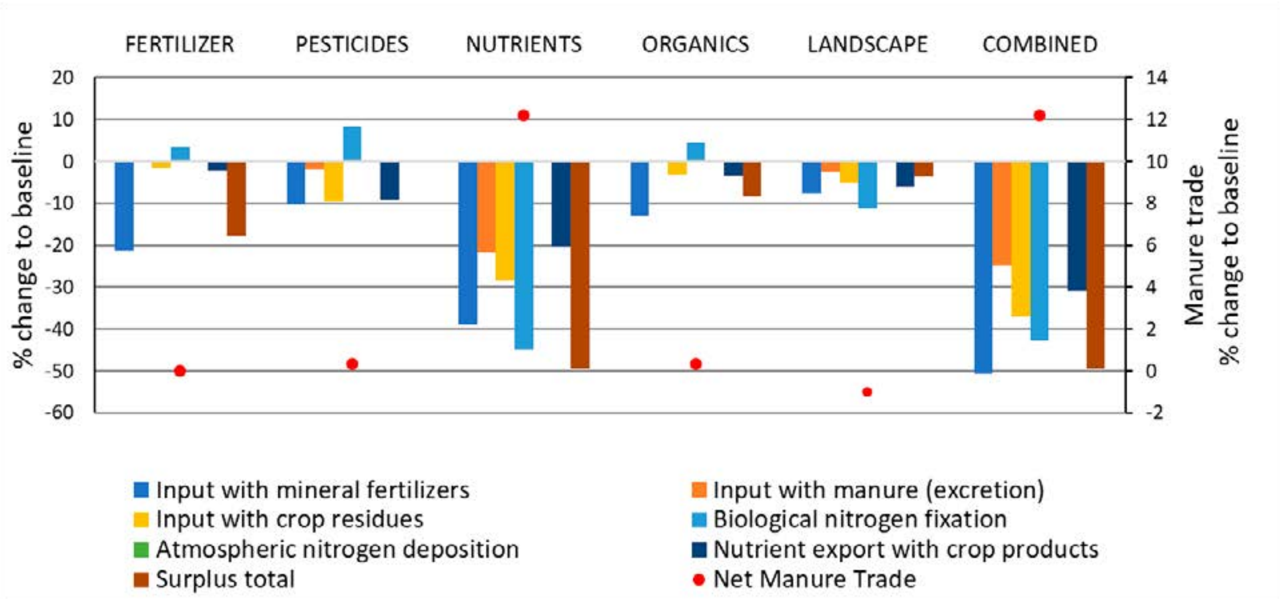
Figure 10 – Production Volume [in constant prices], % change to baseline



Compared to the **price increase** within the EU, the price increases for **non-EU countries** are much more moderate with an average price increase of **+7.4% for beef, +10.2% for pork and +4% for raw milk.** For crops, price increases would vary between **+1.5% for fruits & vegetables** (including permanent crops and wine), **+3.3% for oilseeds and +3.8% for cereals.**

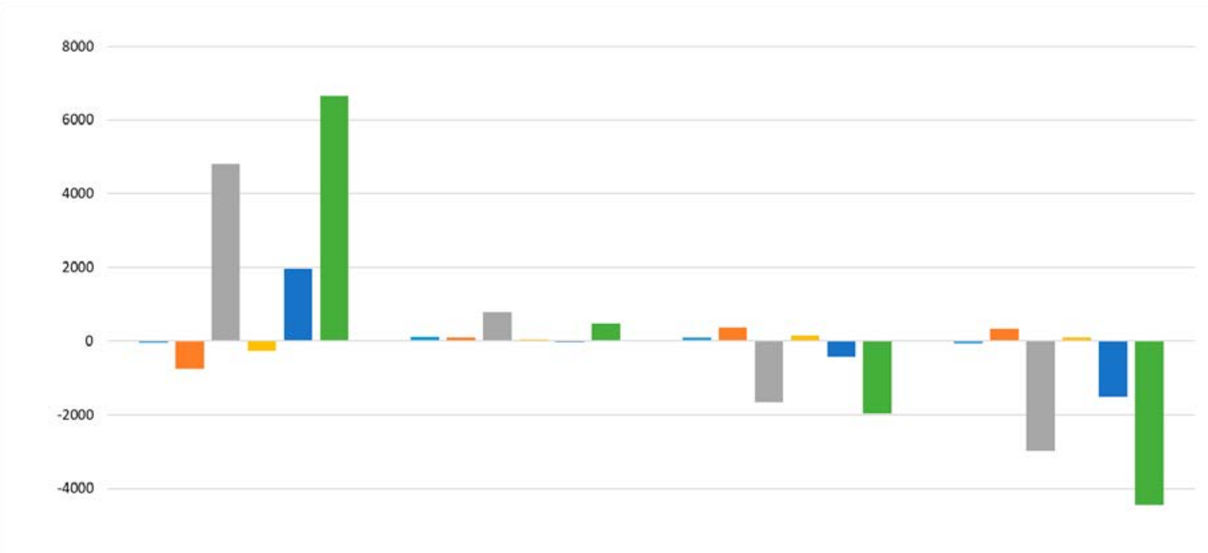
In the EU, the use of mineral fertilizer per hectare (ha) and pesticides per ha is strongly reduced by **-51% and -58%**, respectively, while the use of organic fertilizer is reduced by -25%.

Figure 11 – Components of N balance [in kg/ha], % change to baseline



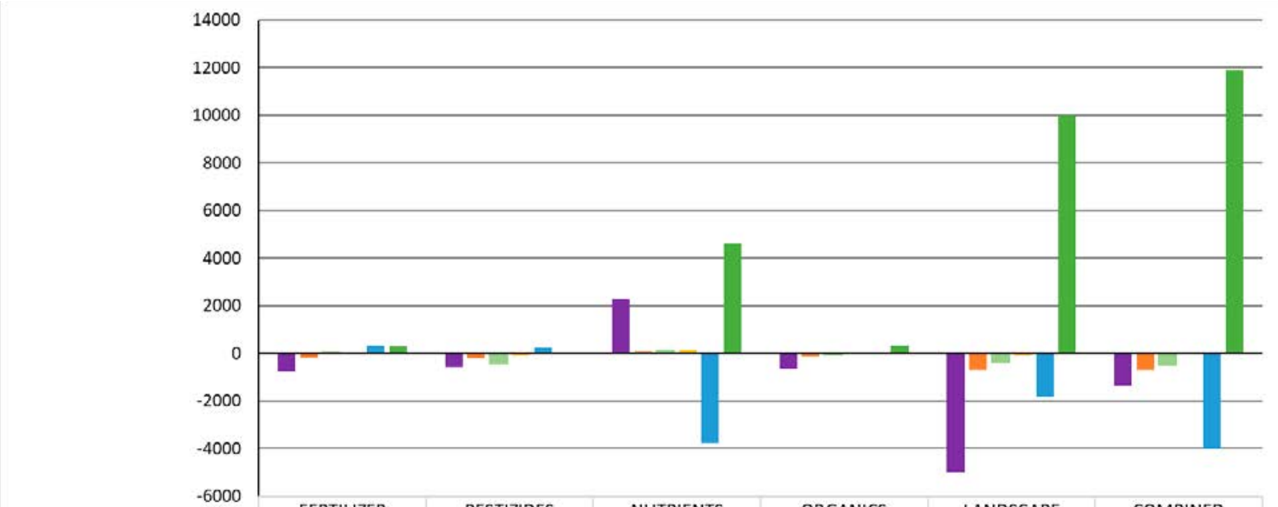
With regard to land-use the implementation of the F2F Strategy by definition implies a **strong growth of set-aside and ecological priority areas by +11 Million ha**, while the use of utilized agricultural area (UAA) as grassland increases by 0.5 Million ha. However, the implementation of the F2F Strategy also implies a transformation of 1.5 Million ha of forest land into UAA.

Figure 12 – Land use change - LULUCF, absolute change to baseline [in thousand ha]



	Utilized agricultural area	Grassland	Forest	Other land
fertilizer	-61	105	102	-77
pesticides	-758	88	377	328
nutrients	4810	789	-1644	-2995
organics	-255	44	149	88
landscape	1967	-38	-420	-1519
f2f	6635	479	-1970	-4455

Figure 13 – Land Use Change - UAA, absolute change to baseline [in thousand ha]



	FERTILIZER	PESTIZIDES	NUTRIENTS	ORGANICS	LANDSCAPE	COMBINED
Cereals	-742	-580	2282	-653	-4980	-1343
Oilseeds	-190	-226	74	-119	-672	-682
Other arable crops	53	-440	133	-66	-372	-481
Vege. and Perm. crops	0	-117	115	-31	-108	-34
Fodder activities	322	229	-3768	60	-1839	-4017
Set aside and fallow land	305	61	4602	334	9994	11902

With regard to adjustments of the input and land-use structures the strongest effects are again obtained by reducing the N-balance. One exception would be the reduction of pesticide use by 50%, which by design yields a strong effect of -50% on the use of pesticides. Similarly, an increase of high diversity landscape features to at least 10% would yield an extension of set-aside areas by approximately 10 Million ha. Interestingly enough, the N-balance reduction itself would result in an extension of set-aside areas by +5 Million ha, while an increase of organic farming would only result in a 0.33 Million ha extension of those areas. In addition to that, an extension of organic farming as well as the reduction of pesticides and mineral fertilizer would result in an increase of forest land, with a margin of 0.125, 0.35 and 0.06 Million ha, respectively.

3.2. Trade

The decrease of production of the European agriculture implies a general reduction of net exports by the EU. If all F2F measures are simultaneously implemented, the EU net export position for cereals and beef would revert to a net import position. According to the F2F Strategy, the current net export of cereals would be reduced from +22 Million tonnes to a net import of -6.5 Million tonnes, while the net beef export would sink from +22.5 thousand tonnes to a net import of -950 thousand tonnes. Furthermore, pork would be reduced from a net export of +4.3 million tonnes to +1 million tonnes, milk export would be reduced from +5.9 million tonnes to +4.9 million tonnes while the net import of oilseeds would increase from -17 to -22 million tonnes. Lastly, the net import of fruits & vegetables would also increase from -10 million to -22 million tonnes.

Figure 14 – Market balance - cereals

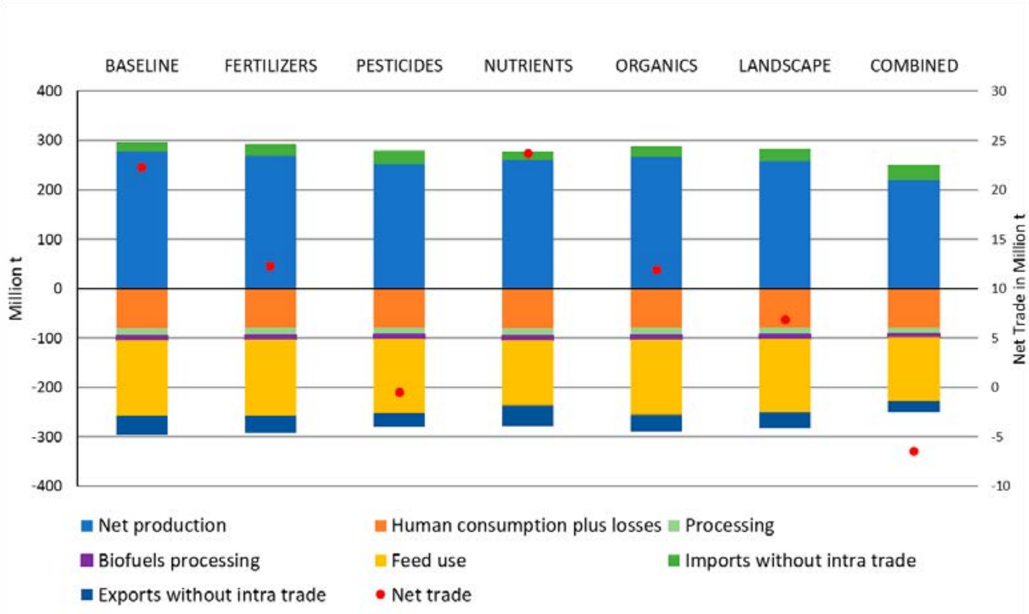


Figure 15 – Market balance - oilseeds

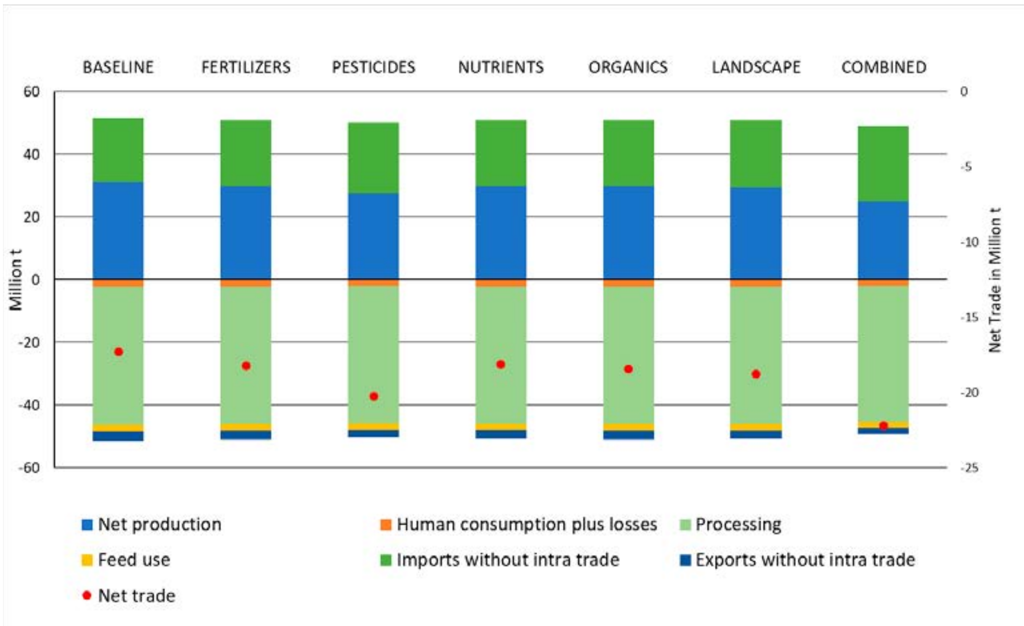


Figure 16 – Market balance - beef

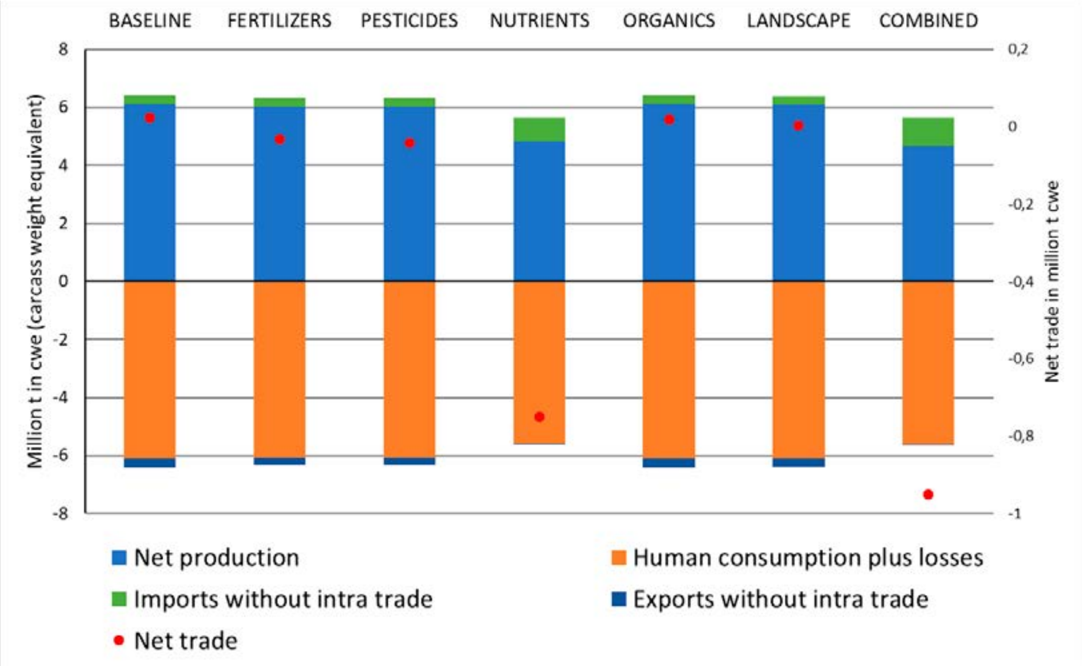


Figure 17 – Market balance - pork

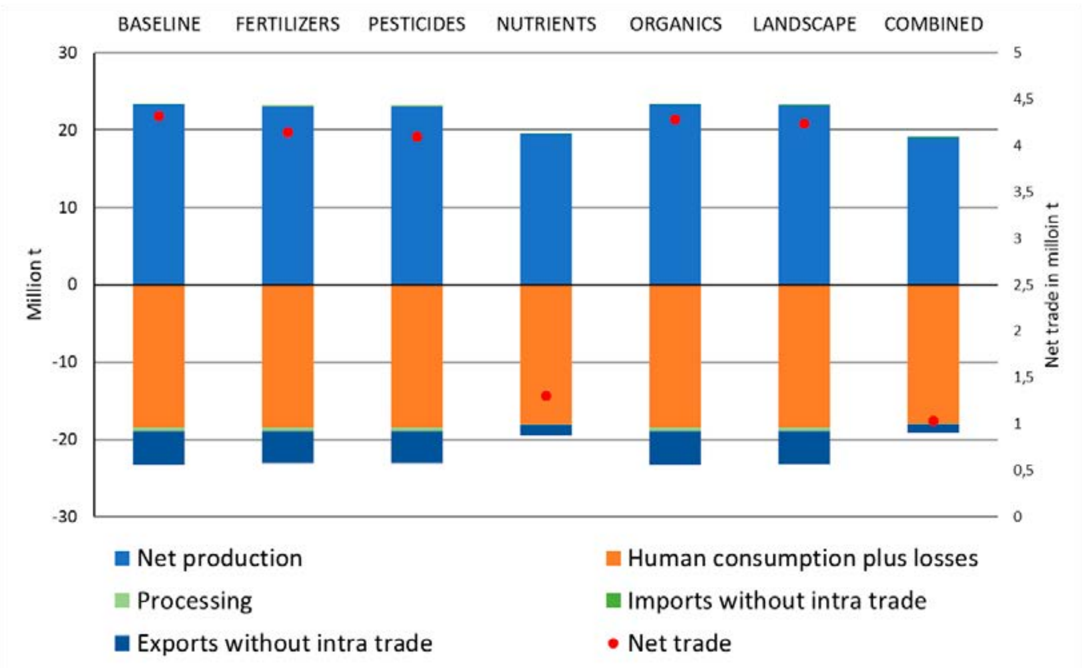
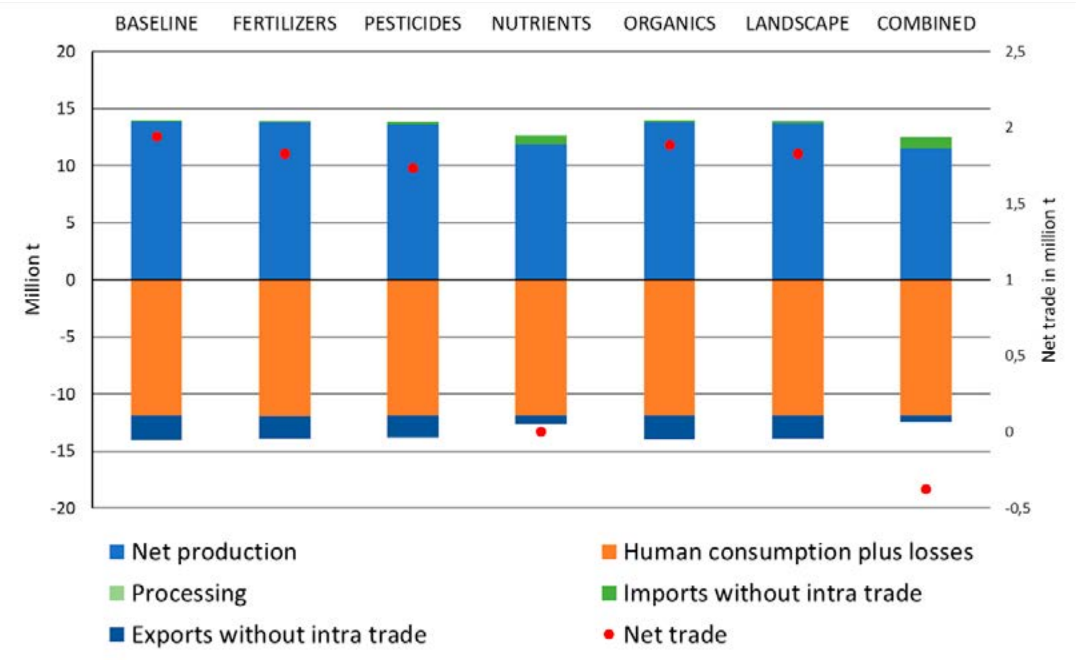


Figure 18 – Market balance - poultry

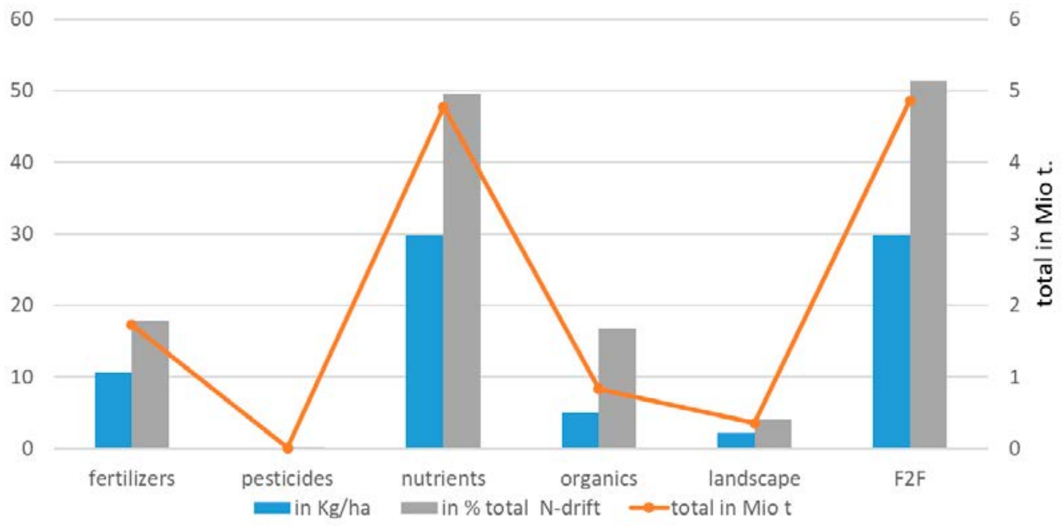


3.3. Ecosystem

The F2F measures significantly increase the ecosystem services of all EU member states. Similar to the production effects, the strongest effects would once again be generated by the reduction of the N-balance.

In fact, this would cause a **N-balance reduction of approximately -50%** from 61 kg/ha to 30 kg/ha of utilised agricultural area (UAA). This effect can mainly be attributed to the 50% **N-balance reduction**, however, the reduction of mineral fertilizer by 20% would also result in a significant reduction of the nitrogen loss by -10 kg/ha. Other individual measures only yield a moderate to no effect as increasing organic farming to 25% would only implied a rather minor nitrogen loss reduction of -5 kg/ha, while the increase of high diversity landscape features would only result in a reduction of -2.5 kg/ha.

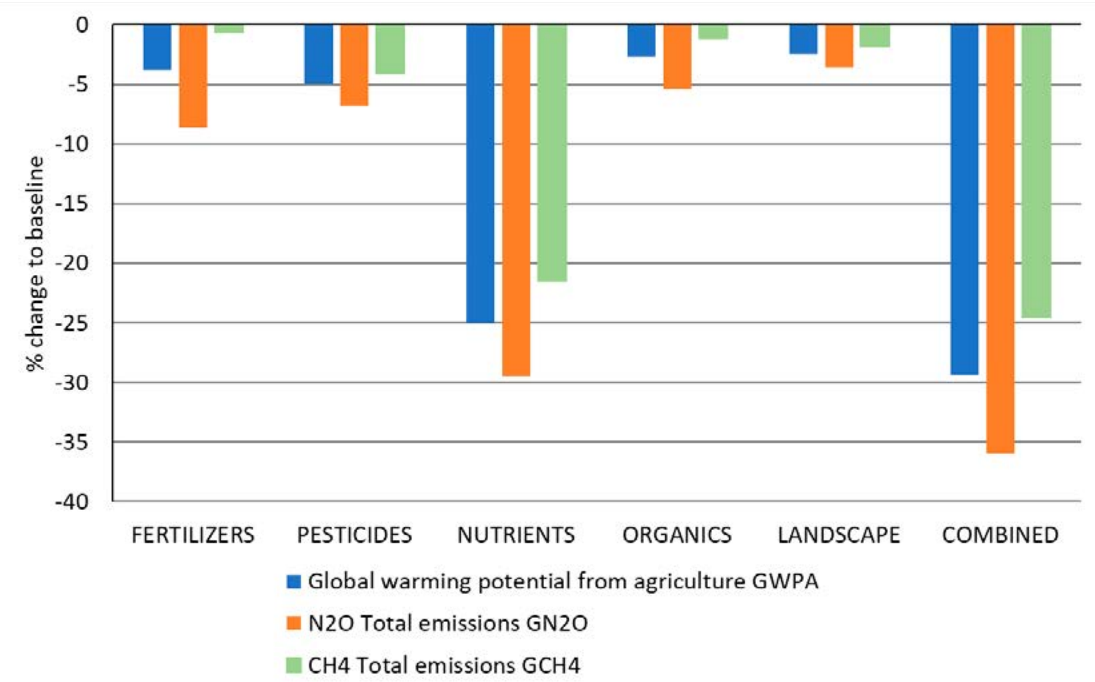
Figure 19 – Ecosystem services - N-balance, % change to baseline



Agricultural GHG-emissions would be reduced of -109 million t CO_2eq., which translates to a -29% reduction of the agricultural global warming potential (GWP) compared to baseline. Looking at the individual GWP-components, N2O-emissions would be reduced by -37.5%, while CH4-emissions would be reduced by -22.7%. With regard to GHG-emissions the strongest impact is again observed for the 50% N-balance reduction, which results in a GHG-emission reduction of -26%. All other measures would only produce lower reduction rates, all of which are less than -5%, with the sole exception of the 50% reduction of pesticides, which would imply a reduction of -5.5%.

Besides direct agricultural GHG-emissions, the GHG-balance of the LULUCF sector (Land-Use, Land-Use Change and Forestry) is also crucial for a comprehensive assessment of the F2F Strategy's impact on the GHG-balance of European agriculture. The EU LULUCF sector is explicitly integrated in the CAPRI-model, which predicts that the implementation of the F2F Strategy would lead to a reduction of CO_2 storage in the LULUCF-sector by 50 million tonnes of CO_2eq. This can mainly be attributed to the transformation of forest into UAA, resulting in a net balance of 109-50=59 million tonnes of CO_2eq. Each individual F2F measure yields different LULUCF effects. While N-balance reduction and the extension of high diversity landscape features imply a negative effect on the LULUCF sector, positive effects can be observed for the reduction of pesticides as well as mineral fertilizer use with a respective CO_2 storage of -2.7 and -5.9 million tonnes CO_2eq. Increasing organic farming further induces a positive effect on the LULUCF-sector with a CO_2 storage of -5.1 million tonnes CO_2eq., however, increasing high diversity landscape features only leads to an extension of agricultural land and thereby has a negative LULUCF effect with a GHG-emission range of +21 million tonnes CO_2eq.

Figure 20 – Ecosystem services - GHG emissions, % change to baseline



The influence of agricultural production on biodiversity is difficult to assess based on the current state of science and therefore even harder to predict and model. The CAPRI-model approximates this influence by using a so-called **Biodiversity friendly production index (BFP)**, which can attain values between 0 and 1. Through the implementation of the F2F Strategy, the **CAPRI-Biodiversity index** would increase from 0.62 to 0.7, which equals 0.08 units or **+12.9%**. Interestingly, increasing high diversity landscape features to 10% and reducing the N-balance both have a positive effect on biodiversity, with a BFP-index increase of 0.06 units or +9.7%. One weakness of the BFPindex, however, is that it does not include the direct impact of pesticide use on biodiversity. As a consequence, simulations based on the CAPRI-model only imply very limited positive effects of a 50% pesticide reduction on biodiversity with a modest BFP-index increase of 0.01 units or +1.6%.

Figure 21 – LULUCF - GHG emission, change to baseline [Mio. t Co_2eq.]

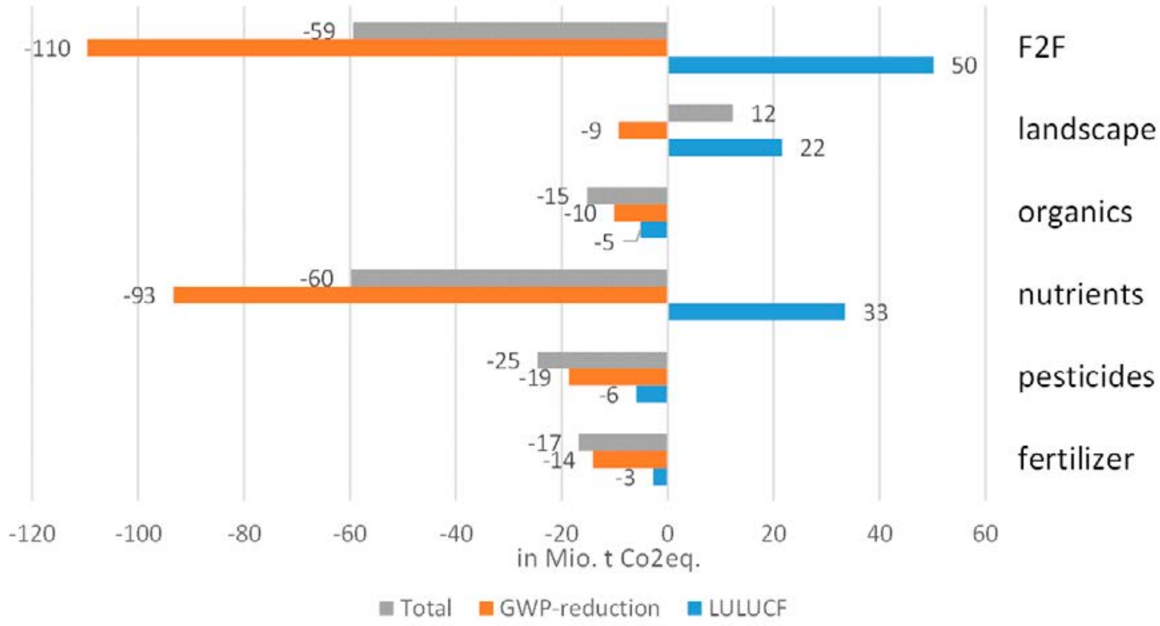
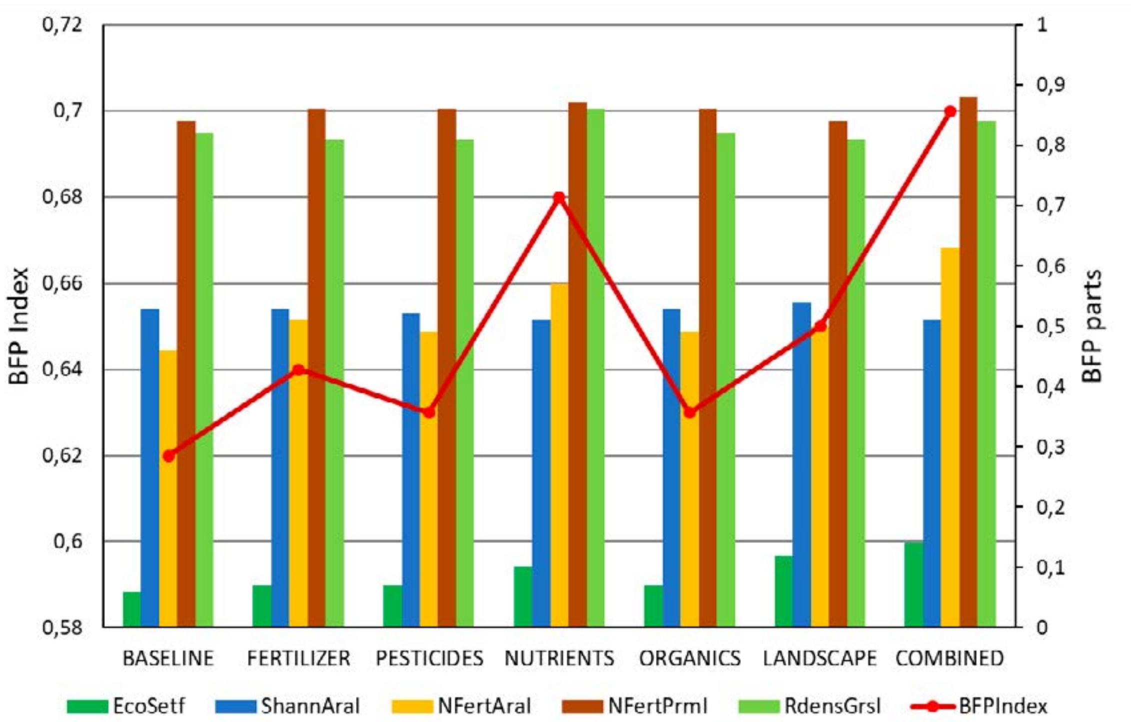


Table 1 – LULUCF effects [in Mio. t CO_2eq.] and absolute change to baseline

	base	fertilizer	pesticides	nutrients	organics	landscape	f2f
LUC related	-336281	-339031	-342221	-302788	-341414	-314718	-286092
emissions		-2750	-5940	33494	-5132	21563	50190
CO_2 emissions	37904	36230	33217	23103	34154	38884	23434
from the cultivation of of organic soils		-1674	-4687	-14801	-3750	980	-14470
CO_2 emissions	-369815	-370840	-373422	-351429	-371211	-364826	-345991
from losses of carbon in biomass and litter		-1024	-3607	18386	-1396	4989	23824
CO_2 emissions	-11379	-11417	-8860	18254	-11342	3957	28787
from soil carbon losses		-38	2519	29633	37	15337	40166
Global warming	373114	359011	354489	279815	363022	363825	263537
potential from agriculture		-14104	-18625	-93300	-10092	-9289	-109578

Figure 22 – Ecosystem services - biodiversity [in BFP-index], % change to baseline

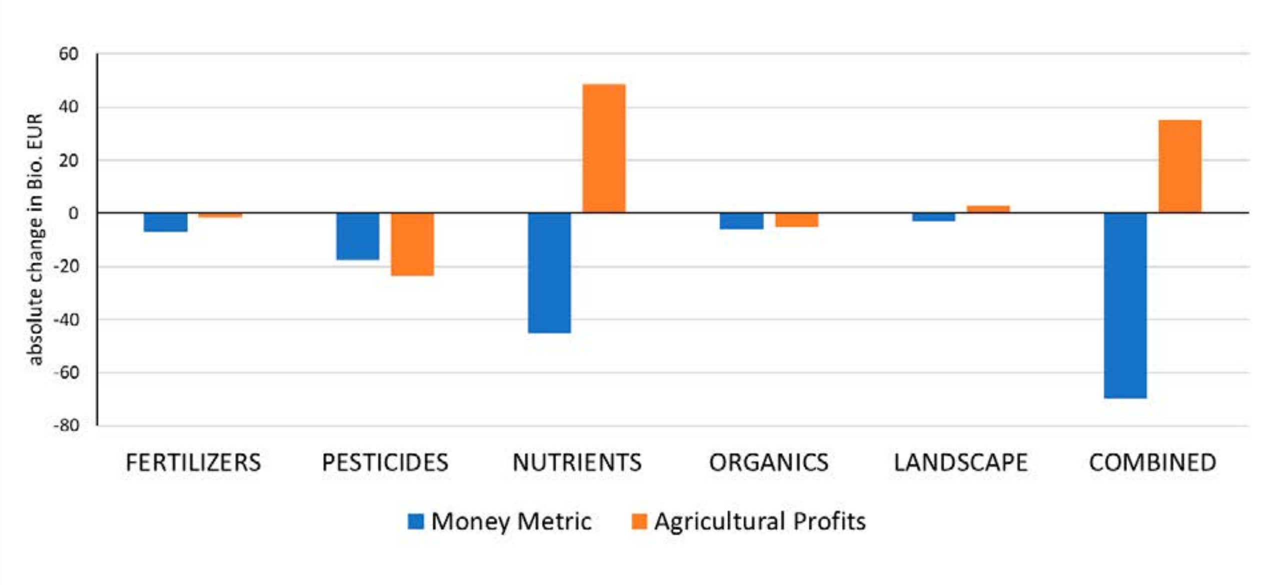


3.4. Welfare

The implementation of the F2F Strategy leads to corresponding public **adjustment costs** of approximately **42 billion Euro.**

Due to strong price responses projected by the CAPRI-model based on assumed low Armington elasticities, the major share of **adjustment costs would be financed by consumers** with an estimated consumer welfare loss of 70 billion Euro (money metric), equalling to 157 Euro per capita. In contrast to that, the **farmers' income** is expected to increase by up to +35 billion Euro, while pro t margins in the dairy and oil processing industry are being reduced by -4 billion Euro each.

Figure 23 – Welfare changes caused by F2F for farmers and consumers, change to baseline [in billion Euro]



Looking at the individual F2F measures, the reduction of pesticides by 50% would require a high social cost of 38 billion Euro while the N-balance reduction would only require 15 billion Euro. Increasing high diversity landscape features to 10% and increasing organic farming to 25%, would entail a rather moderate cost of 2.6 billion Euro and 10 billion Euro, respectively. However, in order to fully assess each individual F2F measure, adjustment costs alone are not a conclusive indicator. On the one hand, there are clear synergies between each measure, and on the other hand, the induced additional ecosystem services need to be factored in as well. The relevant factor is the net benefit, meaning the difference between the benefits and the cost of the increased ecosystem services.

Increasing agricultural income through the implementation of the F2F Strategy seems unexpected and counterintuitive at first glance, however, it can be explained by the very inelastic demand for agricultural products and the low reactivity of agricultural trading. If the European demand is sufficiently inelastic and agricultural trading is sufficiently less reactive (conditions which especially apply with regard to animal products within the EU), a decline in production leads to a disproportionate price increase resulting in an overall increase in the added value of European agriculture, despite the decline in production. This phenomenon can be considered as a reverse treadmill effect based on the theory of Cochrane. The latter is empirically proven with regard to agriculture and explains the unexpected negative effects of technical progress on agricultural incomes. The production restrictions imposed by the F2F Strategy correspond to a negative technical progress, resulting in a reversed treadmill effect. However, the F2F Strategy impacts asymmetrically on animal and crop production. While the **gross margins for animal products**, especially milk, beef and pork, **increase by 55 billion Euro** (24.5 billion Euro for milk, 6.5 billion Euro for beef and 24 billion Euro for other meat, especially pork), the **gross margins for crop production** is reduced by -21.3 billion Euro, with a reduction of **-5.8 billion Euro for cereals and oilseeds and -9.2 billion Euro for fruits & vegetables** (including wine).

The F2F adjustment costs are not only distributed asymmetrically between consumers and farmers but also among the farmers themselves. While consumers face a cost of 157 Euro per capita, farmers are looking at a pro t margin of up to 4,022 Euro per capita. However, those implied pro ts vary depending on the specialisation of production. On average, the F2F Strategy implies an increase of total gross margins by 218 Euro per ha UAA. As mentioned, the adjustment costs vary for each farming specialisation with a -94 Euro decrease per ha UAA for cereals, equalling to -26% of the gross margin realized in the baseline, a -661 Euro per ha UAA for fruits & vegetables - translating to -11% of the gross margin in the baseline - while beef and milk producers are faced with a gross margin increase of 423 Euro and 693 Euro per animal, respectively, as a result of the F2F Strategy[1].

When interpreting each individual component of the total social costs, it is important to note that the calculated welfare for each consumer and farmer are used as a mere estimate of the total welfare change implied by the implementation of the F2F Strategy. The fully realised welfare impact for each socio-economic group depends on the concrete agricultural implementation of the F2F Strategy, which has not been explicitly included in the CAPRI-simulations. It is also important to note that the calculated welfare changes correspond to aggregated measures and can therefore vary across individual members within a specific socio-economic group. In fact, even among the clear beneficiaries of the F2F Strategy, i.e. the milk and beef producing farmers, a heterogeneous distribution of the individual benefits is to be expected. It is especially likely that the induced decrease in supply would be distributed asymmetrically among individual farms: less competitive farms would completely give up production and more competitive farms survive to collect the higher pro ts resulting from higher farm prices while exiting farms would realise a loss.

1 Calculated per animal as well as per UAA gross margins that are based on UAA and animal head counts of the baseline.

If all F2F measures are implemented as planned, they will yield an average pro t increase of 218 Euro per ha. This increase can be mainly attributed to the 50% N-balance reduction, which alone implies an increase in value-added of approximately 300 Euro per ha, while other F2F measures, such as the reduction of pesticides by 50% or increasing organic farming imply a decrease in value-added of -146 Euro and -33 Euro, respectively.

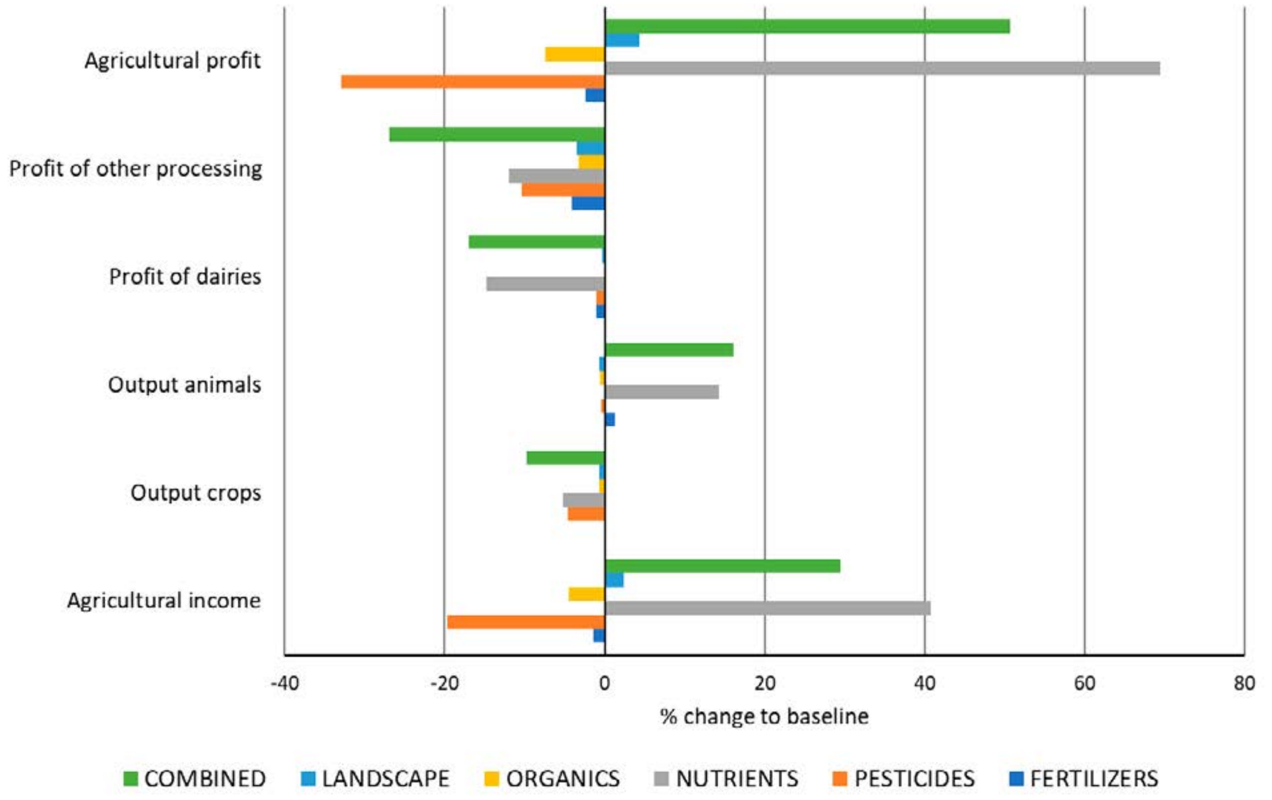
In contrast to farmers, agricultural processing industries are faced with a decrease in value-added by the F2F strategy, varying from -0.02% up to -26.9% depending on the industry. For example, the processing industry only faces a relatively mild loss of pro t by the 25% increase of ecological priority areas with -0.25% for milk and -3.3% for other processing industries, while the 20% reduction of mineral fertilizer implies a low pro t loss for the dairy industry and a moderate loss of roughly 5% for the oil processing industry. A 10% expansion of organic farming results in a -3.6% loss of pro t for the oil processing industry and an even mild pro t gain of 0.15% for the dairy industry. In contrast to that, a 50% N-balance reduction would lead to a strong pro t reduction for the milk processing industry with a loss of -14.5% and -13.2% for other processing industries.

When putting the absolute welfare reduction in relation to the income per capita or rather total food expenditures, they become strongly relativised. In absolute numbers, the cumulated loss of welfare only amounts to 0.26% of the total income or 3% of total food expenditures of European consumers, while the increase in farmer income amounts to 49% of total pro ts by European agriculture.

Table 2 – Welfare change of relevant socioeconomic groups [in billion Euro]

		Difference from baseline					
	baseline	**Fert.**	**Pest.**	**Nutr.**	**Org.**	**Land.**	**F2F**
Total	16394	-11,00	-38,88	-15,72	-10,40	-2,64	-42,03
Consumer (Money Metric)	16246	-6,94	-17,61	-44,92	-5,87	-3,01	-69,71
Income farmers	119	-1,69	-23,47	48,51	-5,30	2,91	35,08
Processing Industry: Milk	26	-0,01	-0,30	-3,72	0,04	-0,07	-4,45
Processing Industry: other	15	-0,73	-1,49	-1,96	-0,54	-0,49	-4,03
Tax payer	-40	-0,15	-0,90	-3,19	-0,33	-0,17	+4,64
Conversion land	27	-1,80	3,09	-16,82	0,94	-2,15	-3,57

Figure 24 – Welfare change caused by F2F in Agribusiness [in million Euro], % change to baseline



4. Future Policy Options Implementing the F2F-strategy

4.1. Optimal policy mix to implement Green Deal in EUagriculture

Chapter 3 shows how F2F impacts the EU27. However, suggested F2F-measures correspond to only one option to implement the Green Deal in agriculture. As explained above the F2F-strategy as suggested by the EU-Commission comprises five different measures, where for each measure a specific level has been formulated, e.g. for the F2F-measure 'Reduction of nitrogen-balance surplus (labeled 'nsurplus' in the following figures) a reduction of 50% has been suggested. However, this particular measure could also be implemented at a different reduction level, e.g. 25% or 60%. Basically, this applies to all individual F2F-measures. Thus, the question arises what will be the best policy options (i.e. the optimal mix of F2F-measures) to implement Green Deal in agriculture.

Given the fact that each of the five measures could be implemented at different levels, e.g. nitrogenbalance surplus could also be reduced by only 25% or even higher by 60% or 80%, the question is what would be the optimal level for each individual F2F-measure. To derive an optimal policy an overall evaluation of policy outcomes is needed. The latter can only be derived from a consistent evaluation of outcomes induced by an implemented F2F-strategy. Relevant outcomes include on the one hand induced changes in ecosystem services, i.e. GHG and nitrogen emissions as well as a changed level of biodiversity. On the other hand this include a change in economic welfare of total society, e.g. change in consumer welfare as well as change in farm pro ts and pro ts of agribusiness industry, respectively, induced by a F2F-strategy .

Thus, optimal policy can be derived from social welfare maximization, where total social welfare corresponds to a weighted sum of goal achievements. In detail, let $z_i = dZ_i / Z_i$ denote the percentage change in achievement levels for a goal $_i$, while β_i denotes the social importance of goal $_i$ from the viewpoint of total society, with $\sum_i \beta_i = 1$, it follows that total evaluation results as :

$$W(z_i) := \sum_i \beta_i z_i$$

As is explained in detail in the appendix relative weights of policy goals vis-a-vis economic welfare, β_i , can be derived from society's willingness-to-pay for different eco-system services. Moreover, let γk denote the level of a F2F-measure k. Then policy outcomes, $z = \{z_i\}$, can be derived from the CAPRI model simulations assuming the policy input $\gamma = \{\gamma k\}$. Thus, to find an optimal policy mix we could simulate relevant policy outcomes derived from the CAPRI model for different policy inputs. Evaluating each policy outcome, $z(\gamma)$ with the social welfare function $W(z(\gamma))$, allows us to select the policy input which implies the highest welfare.

However, technically, identifications of a optimal policy mix based on CAPRI-simulations requires an extremely high computational effort. Therefore, we developed a smarter procedure to identify optimal policies applying metamodeling techniques (see Ziesmer, 2022; Ziesmer, 2023 as well as the methodological appendix). as well as the methodological appendix). In essence, we identified induced changes in relevant policy outcomes, z_i, via policy impact functions, defining relevant policy outcomes as explicit functions of policy inputs:

$$z_i = F^i(\gamma) = \alpha_0^i + \sum_k \alpha_k^i \gamma_k + 0.5 \sum_k \sum_{k'} \delta_{kk'}^i \gamma_k \gamma_{k'}$$

Beyond the identification of optimal levels of the five F2F-measures, an optimal policy mix might also include other policy measures.

In this regard, we will analyze to what extend a pricing (e.g. taxation) of GHG-emissions will be an efficient additional policy intervention to implement the Green Deal in EU-agriculture.

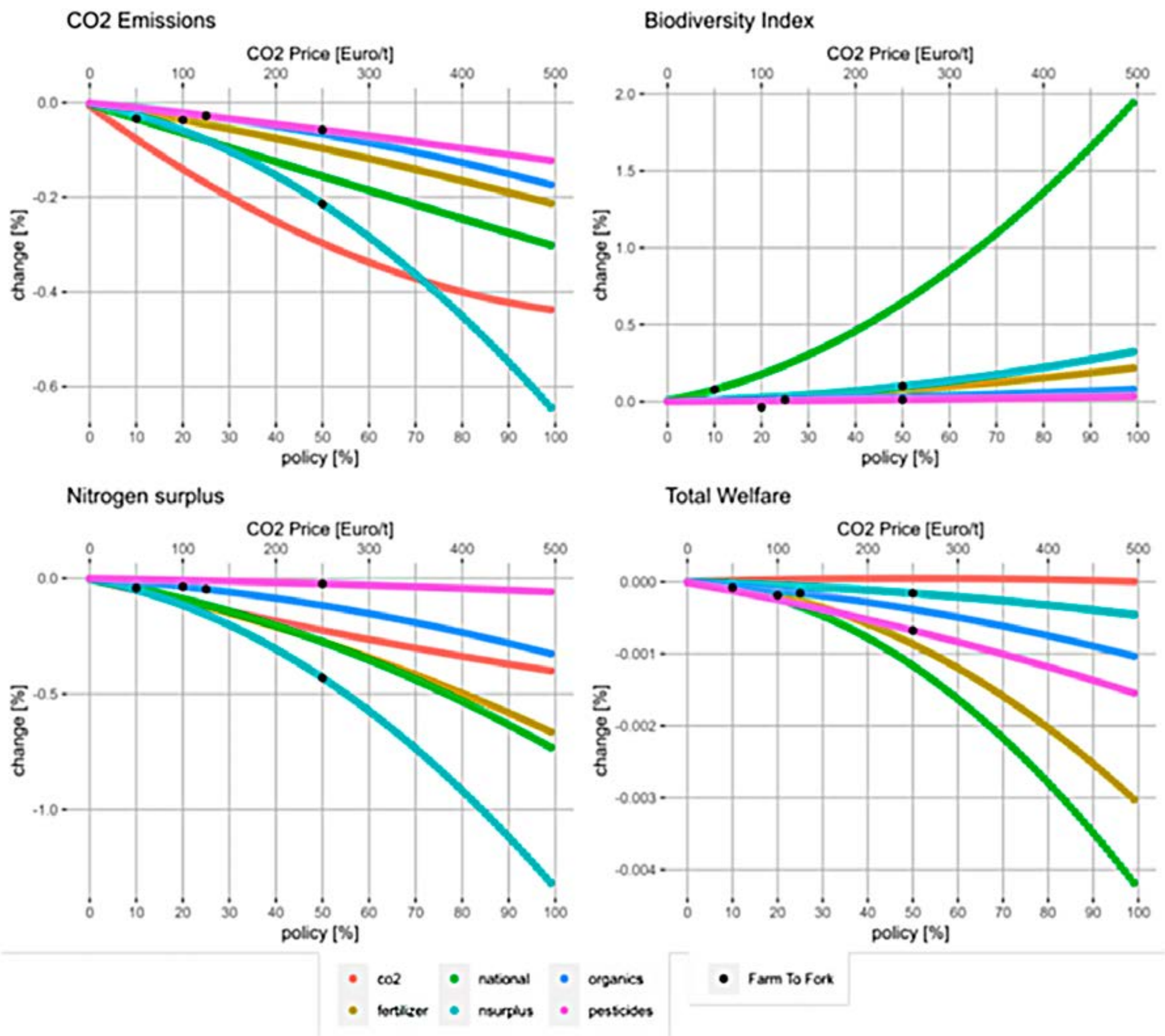
4.1.1. Relative effectiveness and efficiency of individual F2F-measures on ecosystem services

Before we analyze the optimal policy mix derived from social welfare maximization, it is instructive to analyze policy impact functions estimated based on simulations of the CAPRI-model.

In figure 25 estimated policy impact functions for the five F2F-measures as well as the GHG-tax are reported for each policy goal.

As can be seen from figure 25 all five F2F-measures have a positive impact on all ecosystem services and a negative impact on total welfare. This corresponds to the basic intervention logic of these measures, i.e. restricting agricultural production to increase ecosystem services. Thus, technically ecosystem services and agricultural production can be understood as joint products, for which a trade-o regarding the use natural resources exists, i.e. an increase in production of ecosystem services implies, ceteris paribus, a decrease in agricultural production. However, as can be seen from figure 25 this trade-o is non-linear and depends on the specific policy measure that is used to restrict agricultural production. Obviously, a policy instrument is the more efficient the higher the additional ecosystem service is that can be achieved per unit of reduced total economic welfare. Based on estimated policy impact functions we can calculate average and marginal welfare trade-o s for different eco-system services. For example, assuming a GHG-price of 150 Euro per t CO_2.eq. is implemented implies a reduction in GHG-emissions by 20%, while it also implies a total economic welfare loss of roughly 0.03%, while an increase of organic farming to 40% implies a reduction of GHG-emissions by only 6%, while it decreases total economic welfare by roughly 0.07%. Hence, applying organic farming to reduce GHG-emissions corresponds to a trade-o of roughly 86, while applying GHG-pricing corresponds to a trade-o of 666. This means one will get roughly 77.7 times more tons GHG-emission per one unit of economic welfare loss applying the measure of GHGpricing when compared to increasing the share of organic farming. In other words GHG-pricing is a much more efficient measure to reduce GHG-emissions when compared to organic farming. Analogously, one can calculate terms of trade effects for the ecosystem service reduction of nitrogen surplus comparing the F2F-measure organic farming with for example the F2F-measure reduction of nitrogen surplus balance. In detail, we get a trade-o of 170 for organic farming, while we get a trade-o of 1667 for reduction of nitrogen surplus balance, i.e. the latter is almost 10 times more efficient, when compared to organic farming. Please note that pricing of GHG-emission is also less efficient regarding the reduction of nitrogen surplus when compared to the F2F-measure 'reduction of nitrogen surplus' given a trade-o of 286 for the latter. However, even regarding nitrogen surplus balance GHG-pricing is a more efficient measure when compared to organic farming.

Figure 25 – Separate impacts of F2F policies on selected goals



Finally, please also note that trade-o s change with the level of an applied measure, for example for a GHG-price of 300 a trade-o of only 390 results for GHG-emission reductions which is only 60% of the trade o realized at a GHG-price of 150 Euro t CO_2eq.

Overall, maximization of net-benefits takes the efficiency of different F2F-measures for the different ecosystem services as well as the social willingness-to-pay for different ecosystem services into account. Basically, as farm pro t maximization implies a specific mix of variable farm inputs, maximization of social net-benefits implies an optimal mix of applied F2F-measures. While the relative efficiency of different farm input is captured in the agricultural production function, efficiency of different policy measures is captured in estimated policy impact functions.

Furthermore, beyond relative efficiency of different F2F-measures optimal policy mix obviously depends on willingness-to-pay of a society. As both policy impact functions as well as willingness-to-pay for different ecosystem services can vary across EU member states, it follows that optimal EU-policies vary from the view point of different member states.

4.1.2. Optimal policy choices

Based on specified policy impact functions and specified social welfare functions the optimal policy mix, that is the combination of policy measures that maximized social welfare or net-benefit derived from greening EU-agriculture, can be derived. Given the fact that for specific measures simulation of CAPRI was not feasible across the full range of a policy measure, e.g. ecological set-aside could only be implemented up to a level of 15%. Moreover, reduction of pesticide could also only be realistically modeled within CAPRI framework for levels lower than 75%. Accordingly, we had to add specific restrictions on policy levels to our maximization problem.

In detail, we used our approach to find optimal policies from the viewpoint of the total EU, e.g. maximizing social welfare of total EU population. Additionally, we used our approach to identify optimal set-ups of EU-policies from the viewpoint of individual EU member states. For the latter we used social welfare functions derived for individual members states. Moreover, we estimated policy impact functions for individual member states. The latter takes into account that both nitrogen pollution as well as biodiversity is considered as a local public good, i.e. each member state only values pollution and biodiversity levels observed in its own country. In contrast, GHG-emissions are considered as a global public good, i.e. the policy impact functions for GHG-emission reduction are the same for all EU-member states. *In table 3 calculated optimal polices are reported.*

Looking first on optimal policy set-ups at supranational EU-level it is interesting that two original F2F-measures are not included in the optimal policy set-up, namely, increase of organic farming and reduction of mineral fertilizer input. In other words, maximizing social welfare of EU-society the optimal level for these two measures is zero. At a first glance this appears counter-intuitive given the fact that especially organic farming is promoted as the universal policy measure to promote sustainable land use. However, a closer analysis reveals that although organic farming definitely has a positive impact on ecosystem services, especially on biodiversity, it simultaneously has a significant negative impact on total welfare due to the fact that nowadays organic farming still has rather low yields when compared to ecologically intensified crop productions. Therefore, trade-o s for most ecosystem services are still comparatively low. In other words organic farming is a comparatively expensive way to increase ecosystem services. Moreover, regarding nitrogen pollution organic farming even has only limited positive impact due to the fact that organic farming only restricts input of mineral fertilizer but not organic fertilizer. Hence, farms substitute mineral by organic fertilizer, where the latter is significantly less efficient when compared to mineral fertilizer, i.e. for organic fertilizer effective use of nitrogen-input is as low as 25% compared to 65-70% for mineral fertilizer. One caution has to be formulated. Within the CAPRI-model biodiversity is measured applying specific biodiversity index, BFI. At least at present the BFI does not, yet, correctly reflect the positive impact of organic farming on biodiversity. Moreover, the BFI does not correctly reflect the negative impact of pesticide use on biodiversity. Accordingly, optimal policies might changed if an improved index is used by CAPRI. But, the general result that organic farming compared to other measures is less efficient in increasing ecosystem services will remain even if an up-dated measurement of biodiversity will be applied by the CAPRI model.

A further very interesting finding is that assuming member states maximize social welfare implies that there will be a significant homogeneity in nationally preferred policy-set-ups implementing the Green Deal at EU-level. In particular, from the view point of individual members states the optimal policy set-up basically corresponds to the optimal policy mix derived from social welfare maximization

Table 3 – Optimal policy mix at EU and member state level

	GHG-tax	Set-aside	Nsurplus	Pesticides
EU27	274.03	15	75	75
Austria	293.12		75	75
Bulgaria	299.25	15	75	75
Belgium	296.94	15	75	75
Cyprus	281.06	15	75	75
Czech Republic	309.24		75	75
Germany	291.65		75	75
Denmark	274.27	15	75	75
Estonia	278.68	15	75	75
Greece	290.06		75	75
Spain	286.70		75	75
Finland	280.77	15	75	75
France	287.10	7.83	75	75
Croatia	291.07	15	75	75
Hungary	297.29	15	75	75
Ireland	278.91		75	75

	GHG-tax	Set-aside	Nsurplus	Pesticides
Italy	291.03		75	75
Lithuania	279.71	15	75	75
Latvia	283.05	15	75	75
Malta	286.04	15	75	75
Netherlands	284.35	15	75	75
Poland	291.57		75	75
Portugal	277.57	7.91	75	75
Romania	299.40		75	75
Sweden	304.63		75	75
Slovenia	273.77	15	75	75
Slovakia	302.29		75	75

Individual Member States at supranational EU-level. That is the optimal policy set-up will include only four out of six policy measures, where both minimum level of organic farming as well as reduction of mineral fertilizer input will not be implemented. Furthermore, similar to the EU-level even from the perspective of a national member state optimal reduction of N-surplus as well as pesticide use will be 75%. Some variance across member states can be observed regarding the pricing of GHG-emissions as well as the level of set-aside. Regarding the former preferred GHG-price levels range between 273.8 Euro t CO_2eq (Slovenia) and 309 Euro t CO_2eq (Czech Republic), while regarding the optimal set-aside area a subset of member states including e.g. Austria, Germany as well as Romania, prefers no regulation of set-aside, while another sub-set prefer maximal regulation at a share of 15%. The latter set includes for example Bulgaria, Belgium, and the Netherlands. France as well as Portugal take a middle ground position preferring a share of set-aside of roughly 8%.

4.1.3. Political feasibility of policy options

So far, we have identified optimal policy positions of individual member states as well as of supranational institutions, i.e. the EU-commission assuming political agents maximize social welfare. However, in political reality policy preferences of relevant political agents engaging in political decisionmaking are never derived from maximizing social welfare of their constituency. In contrast, policy preferences are derived in a political game involving politicians who maximize their electoral support derived from voters and interest groups which partly control voter responses to policy choices of elected political agents Persson and Tabellini (2000); Henning et al. (2018). Policy preferences resulting from this game often differ substantially from policy preferences derived from social welfare maximization due to two reasons. First, in the political process different social groups are asymmetrically represented, i.e. maximizing electoral response political agents derived their preferred policy preferences form an additive weighted welfare function, where political weights of specific social groups often differ significantly from their corresponding weights in social welfare functions. Second, real world politicians as well as representatives of socio-economic interest groups have often only limited knowledge regarding the impact of policies on relevant policy outcomes. Accordingly, they approximate policy impacts applying policy beliefs, that are simple heuristics (narratives).

Simple heuristics or narratives are often rather biased when compared to true policy impacts. Hence, optimal policies derived from policy beliefs are also biased and might substantially differ from corresponding optimal policies derived from social welfare maximization or even from maximization of weighted social welfare.

However, observed policies always correspond to policy preferences of real political actors and hence correspond to their policy beliefs. Therefore, we conducted a stakeholder survey to obtain empirical data on policy preferences from real political actors and compare these with optimal policies derived from social welfare maximization. Based on this comparison we can draw conclusions on the efficiency of political feasible policy options, on the one hand, and on the political feasibility of optimal (most efficient) policies on the other hand.

4.2. Farm to fork survey

A stakeholder survey among the most important actors of German agriculture was carried out between March and July 2022 in order to measure policy preferences of social groups. In particular, the questionnaire followed an established structure and consisted of three parts:

1. Importance of policy goals: Stakeholders were asked to state the relative importance of different policy goals.

2. Achievements of policy goals: Stakeholders were asked to state their preferred state of the world in different policy goals for two time dimensions (2030, 2050).

3. Policy measure preferences: Stakeholders were asked to state their preferred positions for selected policy instruments.

Parts 1 and 2 refer to policy goals like ecosystem services (i.e. greenhouse gas emissions, nsurplus or biodiversity), food security and economic welfare. The policy instruments proposed in the Farm to Fork strategy were key questions of part 3. Hence, interviewees were asked to state their concrete preferred policy positions regarding the five F2F-measures, i.e. *fertilizer, pesticides, nutrients/nsurplus, landscape/national and organics.*

The total number of interviewed stakeholder organizations was 56. In detail, different interviewed organizations are reported by organization type in table 4.

Table 4 – Number of stakeholders

Group	N
Agribusiness	8
Agriculture	11
Animal Protection	2
Environment Protection	9
Federal Agencies	2
Federal Governance	1
Other	5
Parliamentary Group	5
Science	5
State Government	8

4.2.1. Policy goals

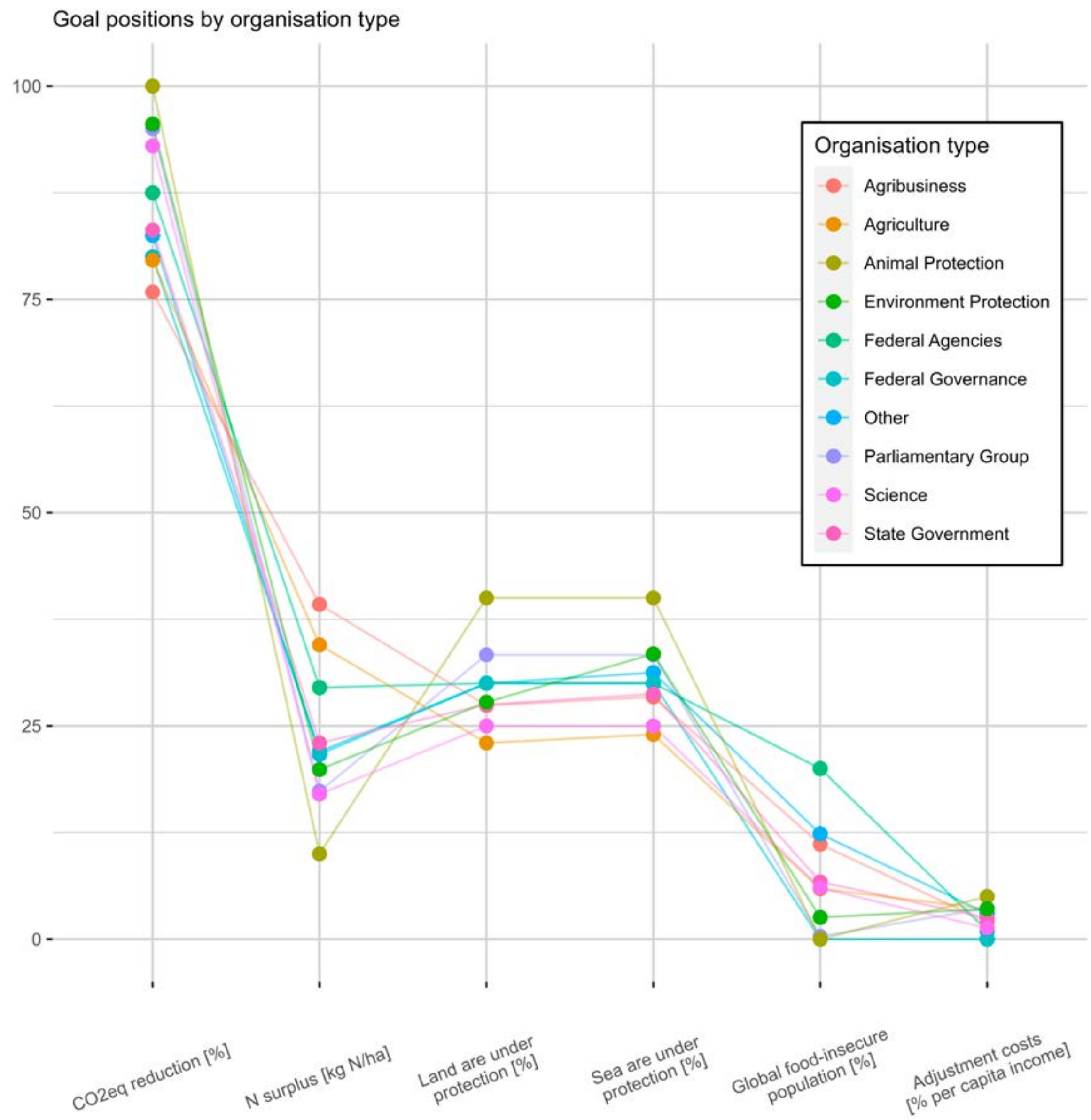
As can be seen from table 5 a clear ranking of policy goals can be found for the different stakeholder groups. In particular, environmental organizations rank ecosystem services, especially reduction of GHG-emissions high with a total relative importance of 90.9% compared to only 9.1% for economic welfare. However, agricultural producer as well as interests groups of agribusiness industry put a relative higher importance on economic welfare with 26% and 19.4%, respectively. Regional and national government organizations also tend to favor environmental goals when compared to economic welfare with relative importance of 11.7% and 14.0%, respectively. Within environmental goals federal government puts a clear focus on biodiversity with a relative importance of 38.3%, while state governments are more balanced between biodiversity and GHG-emission reductions. Parliamentary groups put a comparatively high importance on food security followed by GHG-emissions. This pattern can also be observed for animal welfare organizations, while environmental organizations rank GHG-emission cuts before biodiversity and put rather low importance on food security. Agricultural producer and agribusiness organizations put more or less equal importance on all three ecosystem services, i.e. GHG-emissions, biodiversity and N-surplus, while science puts clear focus on GHG-emission cuts with a relative importance of 40%.

Table 5 – Relative Importance of policy goals across stakeholder groups

Stakeholder group	GHG	Nsurplus	Biodiversity	Food security	Economic welfare
Federal Governance	18,3%	18,3%	38,3%	13,3%	11,7%
State Government	27,4%	16,9%	24,0%	17,8%	14,0%
Parliamentary Group	26,4%	16,9%	17,7%	28,6%	10,3%
Agribusiness	22,8%	18,4%	16,5%	15,6%	26,8%
Agriculture	23,2%	20,0%	22,1%	15,4%	19,4%
Animal Protection	35,0%	15,0%	15,0%	30,0%	5,0%
Environment Protection	33,9%	16,4%	27,8%	12,8%	9,1%
Science	40,0%	12,0%	19,0%	16,0%	13,0%
Other	21,0%	15,0%	21,4%	22,0%	20,6%
Total	27,2%	17,0%	22,5%	17,4%	15,9%

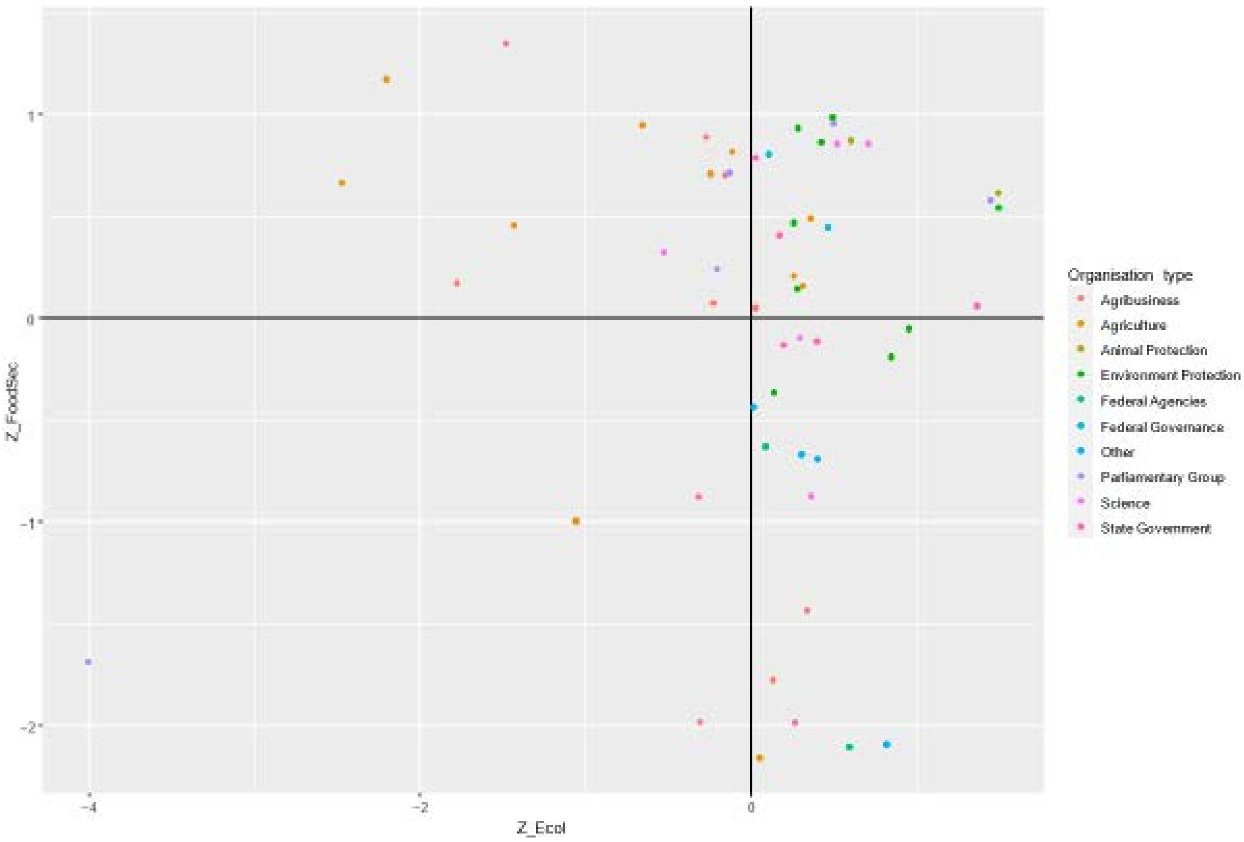
Beyond relative importance of different policy goals we also asked stakeholders for their desired goal achievements using different performance indicators. As can be seen from figure 26 stakeholders are rather ambitious regarding GHG-emission, where average achievement levels vary from a reduction of 75% to 100% of total GHG-emissions of agriculture for different stakeholder groups. Most ambitious are animal welfare as well as environmental organizations, while regional governments (Landesregierungen) as well as agricultural producers and agribusiness are less ambitious envisaging a reduction level of 75%-80%. In contrast, envisaged achievement levels are far less ambitious for reduction of nitrogen surplus, where reduction levels ranging between 10% to 43% are envisaged. Interestingly, regarding reduction levels for nitrogen surplus the lowest envisaged achievement levels can be observed for environmental and animal welfare organizations, while the highest levels are observed for agricultural producer and agribusiness organizations. Regarding biodiversity two performance indicators have been used, i.e. the share of land area as well as the share of maritime area under conservation programs. Here achievement levels range between 23%-40%, where especially environmental and animal welfare organizations are relatively ambitious with levels of close to 40% compared to an achievement level of 30% formulated by the EU-Commission. Additionally, we asked stakeholders to report their realistically envisaged achievements regarding food security, where the share of total population under severe or moderate food insecurity was used as performance indicator. As can be seen from figure 26 achievement levels range between 0% and 23%. Given a current share of 26% living in food insecurity stakeholders are moderately ambitious with an average food insecurity level of 12% reached within the next ten years.

Figure 26 – Goal achievements by stakeholder group



Based on reported goal achievement levels we conducted a factor and a cluster analysis to identify different stakeholder clusters characterized by a specific goal achievement pattern. The result of these analyses is summarized in figure 27.

Figure 27 – Policy goal factors



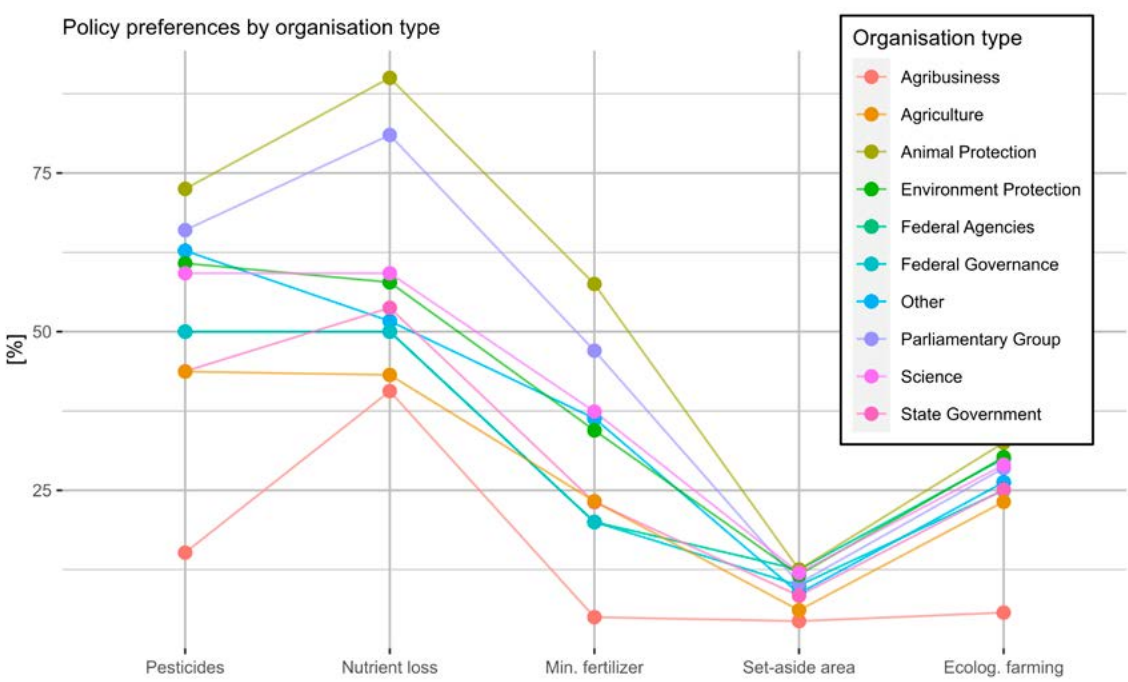
As can be nicely seen from figure 27 two clusters can be distinguished. A first stakeholder cluster located in the upper left orthant. This cluster includes most agriculture and agribusiness interest groups and clearly formulates high achievement levels for global food security, i.e. the EU F2Fstrategy should be formulated in a way that guarantees that EU-agriculture significantly contributes to reduce global food security via suficient EU-food supply for the world population. In contrast, regarding sustainability desired achievement levels are much more moderate. In contrast, the second cluster clearly formulates ambitious achievement levels for ecosystem services and hence is located in the right orthants. However, regarding food security the second cluster is ambivalent, some formulate ambitious achievements also for food security and hence are located in the upper right orthant, while others are more moderate with regard to food security and hence can be found in the lower right orthant. As was expected, most environmental organizations can be found in cluster 2. Interestingly, institutions of federal as well as state government can be found in both clusters.

4.2.2. Policy positions

Average preferred policy positions as reported by interviewed stakeholders are shown for stakeholder groups in figure 28. A first clear observation from figure 28 is that agribusiness as well as agricultural producer organizations prefer the lowest regulation levels when compared to all other stakeholder groups. In detail, especially agribusiness prefers a comparatively low reduction of pesticide as well as mineral fertilizer use by only 20% and 10%, respectively. Analogously, obligatory shares of set-aside area and organic farming are also rather low with levels around 5% for agribusiness organizations, while reduction of N-surplus is 40%. Compared to agribusiness, agricultural producer prefer higher input and output restrictions, i.e. a reduction of pesticide use by 45%, of mineral fertilizer use by 23% and a minimum share of organic farming of 23%. Highest policy intervention levels for input restrictions as well as increase of organic farming and ecological set-aside area can be observed for animal welfare organizations followed by parliamentary groups (especially the Green party) and environmental groups with reductions ranging between 61%-73% for pesticides and between 34%-58% for mineral fertilizer, while preferred shares of organic farming range between 29%-33% and for set-aside between 12%-13%.

Parliamentary groups prefer high input restrictions as well as high shares of organic farming and set-aside area, respectively, while national and regional governments reveal policy preferences which mainly correspond to the F2F-strategy of the EU Commission.

Figure 28 – Preferred Policy Positions by stakeholder group



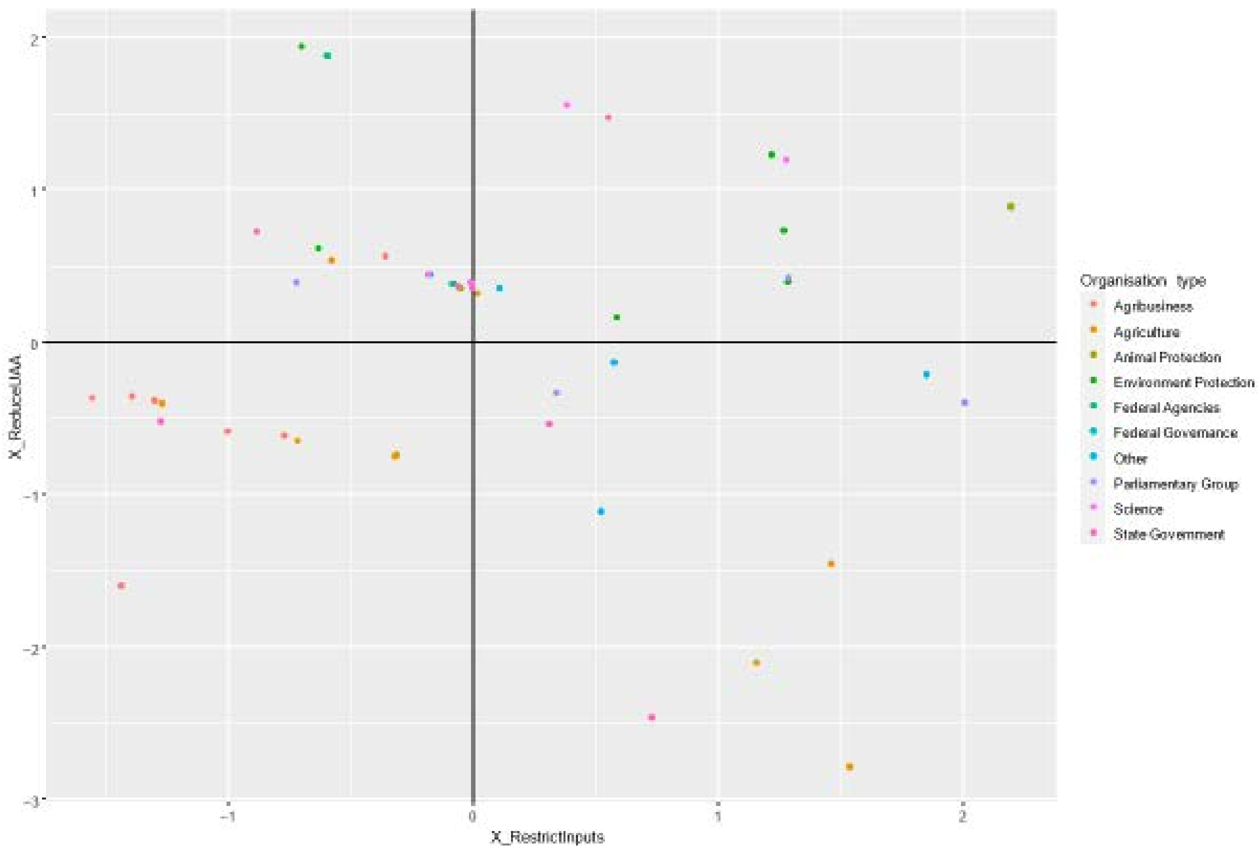
Applying factor and cluster analyses we could identify two main clusters that prefer policy positions that significantly differ from the original F2F-strategy. For a first cluster preferred policy positions correspond to a soft F2F-strategy, that is the pattern of preferred policy positions corresponds to the original F2F-strategy as suggested by the EU-Commission, but the scale of policy interventions is much lower when compared to the original Commission proposal. Basically, the narrative behind the F2F-soft strategy can be interpreted as the belief that already moderate F2F-interventions will be sufficient to trigger innovative technological progress in the farm sector that enables a sustainable agricultural production combining current productivity levels with high standards of ecosystem services.

A second narrative determining stakeholder's policy positions corresponds to ecological farming. Following this narrative stakeholders believe that organic farming is the global solution for sustainable land use. Accordingly, this narrative corresponds to preferred policy positions imposing a complete reduction of chemical inputs, i.e. pesticides and mineral fertilizer, as well as a significant increase of the share of organic farming as well as ecological set-aside area, while other measures are more or less neglected.

Again we conducted a factor and cluster analysis to identify the two different policy clusters and narratives. The results of these analyses are summarized in figure 29.

In detail, agribusiness as well as agricultural producers basically prefer a soft-F2F-strategy, e.g. these groups are located in the lower left orthant, i.e. preferring low input restrictions and low land use restrictions in comparison to the original F2F-strategy of the Commission, while organizations in the upper right orthant prefer an eco-F2F-strategy, i.e. high input restrictions and high shares of ecological set-aside area. Mainly, environmental protection organizations as well as animal protection groups prefer a eco-F2-strategy, see figure 29. However, what can be also seen from figure 29 is that many organizations, especially governmental organizations, also prefer policy positions corresponding to the original F2F-strategy, i.e. these are located close to the origin of the policy space in figure 29.

Figure 29 – Policy narratives



Detailed policy positions corresponding to the F2F-soft and F2F-eco strategy are reported in table 6. As can been seen from table 6 both strategies correspond to significantly different levels for different F2F-measures when compared to the derived optimal F2F-strategy. Moreover, based on their narratives both, the F2F-soft cluster as well as F2F-eco cluster, respectively, do not include a significant pricing of GHG-emissions. Table 6 shows detailed policy positions the four policy strategies derived above: F2F, the original proposal of the European Commission, F2F_optimal, the optimal policy mix derived from social welfare maximization, as well as F2F_soft and F2F_eco, respectively, both derived from our stakeholder survey.

Given the fact that based on our empirical survey data the two narratives, F2F-soft and F2F-eco as well as the original F2F-strategy suggested by the EU-commission obviously dominate formation of policy preferences of real policy actors, i.e. German governmental and non-governmental stakeholders, it appears reasonable to assume that these narratives will also dominate formation of policy preferences of relevant stakeholders in other EU-member states. This assumption implies that expected policy outcomes at EU-level will be more of a compromise between the F2F-eco, the F2F-soft and the original F2F-strategy, while the optimal F2F-strategy will not be a realistic policy outcome.

Table 6 – Scenarios

	F2F	F2F_optimal	F2F_soft	F2F_eco
fertilizer [%]	20	0	0	30
pesticide [%]	50	75	20	75
nutrient loss [%]	50	75	20	0
organic [%]	25	0	0	37.5
national [%]	10	0	5	15
CO_2eq price [USD/t]	0	292.565	50	0

Therefore, the question is how efficient these politically feasible F2F-strategies will be, i.e. how high will be welfare losses implementing these strategies when compared to an optimal F2F-strategy.

This will be analyzed in the next section.

5. Comparing economic and ecological impacts of different F2F-policy options

5.1. Impact on Ecosystem services

As shown in figure 30, F2F_opt leads to significantly highest ecosystem services when compared to the original Commission proposal. In particular, the decrease of GHG-emissions corresponds to over 60% of the current level compared to a reduction of only 29% induced by the original F2F-strategy. For the two strategies preferred by stakeholders even lower GHG-emission cuts below 20% could be expected. Analogously, reduction of Nitrogen surplus would be significantly higher under the optimal F2F-strategy amounting to roughly 80%, while the original F2F-strategy would only imply a reduction of 50%, while N-surplus would be only reduced by less than 20% under the F2F-soft and F2F-eco strategy, respectively. Although for biodiversity a similar picture can be observed, difference in achievement level are less pronounced between strategies [2].

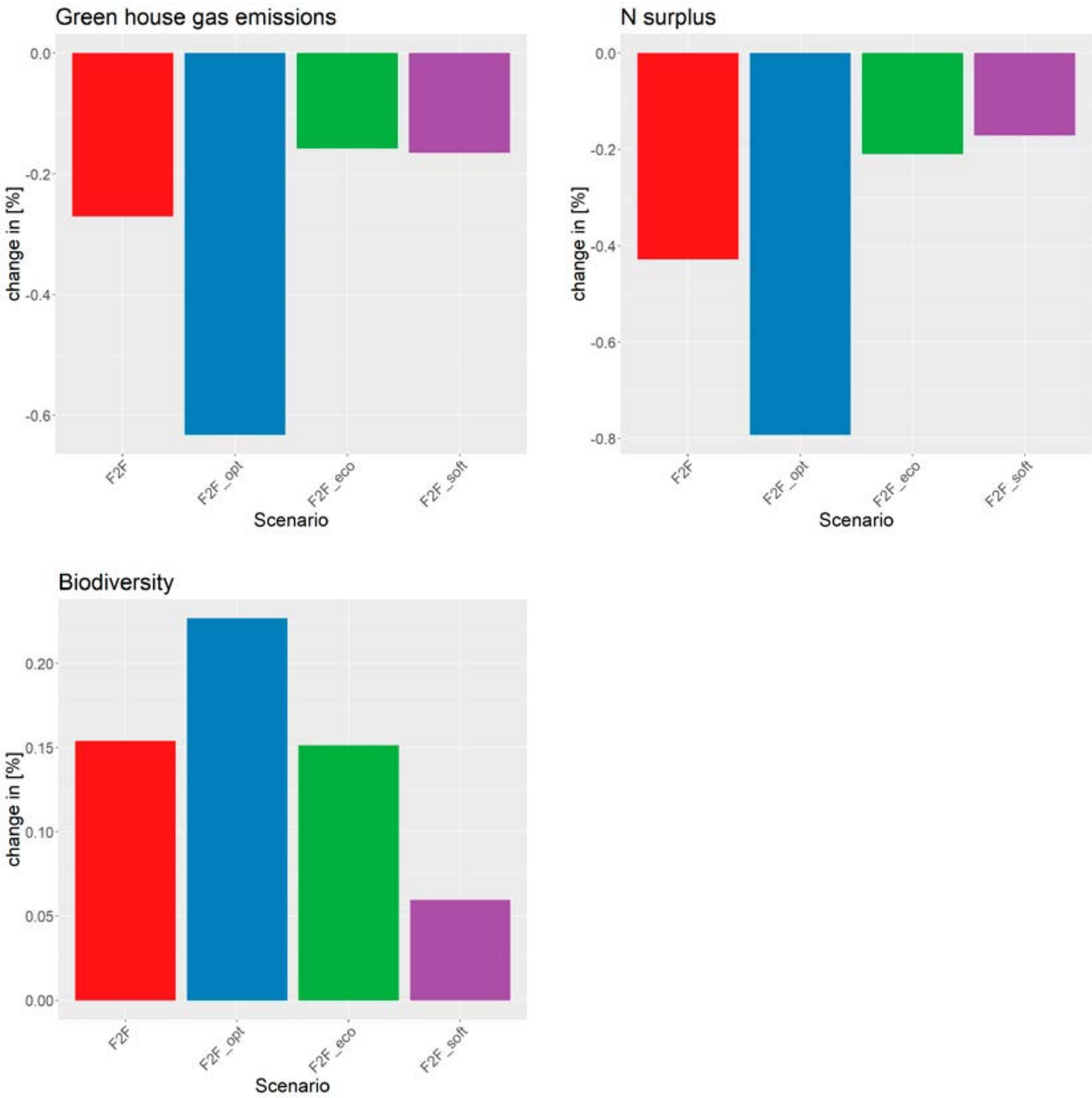
5.2. Welfare impacts

For a complete evaluation of different strategies also the cost of induced higher ecosystem services, e.g. reduction in total economic welfare, have to be considered. Corresponding welfare effects resulting under the different F2F-strategies are reported in figure 31. As can be seen from figure 31 optimal F2F-strategy leads to highest welfare losses, while the F2F-proposal as well as the two F2Fstrategies derived from stakeholder narratives imply far lower welfare costs. In detail, the optimal F2F-strategies imply total welfare losses amounting to 0.5% of per capita income compared to less than 0.3% implied by the original proposal of the commission, while the F2F-soft strategy would imply only minimal welfare losses of less than 0.05% of per-capita income. For the F2F-eco strategy welfare losses are second highest amounting to almost 0.4% of per capita income.

2 Please note also that measurement of biodiversity is rather weak within the CAPRI-model. Thus results have to be interpreted with caution.

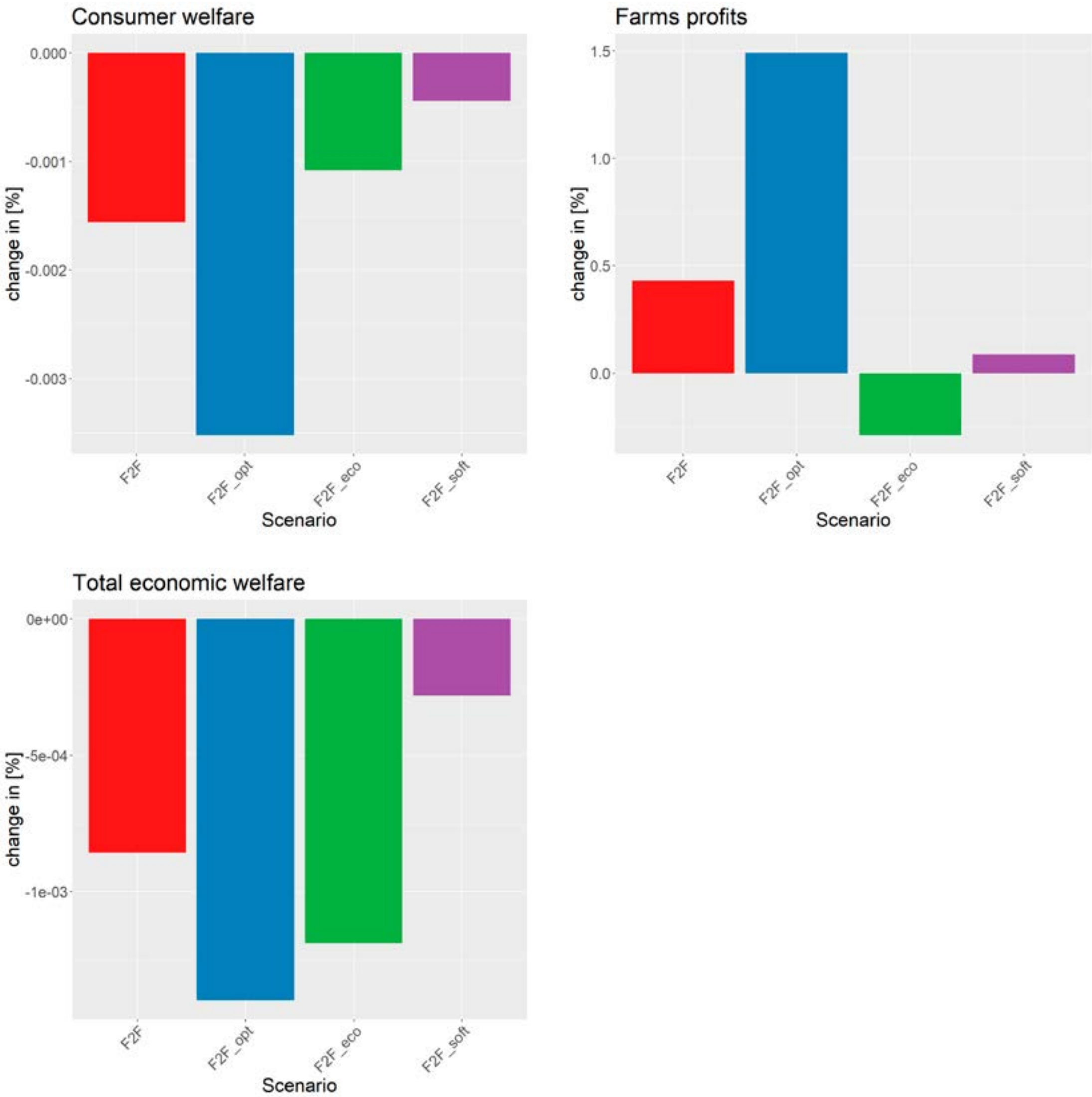
Interestingly, looking on welfare of specific social groups consumers bear the total economic costs of increased ecosystem services, while farmers even make a higher profit. In detail, farm profits increase by 35 billion Euro or 216 Euro/ha for the F2F-strategy of the Commission, while farm profits increase by 131 billion Euro or 810 Euro/ha under the optimal F2F-strategy, but only by 4.4 billion Euro or 27 Euro/ha under the Eco-soft strategy.

Figure 30 – Impact on EU27: Ecosystem Services



Farm profits would even decrease under the implementation of the F2F-eco strategy. The later basically results form the fact that increasing organic farming to almost 40% implies strong reductions in agricultural production which are not fully compensated by induced increases of farm gate prices. Consumer welfare measured as real income loss (measured in payment power) amounts -70 billion Euro or -157 Euro per capita for the original F2F strategy, while real income losses of consumers are even higher under the optimal F2F-strategy amounting -153 billion Euro or -344 Euro per capita. For the F2F-eco as well as F2F-soft strategies consumer losses are comparatively lower -44 billion Euro (-98 Euro per capita) and -14 billion Euro (31 Euro per capita), respectively.

Figure 31 – Impact on EU27: Welfare



However, comparing overall net-benefits resulting from different strategies willingness-to-pay for ecosystem services have to be taken into account.

In table 7 net-benefit resulting from the implementation of the Green Deal in agriculture resulting under the different F2F-strategies is reported.

As can be seen for all strategies a net-benefit result for all four F2F-strategies. However, total netbenefits realized by EU-society vary significantly across strategies, where net-benefits are significantly lower for all F2F-strategies when compared to net-benefits realized under the optimal strategy. In detail, the net-benefit of total society corresponds to 219 billion Euro or 491 Euro per capita under the optimal F2F-scenario compared to only 93 billion Euro or 211 Euro per capita, thus only 43% of the net-benefit realized under the optimal strategy. However, following narratives determining preferred policy positions of the majority of German stakeholders net-benefits derived from the implementation of the Green Deal would be much lower, i.e. only 42 bill (42 Euro per capita) under the F2F-eco strategy and only 56 bill Euros (126 Euro per capita) under the F2F-soft strategy.

Table 7 – Benefits and Cost of Green Deal under different F2F-Strategies

F2F-Strategy		F2F-optimal	F2F-Com	F2F-eco	F2F-soft
Benefits			**in bill Euro**		
Eco-system services	GHG	88	40	21	25
	N-surplus	98	61	25	22
	Biodiversity	74	49	49	19
	Total	261	150	94	67
Costs			**in bill Euro**		
	Consumer	-153	-70	-44	-14
	Farmer	131	35	-16	4
	Total	-42	-56	-52	-11
Net-benefit			**in Euro per capita**		
	Consumer	235	178	111	118
	Farmer	17631	4883	-1834	718
	Total	491	211	94	126

Interestingly, implementation of the Green Deal in agriculture is a win-win-situation, where both consumers as well as farmers realize a net-benefit. However, the amount of net-benefit depends on the specific strategy b< which the Green Deal is implemented. It is worth mentioning that for both groups, consumers as well as farmers, the optimal F2F-strategy leads to the highest net-benefit, although per capita-benefits are rather different for both groups, with a net benefit of almost 18,000 Euros per capita for farmers and a net-benefit of 491 Euros per capita for consumers. For F2F-soft, per capita net-benefits are significantly smaller with only 118 Euro per capita for consumers and only 718 Euros per capita for farmers. For the F2F-eco-strategy farmers would even realize a netloss of -1834 Euros per capita, while consumers would realize a net-benefit of only 111 Euros per capita. These figures show how biased policies derived from popular narratives can be, where most farm and agribusiness organizations follow a narrative preferring a F2F-soft strategy avoiding a strict increase in sustainable land use, while exactly the latter would boost their net-benefits. Vice-versa environmental and animal health organizations arm-in-arm with ecological farming organizations claiming to represent especially consumer and farmer interests favor a F2F-eco strategy focusing on organic farming avoiding industrial inputs, while consumers could realize an almost four times higher net-benefit under smart policy set-up promoting efficient sustainable land use. Please note that farmers would even realize a loss of almost 2000 Euros per capita compared to potential net-gain of almost 18,000 Euros per capita.

These figures clearly demonstrate the tragedy of biased policy beliefs: following simple, but popular narratives often makes efficient policies politically infeasible, while policies corresponding to these narratives are politically feasible, but rather inefficient.

6. F2F-impacts from an international perspective with special reference to Brazil

6.1. Brazilian Economic and Agricultural Overview

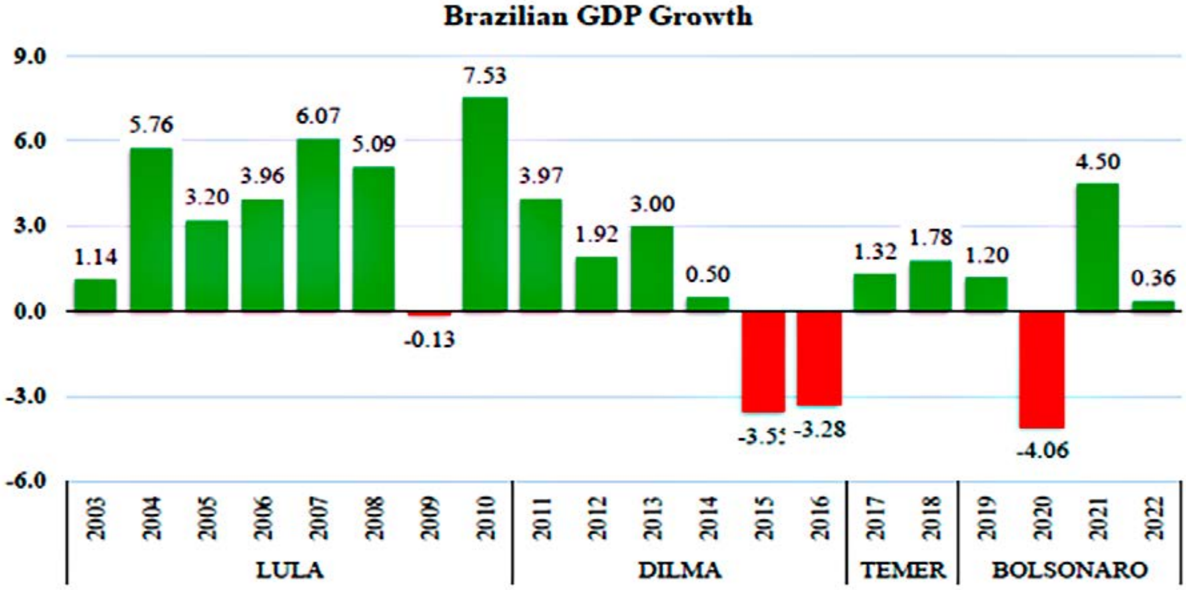
Brazil is the largest country of the world in terms of agricultural land and a major producer and exporter of most agricultural commodities. Moreover, agriculture is a very important sector for the Brazilian economy. Accordingly, Brazilian agriculture and also total economy is impacted by EU Green Deal reforms via international markets. Therefore, we briefly describe economic and ecological structure and development of Brazilian agriculture in the following[3].

6.1.1. Major Macroeconomic Indicators

Brazil ranks among the top 12 largest economies in the world. Brazil's gross domestic product (GDP) is estimated at US$1.65 trillion in 2021, resulting in US$7,760 per capita income. After experiencing years of high growth rates in the first decade of the 2000s, the Brazilian economy slowed down, reaching a recession in 2015 and 2016. After the economic recovery between 20172019, the COVID-19 pandemic in 2020 brought new challenges for Brazil. The GDP growth for 2021 is estimated at 4.5 percent; however, the forecast for 2022 is modest due to the ongoing pandemic challenges and the volatile political climate as a result of the presidential elections in October 2022. Figure 32 shows the evolution of the Brazilian GDP since 2003 associated with the different Brazilian presidential administrations, followed by a table with major Brazilian macroeconomic indicators.

3 These descriptions mainly follow Barros, 2022.

Figure 32 – Macro-Economic Development in Brazil



Source: IBE (Brazilian Institute of Geography and Statistics). 2021 = estimate, 2022 = forecast

6.1.2. Agriculture

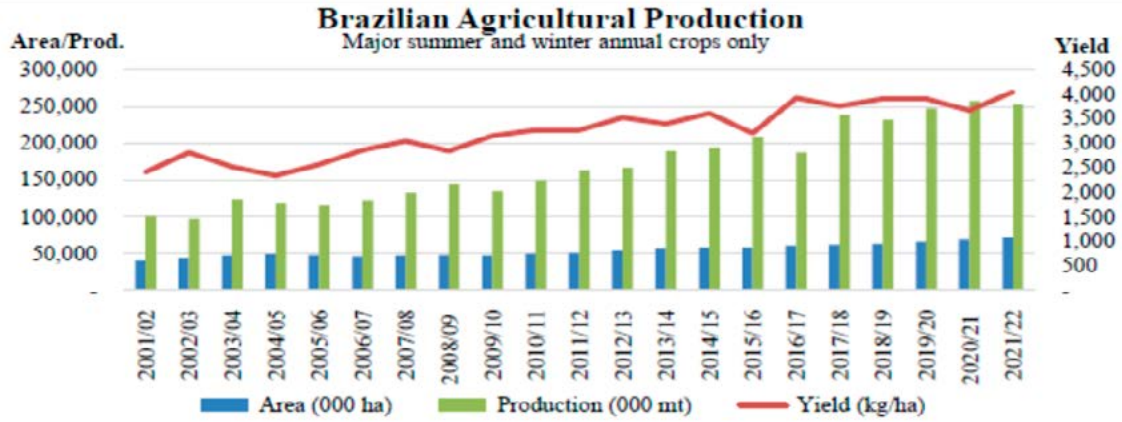
Agriculture is an important sector of the Brazilian economy and is crucial to economic growth and foreign exchange earnings. In 2020, the agribusiness sector (including production, processing, and distribution) accounted for almost 27 percent of Brazil's GDP. Moreover, in 2021, agribusiness represented 43 percent of Brazil's total exports but only 7 percent of total imports. The table 8 below illustrates the Brazilian Foreign Trade in recent years.

Table 8 – Brazilian Macroeconomic Indicators

	2018	2019	2020	2021	2022/f
Ag Contribution to GDP	20.11%	20.51%	26.57%	N/A	N/A
Inflation (IPCA Index)	3.75%	4.31%	4.52%	10.06%	5.03%
Avg Exchange Rate (R$/US$)	3.66	3.95	5.16	5.40	5.60
Central Bank Prime Interest	6.40%	4.40%	1.90%	9.25%	11.75%

Source: IBGE (Brazilian Institute of Geography and Statistics), ESALQ/CEPEA (Agricultural School "Luiz de Queiroz"/Center for Advanced Studies on Applied Economics), BACEN (Brazilian Central Bank). f/forecast.

Figure 33 – Agricultural Production Development in Brazil



Source: MAPA/CONAB (Ministry of Agriculture, Livestock and Supply/National Supply Company

Agricultural Production

Brazil has invested heavily in agricultural research and technology since the early seventies with the foundation of the Brazilian Agricultural Research Enterprise (EMBRAPA). Spurred by overall high commodity prices, improved crop management, high-quality seeds, and biotechnology advances, the country reached significant increases in production without greatly expanding land used. As reported by Brazilian offcial sources, grain yields increased roughly by 50 percent over the past 20 years. Moreover, a large portion of Brazil's planted area can produce two crops per year due to favorable climate conditions. The graph below shows the evolution of Brazilian agricultural production for major summer and winter annual crops. As a leading producer and exporter of agricultural products, Brazil is one of the few countries well placed to lead global food security efforts. Brazil ranks as the number one worldwide producer for soybeans, sugar, coffee, and frozen concentrated orange juice (FCOJ). Brazil is second-largest producer of beef and chicken products and third-largest producer of corn and pork products. table 9 below shows Brazil's production and export figures for major commodities as well as the share in total world production.

Table 9 – Agriculture Production and Trade Structures of Brazil

Brazilian Production and Export Figures for Major Commodities for MY 2021/22					
Commodity	Rank in Production		Rank in Exports		Brazil/World Prod.
Sugar	1	36 MMT	1	26 MMT	20%
FCOJ (65 Brix eq.)	1	967,000 MT	1	1.0 MMT	57%
Coffee	1	56.30 MBags	1	33.22 MBags	34%
Soybeans	1	144 MMT	1	94 MMT	38%
Beef	2	9.70 MMT CWE CWE	1	2.65 MMT CWE	17%
Chicken	2	14.72 MMT	1	4.18 MMT	15%
Corn	3	118 MMT	2	43 MMT	10%
Pork	3	4.45 MMT CWE	3	1.38 MMT CWE	4%
Cotton	4	13.20 MMT	2	8.30 MMT	11%

Source: USDA/PSD Online (updated in December 2021). Note: MMT = million metric tons, CWE = Carcass Weigh Equivalent

Land Use

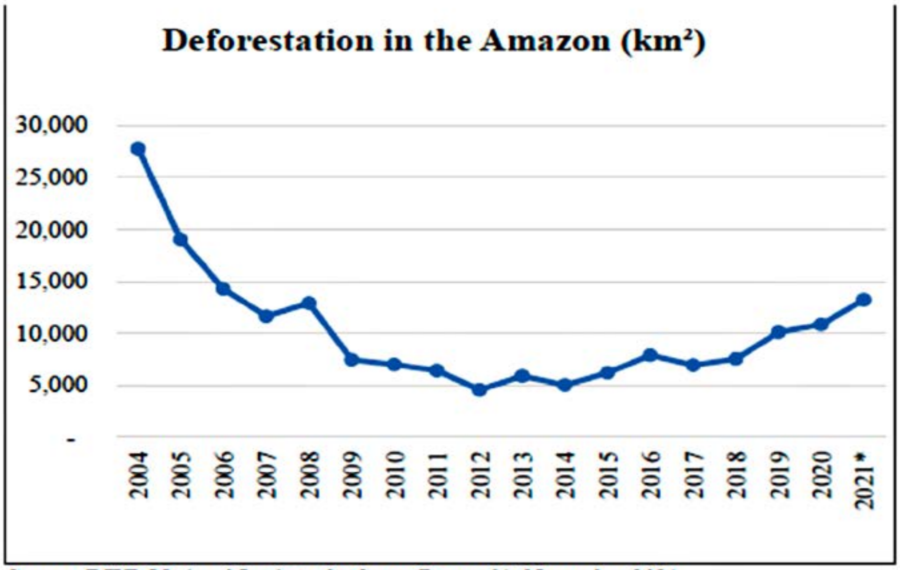
Brazil has a total area of 851 million hectares. Approximately 85 million hectares are in crop production (annual, perennial crops, and planted forests) and roughly 180 million in pasture (both native and managed). Other areas, including native forests, indigenous reservations, national reserves, protected areas, and national parks, account for approximately 556 million hectares. Urban areas represent roughly 3.5 percent of the Brazilian territory.

GHG-emissions

In 2021 at the Conference of Parties (COP26), Brazil reconfirmed its commitment made in 2015 to reduce domestic emissions of greenhouse gases (GHG), announcing a 50 percent reduction by 2030 based on 2005 levels. Brazil also reported that the country's Nationally Determined Contribution (NDC) is compatible with an indicative long-term objective of reaching climate neutrality in 2050. The Brazilian Government has implemented several initiatives to mitigate climate change, such as implementing the National Biofuel Policy (RenovaBio) and enhanced funds to finance the Greenhouse Gases Emission Reduction Program Plan (Plano ABC) which support sustainable agricultural practices.

However, the deforestation of natural forests, notably in the legal amazon, has posed a gigantic issue for the country in recent years. Figure 34 below shows the deforestation rate in the region since 2004. Deforestation has quickly increased since 2018 after a 10-year period of low and stable rates as measured by the Brazilian National Institute for Space Research (INPE).

Figure 34 – Agriculture Production and Trade Structures of Brazil

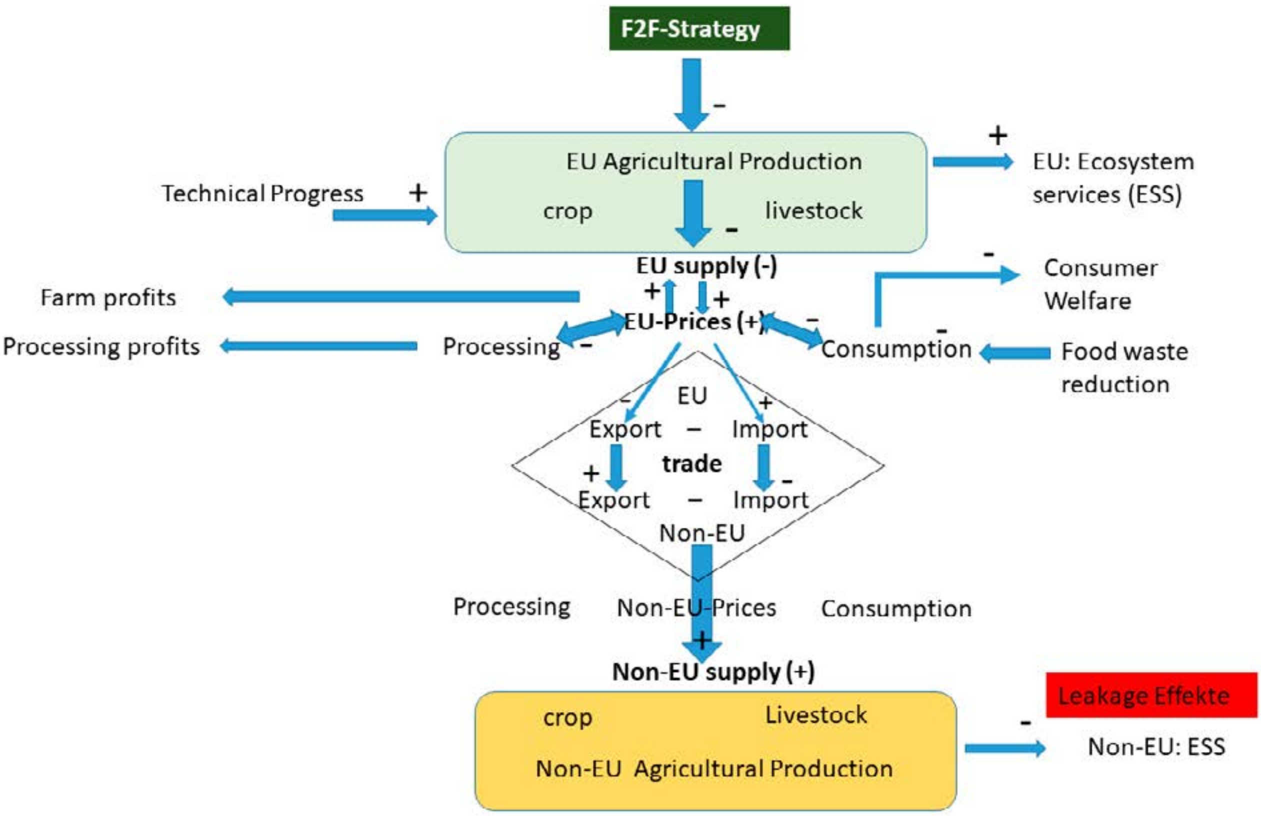


Source: INPE (National Institute for Space Research). November 2021.

6.2. Impact of EU-Green Deal on Brazilian agriculture

Based on the intervention logic described in figure 35 it follows quite plainly that implementation of the Green Deal in EU-agriculture impacts on non-EU countries via trade-effects. In detail, depending on the specific implementation strategy the Green Deal implies a reduction of domestic supply of agricultural commodities. Reduced domestic supply induces an increase in domestic prices for agricultural goods, which c.p. induces an increase in agricultural net-imports, i.e. a decrease in EU-exports to other countries and an increase of imports from non-EU countries into the EU. The change in net-exports induces an increase of agricultural prices on international markets. The latter triggers a higher agricultural production in non-EU countries and c.p. an increase in domestic prices in non-EU countries. Increased domestic prices in non-EU-countries have a negative impact on domestic demand in these countries, while increase in domestic prices triggers domestic agricultural production in non-EU countries. Accordingly, higher agricultural prices increase intensification as well as land use change towards agricultural production in non-EU countries, where the latter is related to higher GHG-emissions as well as higher fertilizer and pesticide use, which both have negative impacts on ecosystem services, i.e. decrease biodiversity, increase GHG-emission and nitrogen pollution.

Figure 35 – Understanding international impacts of the F2F-strategy



However, in quantitative terms the overall effect depends on the specific implementation strategy, i.e. the specific mix of different F2F-measures. To analyze the specific effect of different F2F-measures we applied again metamodeling techniques to identify effects of specific F2F-measures on international prices based on simulation runs of the CAPRI model.

Main results of metamodeling applications are summarized in figures 36 to 41. In particular, these figures show how the international and domestic prices for beef, cereals, oilseeds and, vegetables and permanent crops change in response to implementation of individual F2F-measures. As can be seen from these figures we show domestic price effects on the EU market as well as international price changes on the world as well as South American market and also on domestic market price changes resulting for different agricultural commodities in Brazil.

A first observation from figures 36 to 41 is that the Green Deal implementation has a significantly higher impact on farm gate prices in the EU when compared to the impact on corresponding agricultural prices at international markets as well as domestic prices in Brazil. Moreover, a different pattern of induced price changes can be observed for livestock when compared to crop production. First, generally induced price effects are higher for animal than for crop products. For example, the price increase induced by the original F2F-strategy of the EU commission amounts to 58% for beef and 48% for pork and up to 35% for poultry, while crop prices only increase by roughly 20% with 20% for cereal and oilseeds and even only 12% for vegetable & fruits. In contrast, price effect on international markets are rather low when compared to EU-price effect ranging below 5% for most products. Comparing price effects of individual F2F-measures also a different patterns result for animal and crop products, respectively. While for animal products the largest price effects are induced by the F2F-measures 'reduction of N-surplus balance' followed by 'increase of ecological set-aside area', while 'reduction of pesticide' and 'mineral fertilizer' use as well as 'increase of organic farming' has a comparatively lower impact on livestock prices.

Interestingly, also pricing of GHG-emissions has a relatively low impact on livestock prices with the only exception of beef, for which price impact of GHG-emission pricing has a similar impact on output prices as set-aside. In contrast, for crop prices highest effects can be observed for the individual F2F-Measure 'ecological set-aside' (labeled 'national' in figures 36 to 41) followed by reduction of mineral fertilizer input (labeled 'fertilizer'), while all other individual F2F-measures have a comparatively low impact on prices at EU-level and especially at international level.

6.3. Impact of F2F-strategies on agricultural prices

In this section we analyze how different implementation strategies impact the agricultural prices realized on non-EU markets and especially how agricultural prices change in Brazil under the four scenarios (see table 6) defined above.

As can be seen from figures 42 to 45 compared to the original F2F-strategy the optimal F2F-strategy induced significantly higher increases in agricultural prices in Brazil as well as on average in South America and the world. However, compared to agricultural prices changes induced on EU-markets induced price increases in Brazil are still comparatively low ranging between 1% and 15%. Relative high price increases can be observed for livestock, especially beef, poultry and pork meat with price increases ranging between 6% (poultry) and over 15% for pork, while prices for beef take a middle ground with an increase of 11%. For milk products price increases are comparatively lower with 5%. For crops induced price changes are lower when compared to livestock products, where price increases an optimal F2F-strategy would induce in Brazil are rather low for oilseeds ranging below 1%, while the highest price effects can be found for cereals with an increase of 5% in Brazil. For vegetables & fruits induced price increases are also comparatively low with an increase of roughly 2%. Interestingly, basically the same pattern of price adjustments can be observed for South American as well as world markets. However, only prices for dairy products increase significantly higher on world markets, when compared to South American markets as well as domestic Brazilian markets. The latter follows from the fact that at least for dairy products the European Union has relatively low trade relations with South America and Brazil, respectively.

Very low price effects result for the F2F-soft strategy. This is logical given the fact that under this strategy all F2F-measures are implemented on a very low level. Hence, induced production restrictions are low and hence also induced price changes are low on all markets. Compared to the optimal F2F-strategy price effects are roughly one tenth of the corresponding price effects induced by implementing the optimal F2F-strategy.

Basically the same applies to the price effects derived under the F2F-eco strategy. However, under this strategy cereal prices would increase relatively much by 6% in Brazil.

An induced increase in the price of a specific agricultural commodity increases economic welfare of total Brazilian society as long as Brazil is a net-exporter for this commodity. Accordingly, given the fact that Brazil is a net-exporter for almost all agricultural products, especially the livestock products beef, poultry and pork as well as for many crop production, implies that implementation of the Green Deal in EU-agriculture implies an increase in total economic welfare. This increase is c.p. the higher the higher the induced price increases for agricultural products, for which Brazil is a net-exporter, e.g. beef, pork and poultry meat.

Figure 36 – Price impacts of individual F2F-measures: Beef

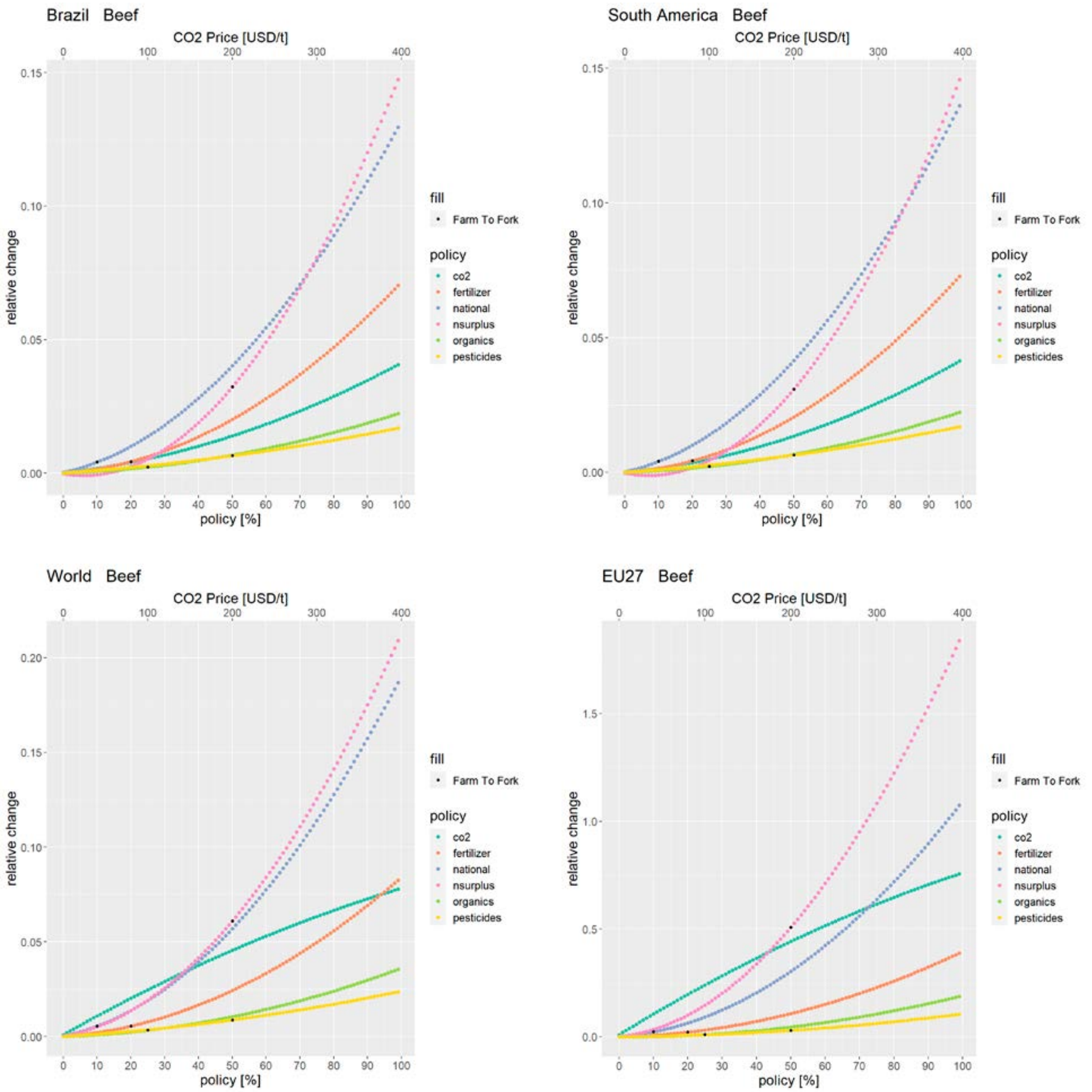


Figure 37 – Price impacts of individual F2F-measures: Poultry

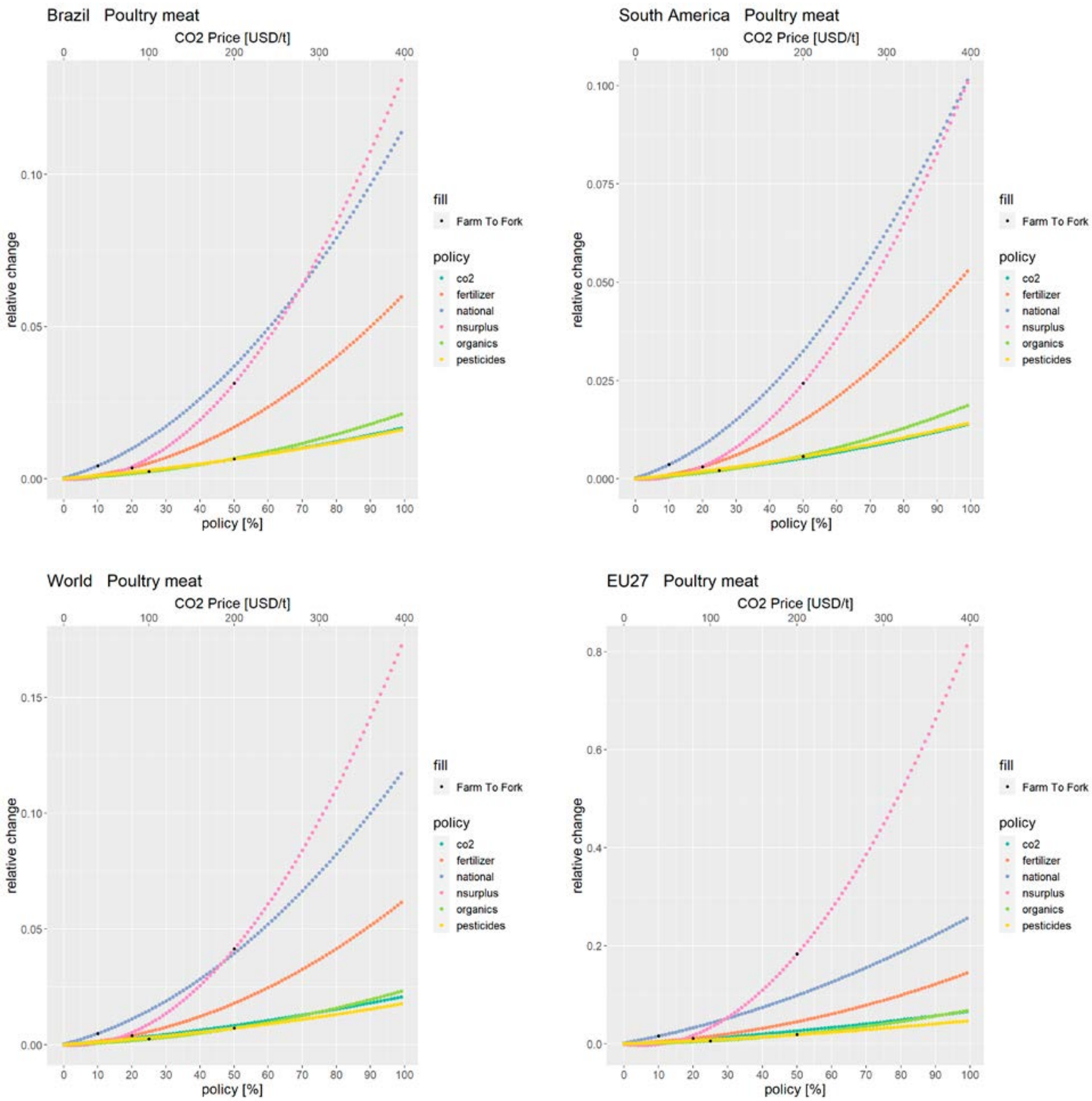


Figure 38 – Price impacts of individual F2F-measures: Pork

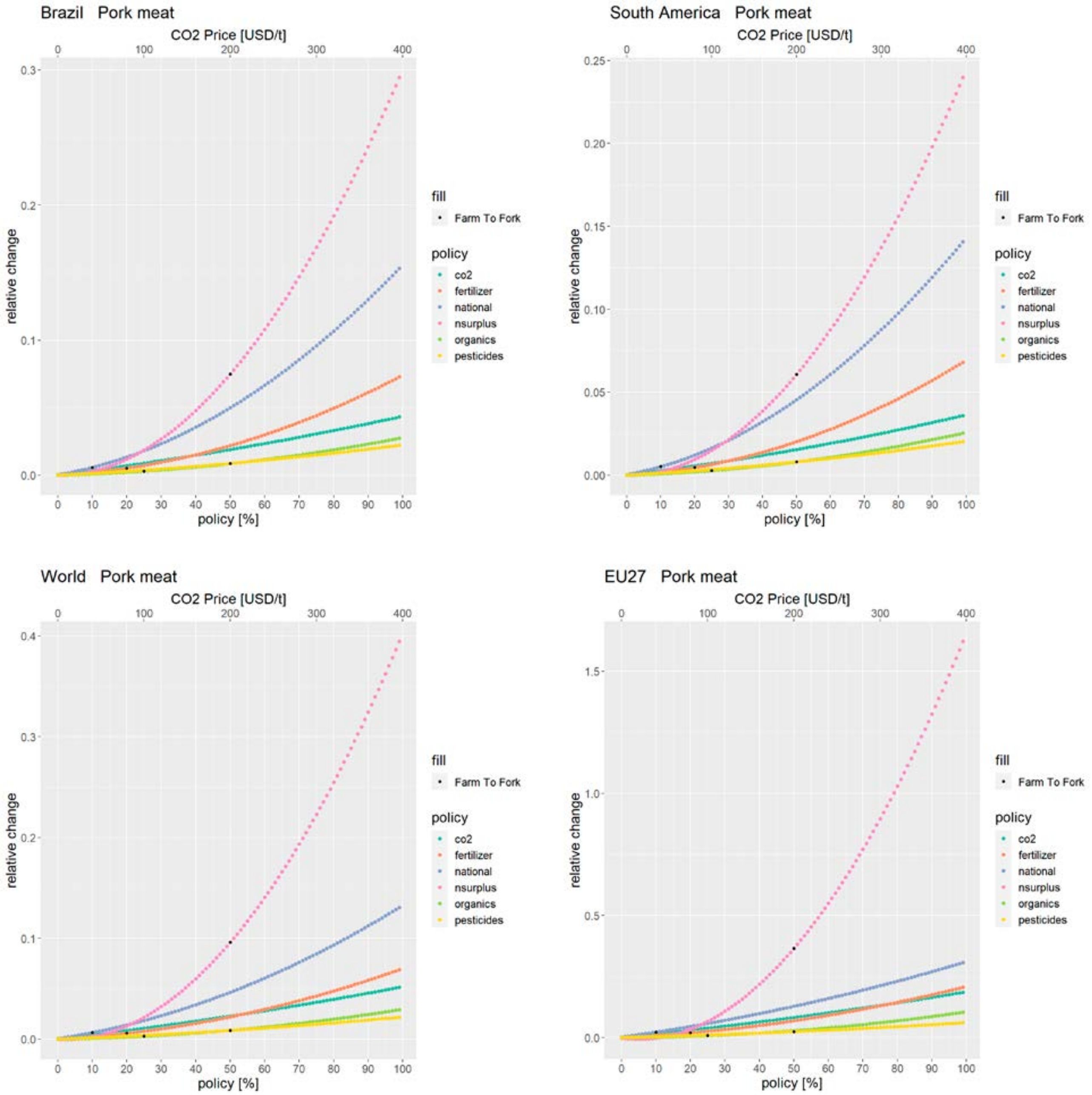


Figure 39 – Price impacts of individual F2F-measures: Oilseeds

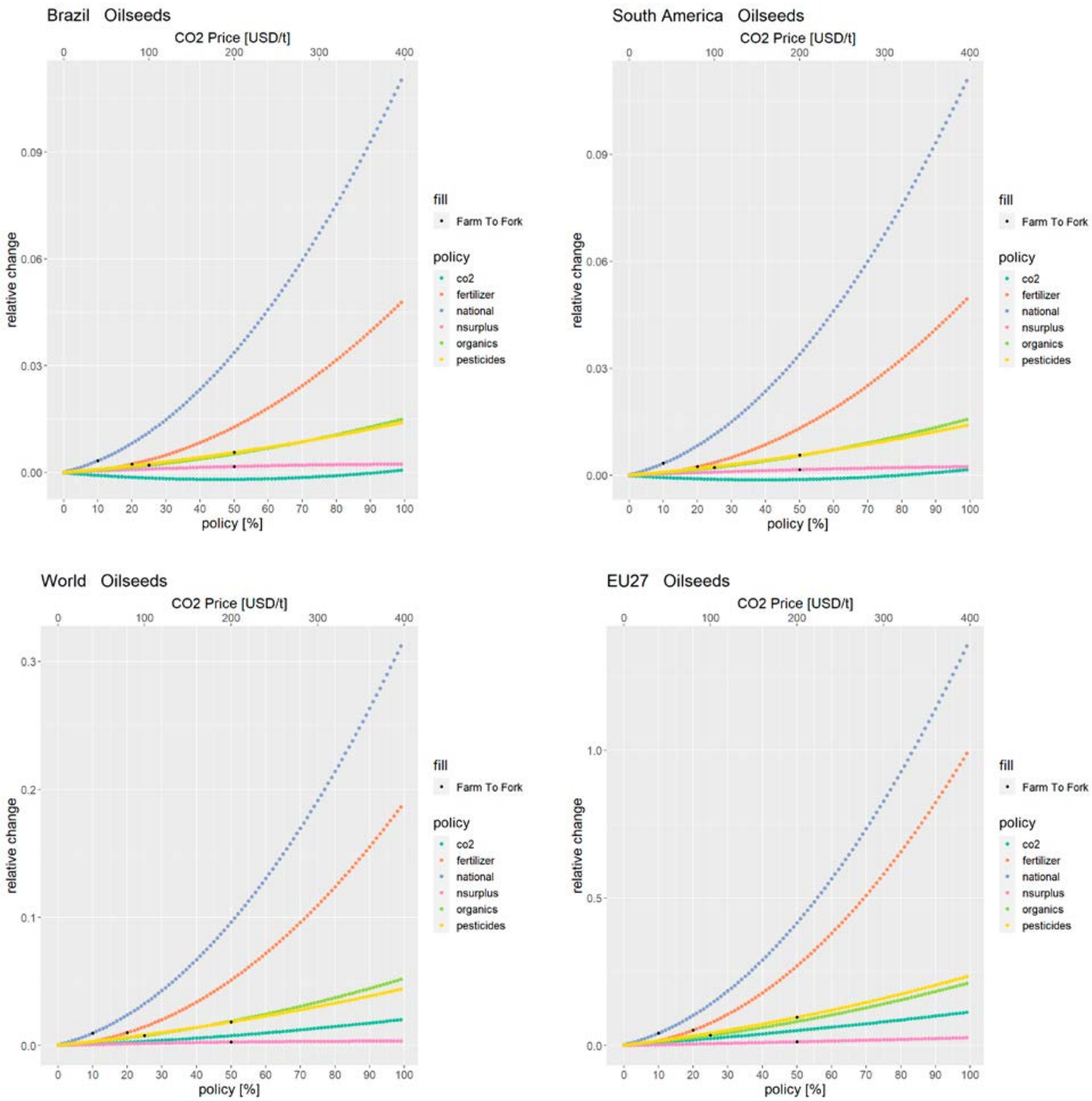


Figure 40 – Price impacts of individual F2F-measures: Cereals

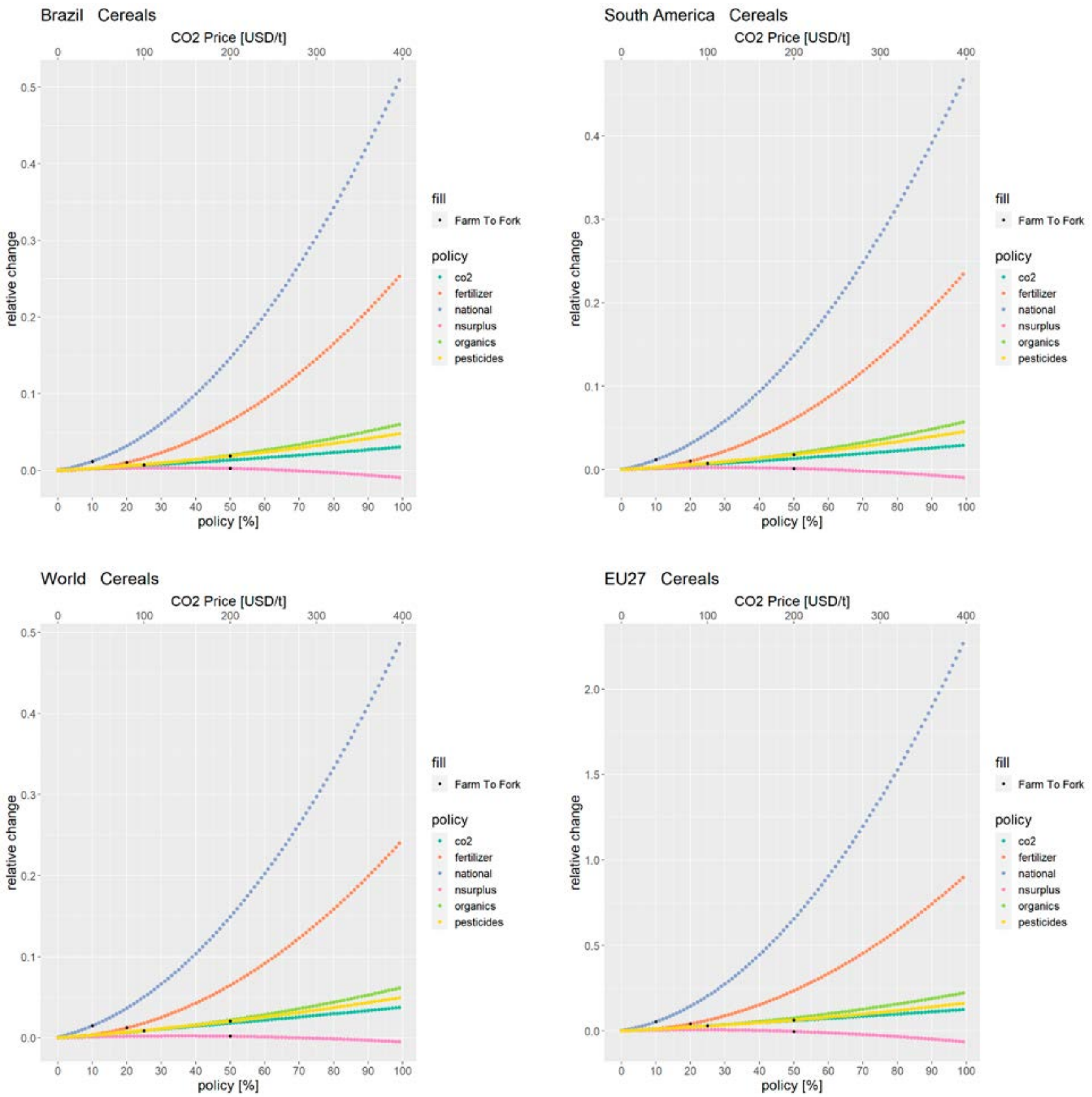
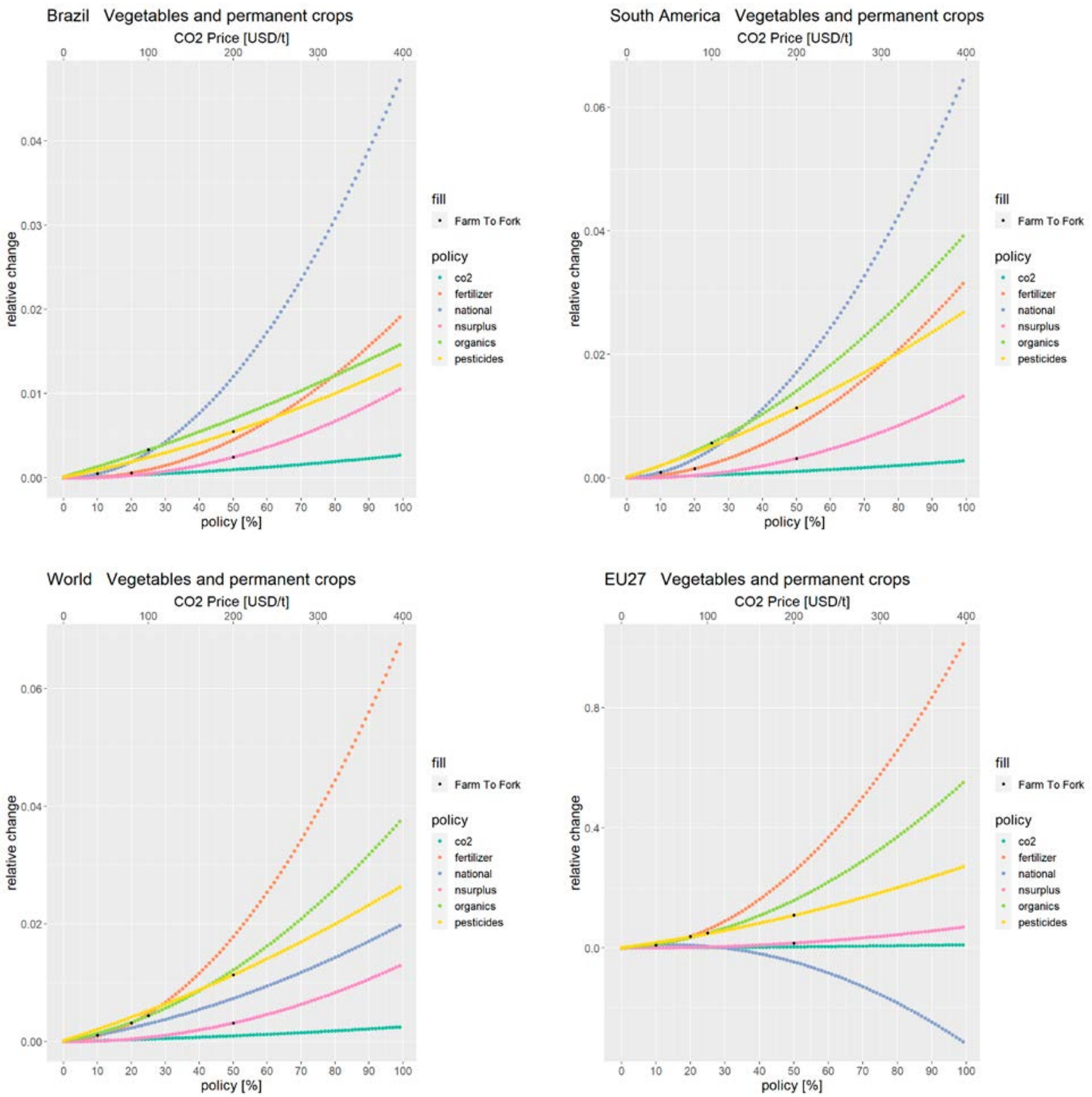


Figure 41 – Price impacts of individual F2F-measures: Vegetables and Permanent Crops



However, beyond economic spillover effects implementation of the Green Deal in EU-agriculture also implies spillover effects for ecosystem services. In particular, higher agricultural producer prices induce intensification of agricultural production as well as land use change towards agricultural land, i.e. transformation of forest land into agricultural land. The latter land use change implies additional GHG-emissions given the fact that forest is a carbon sink. Moreover, in Brazil deforestation is a major factor of decreased biodiversity. For example, based on simulations of the CAPRI model the implementation of the F2F-strategy would induce a deforestation of 2.3 Mio ha in South America. Given the fact that Brazil has a major share in the total forest area of

South Amercia (roughly 60%) a major share of deforestation induced by F2F-stratgey would fall on Brazil.

Therefore, for a complete evaluation of the overall welfare effect induced in Brazil by the implementation of the Green Deal in EU-agriculture beyond economic welfare also spillover effects with regard to ecosystem services have to be taken into account.

A detailed quantitative assessment of these spillover effects is beyond the scope of this report.

Figure 42 – Price changes: F2F

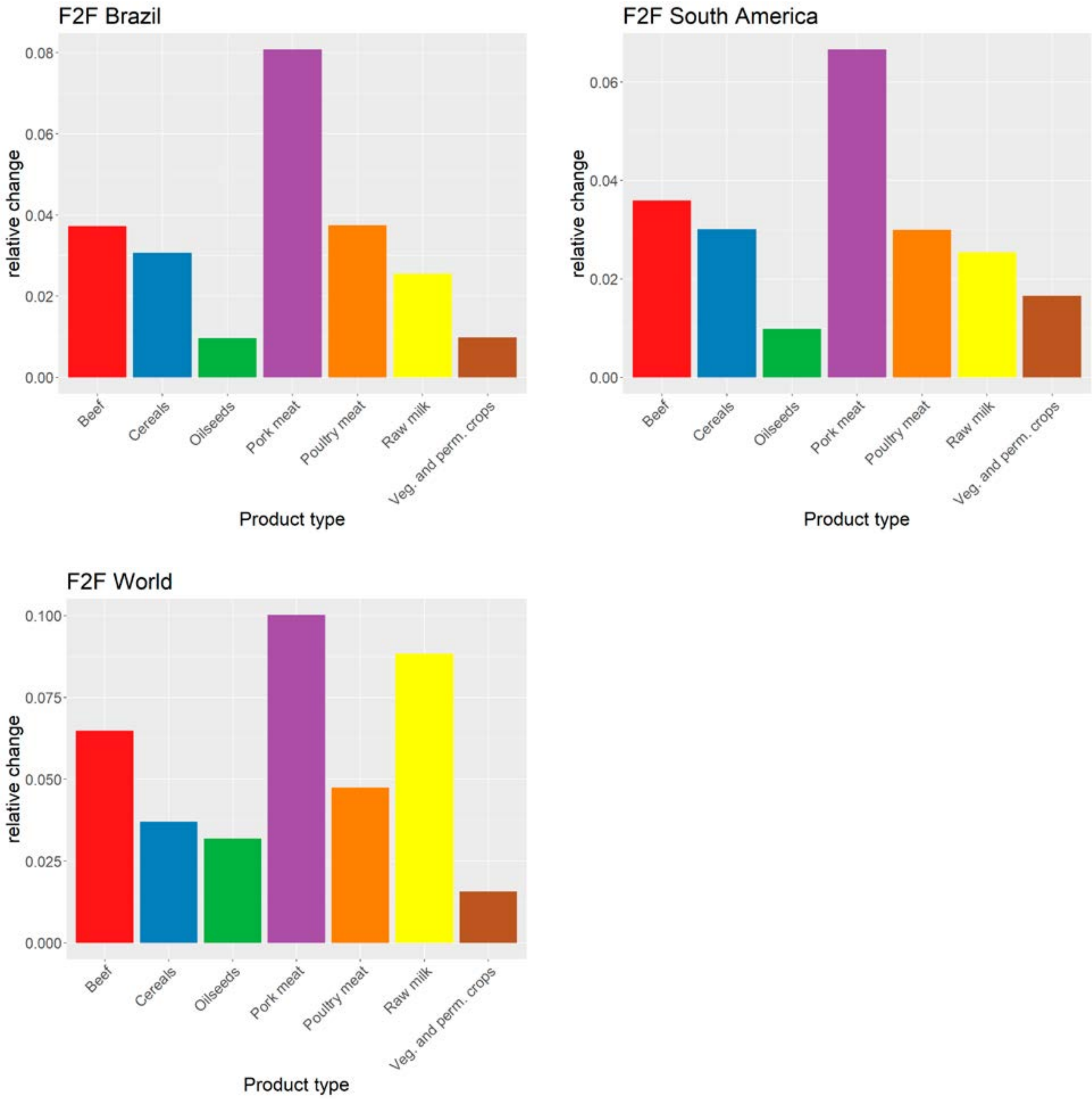


Figure 43 – Price changes: F2F_optimal

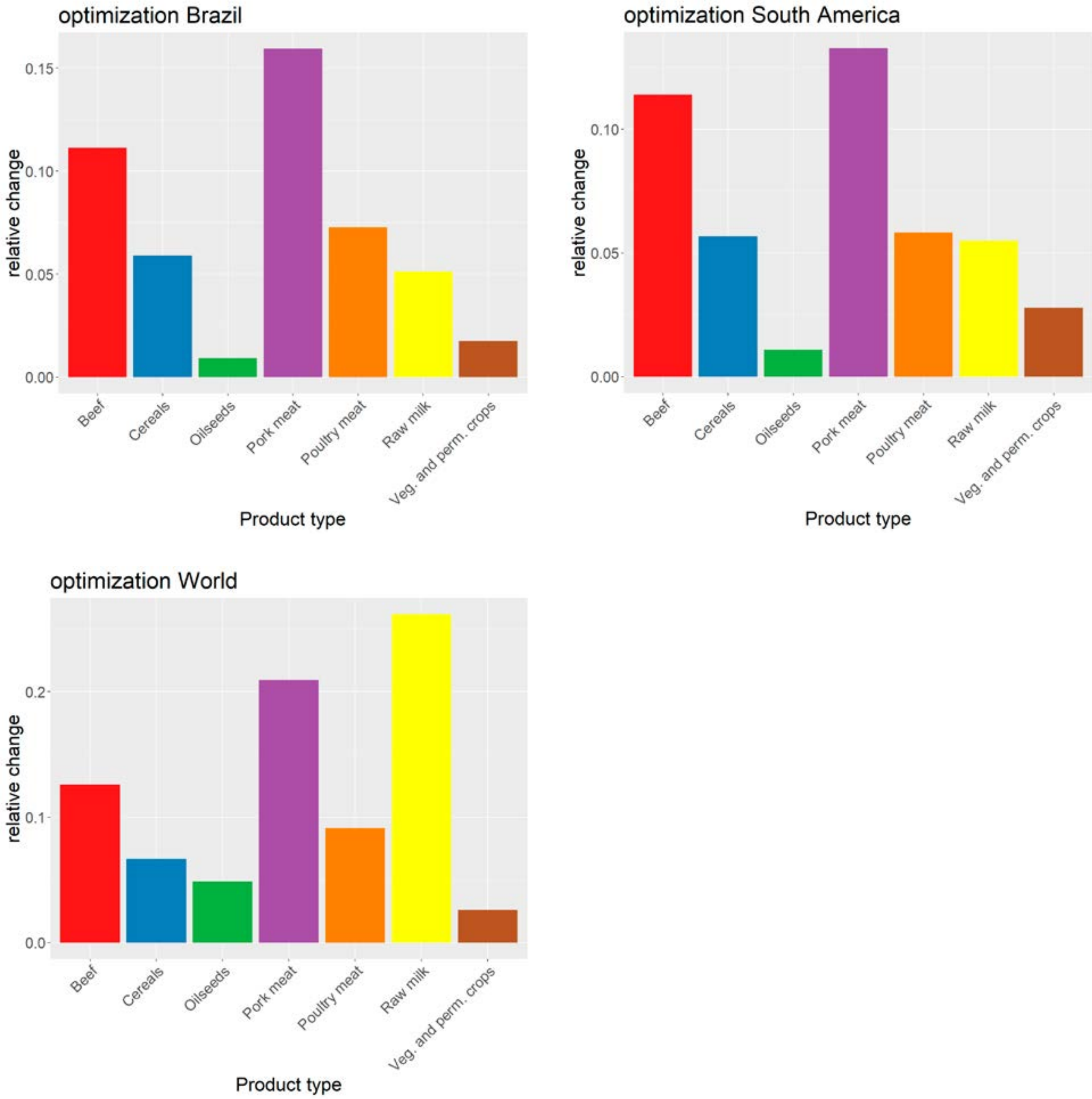


Figure 44 – Price changes: F2F_soft

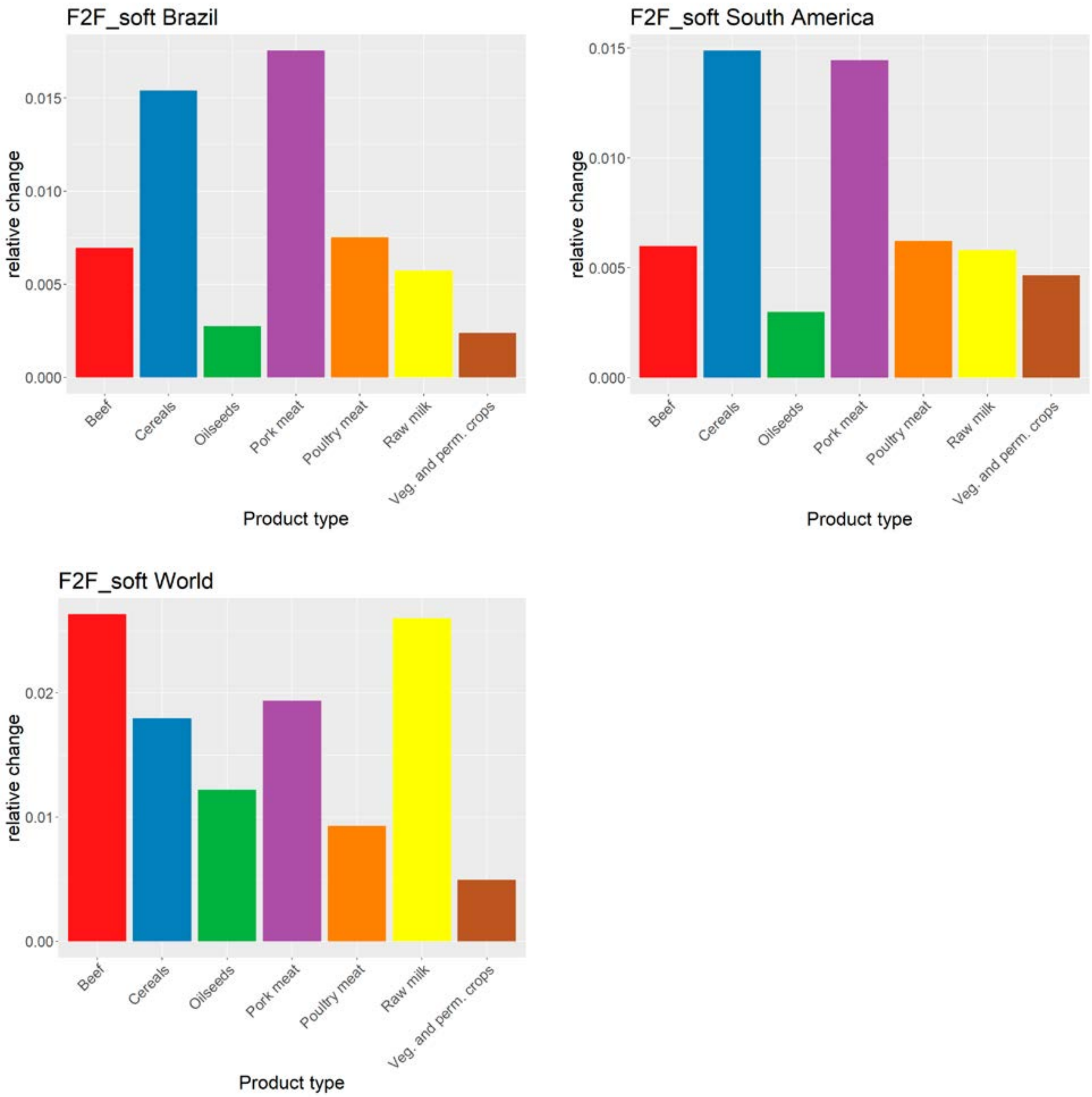
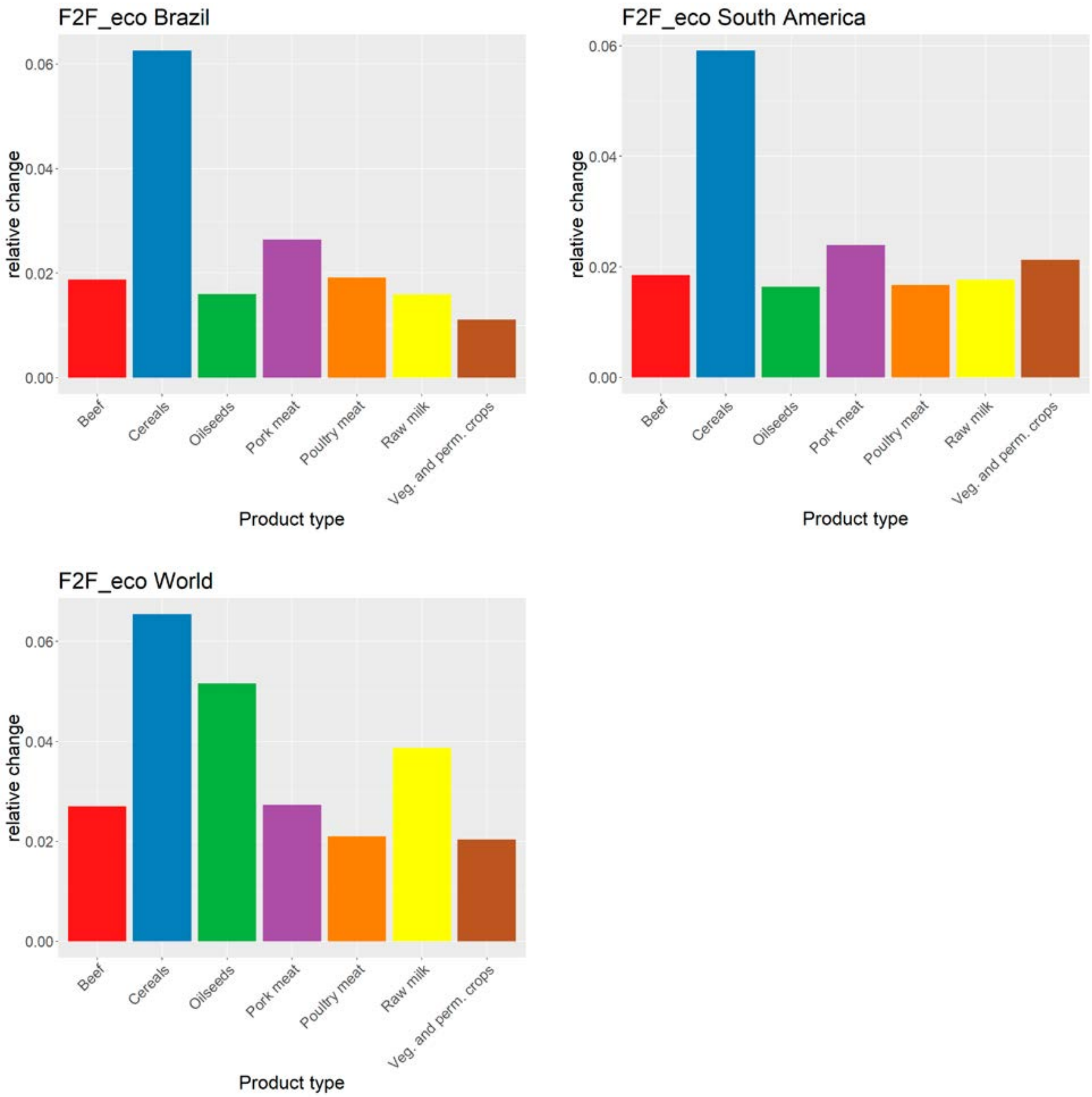


Figure 45 – Price changes: F2F_eco



6.4. Impact of a ban of soy imports into the EU

In the context of its strict policy regarding GMO-containing products the EU considers an import ban of soy products stemming from the US, Brazil, and Argentina. To analyze potential impact of such a soy ban on international markets we have analyzed total production, demand and trade effects derived from a ban of soy imports into the EU based on the CAPRI model. In particular, four scenarios have been model:

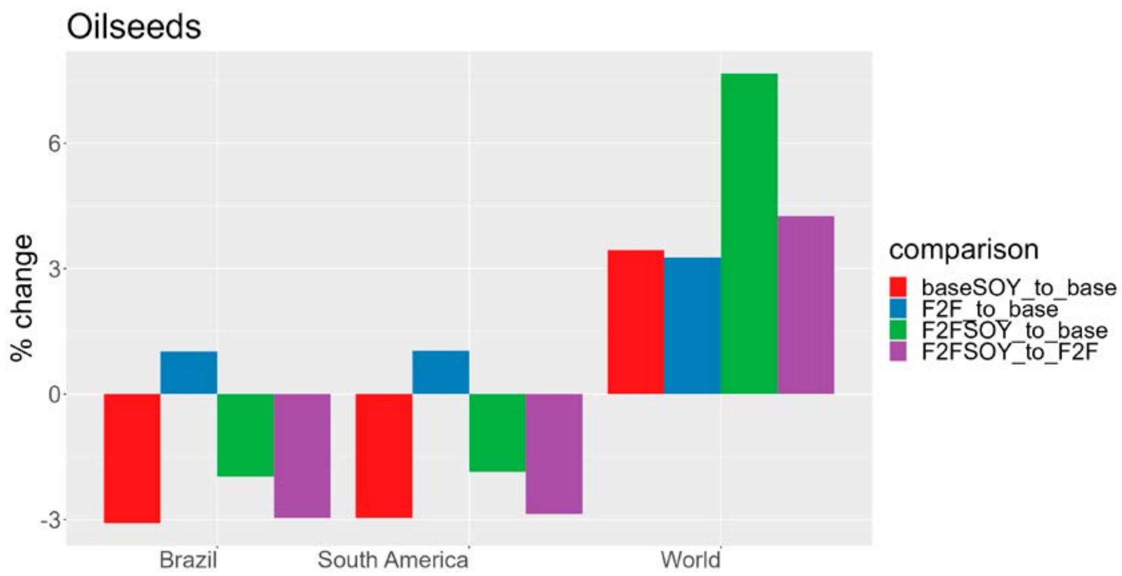
- *baseSOY_to_base: % change in price if soy import is introduced compared to baseline (no change)*
- *F2F_to_base: % change in price if F2F is introduced compared to baseline (no change)*
- *F2FSOY_to_base: % change in price if F2F and soy ban are introduced compared to baseline (no change)*
- *F2FSOY_to_F2F: % change in price if F2F and soy ban are introduced compared to F2F*

Although the focus in this section is on impacts of different F2F-strategy option on agricultural development in Brazil, we brie y summarize the main effects resulting from a soy ban when compared to the base-run (scenario baseSOY_to_base). The summary of main impacts of a soy ban have been taken from Witzke und Jansson 2021 who did a detailed analysis of impact of a soy ban based on the CAPRI model.

- A drastic reduction in EU soy cake use (-85%) that would need to be compensated by increases in most alternative protein sources like other oil cakes (in particular from rape, +91%), pulses, DDGS but also cereals and grass.
- EU prices would increase by about 150% for soy seed and 110% for soy cake in the medium run and prices of other oilseeds and their cakes would increase by 30% to 45% while meat prices would increase by about 13% (pork meat).
- EU trading partners, most importantly the Americas would face declining prices for soy and soy cake (-5% to -15%) while they would participate in the price increases of other oilseeds (+5% to 30%). The soy price cuts would imply economic losses for producers in these countries and difficult to anticipate political responses.
- Production changes in EU and non-EU regions would go along with changes in areas and animal herds. In the EU, the soy area could more than double, but starting from a rather low initial level, at the expense of other oilseeds, fodder maize, and set aside land. Agriculture would expand into forestry and other land by about close to 700 kha in the EU. A converse reallocation of land from agriculture to other uses, including forestry, may be expected in North (-0.3 million ha) and South America (-1.4 million ha). Global carbon sequestration may thus be expected to increase with the projected magnitude of course depending on the structure and parameters of the modeling system used.
- Regarding the impact on biodiversity we have opposing effects in Europe and South America, respectively. While soy ban induces a land use change towards agricultural land and a decrease in forest, the opposite is true for South America. It is difficult to trade o the likely benefits induced in South America against the likely damage in Europe. It should also be noted that in Europe there would not only be an expansion

of agricultural area but also a non-negligible loss of set aside and fallow land that may be partly of high ecological value.

Figure 46 – Oilseeds price changes in response to soy import ban in the EU

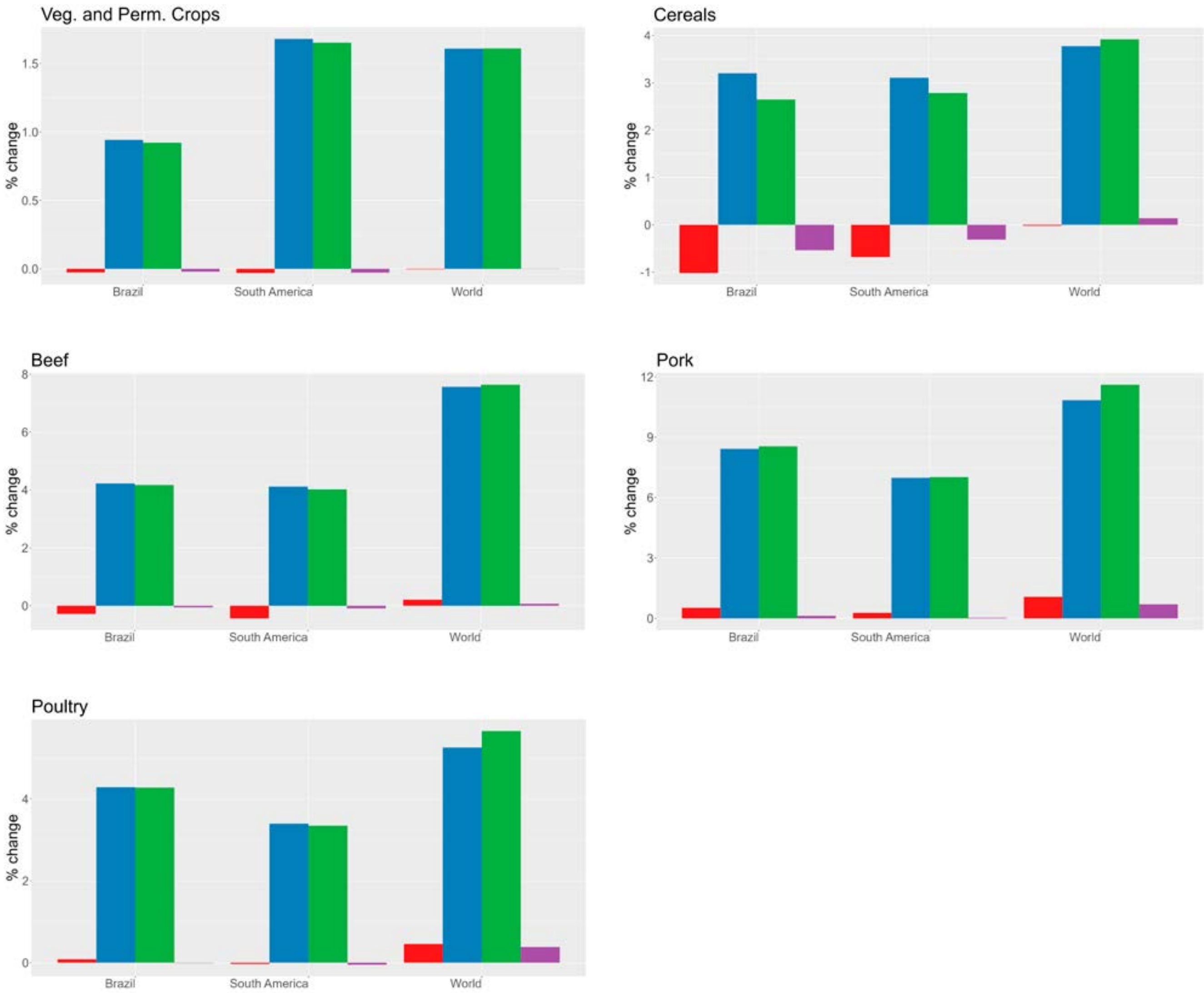


- Effects on nutrient balances are only moderate and heterogeneous in Europe, because they are the bottom line of opposing changes, including changes in mineral fertilizer and biological fixation that vary by country and less excretions from a shrinking animal sector.
- Regarding the GHG-emissions of agriculture a clear effect results. While EU-emissions would decline by 2.6 million tons (or 0.6%), non-EU regions would increase their emissions by 8.8 million tons (or 0.2%) giving a net increase in global emissions from agriculture of 6.2 million tons in the short run. The fact that this emissions leakage is harmful globally reflects the fact that EU-livestock production is relatively efficient in terms of their GHG effects compared to other regions. The percentage effects are rather low compared to policies directly targeting GHG effects (e.g. in Perez-Dominguez et al. 2016) but the direction and magnitude is fully in line with previous results.

Overall, we report in figures 46 to 47 how a ban of soy imports combined with a F2F-strategy in the EU affects aggregated agricultural commodity prices in Brazil, South America and the World. As can be seen on figure 46 the negative effect on oilseeds prices in Brazil induced by the soy ban overcompensates the positive effect resulting from the F2F-strategy. However, please note that price effects for oilseeds at the aggregate level are much lower when compared to price effects on soy, i.e. in the aggregate a decrease of oilseeds prices amounting to only 3% can be observed. This negative effect clearly overcompensates positive price effects for oilseeds induced by the F2F-strategy.

Beyond oilseeds an import ban for soy has generally only neglectable price effects for other crop as well as livestock products. The latter holds true especially for Brazil, where price changes are all well below 1%. This can be nicely seen from figures 47.

Figure 47 – Agricultural price changes in Brazil in response to soy import ban in the EU



7. Appendix

7.1. Methodological Appendix

7.1.1. Deriving social welfare functions to evaluate Green Deal implications

We start with a vector of willingness-to-pay, $\iota = (\iota_1,.\iota_m)$, where ι_j denotes the willingness-to-pay for the eco-system service $j = 1,..,m$. Further, we consider a set of F2F-strategies implementing the Green Deal in agriculture, where k denotes a generate element of the set of F2F-strategies. In particular, each F2F-strategy k comprises of a specific set of F2F-measures, $\gamma = \{\gamma_1,..,\gamma_j,..,\gamma_n\}$. Each F2F-strategy, γ_k implies a shift in eco-system services, i.e. ΔZ_j. Further, each strategy induces a change in economic welfare of total society. We denote the latter by ΔZ_0. Hence, overall net-benefit resulting from a F2F-strategy k results as:

$$\Delta B(\gamma_k) = \sum_{j=0}^{m} \iota_j \Delta Z_j(\gamma_k)$$

where $\beta_0 = 1$. Further, for j =1,..,m let $\bar{Z}_j$ denote the maximal level of ecosystem service which can be supplied, e.g. for reduction of GHG-emissions $\bar{Z}_j$ corresponds to the current level of GHG-emissions. Analogously, for nitrogen pollution $\bar{Z}_j$ corresponds to the current level of nitrogen emissions, while for biodiversity $\bar{Z}_j$ corresponds to maximal level of biodiversity (in the CAPRI model this corresponds to a BFS-index of one. Accordingly, we can reformulate the net-benefit in percentage change in ecosystem services and economic welfare:

$$\Delta B(\gamma_k) = \sum_{j=1}^{m} \frac{\iota_j \bar{Z}_j}{\bar{Z}_0} \frac{dZ_j(\gamma_k)}{\bar{Z}_j} + \frac{dZ_0(\gamma_k)}{\bar{Z}_0}$$

We define:

$$\beta_j := \frac{\iota_j \bar{Z}_j}{\bar{Z}_0}; \quad z_j := \frac{dZ_j}{\bar{Z}_j}$$

Then an optimal F2F-strategy maximizing the net-benefit of a society can be derived from the following social welfare maximization:

$$\begin{aligned} &y^{opt} := \operatorname{argmax} W(z) \\ &s.t. \\ &CAPRI(z,y) \equiv 0 \quad . \end{aligned} \tag{7.1}$$

However, given the fact that a complex model like the CAPRI-model only implicitly defines the relationship between F2F-measures, y and relevant policy outcomes, z, it is often tedious and requires tremendous computational effort to solve the maximization problem eq. 7.1.

In this regard Ziesmer et al. (2022) suggest the application of metamodeling techniques to drive explicit policy impact functions implicitly defined by the CAPRI model, i.e.

$$z := F(y)$$

Substituting the policy impact functions implies that the maximization problem eq. 7.1 can be easily solved.

7.1.2. The concept of metamodeling

Metamodeling techniques are widely used in a variety of research fields such as design evaluation and optimization in many engineering applications (Simpson et al., 1997; Barthelemy and Haftka, 1993; Sobieszczanski-Sobieski and Haftka, 1997), as well as in natural science (Razavi et al., 2012; Gong et al., 2015; Mareš et al., 2016). In recent years, metamodeling is increasingly being applied to economic research. For example, Ruben and van Ruijven (2001) have applied the approach to bio-economic farm household models to analyze the potential impact of agricultural policies on changes in land use, sustainable resource management, and farmers' welfare; Villa-Vialaneix et al. (2012) have compared eight metamodels for the simulation of N_2O fluxes and N leaching from corn crops; Yildizoglu et al. (2012) have applied the technique to two well-known economic models, Nelson and Winter's industrial dynamics model and Cournot oligopoly with learning firms, to conduct sensitivity analysis and optimization respectively. Regardless of the research fields, the metamodeling technique simplifies the underlying simulation model, leading to a more in-depth understanding. The technique also brings the possibility of embedding simulation models into other analysis environments to solve more complex problems, such as the previously described policy optimization problem. In particular, metamodeling implies the derivation of explicit functional relations between policies, model parameters and model outputs via simulation analysis, which are only implicitly defined by large, complex scientific models.

To explain the metamodeling technique intuitively, let (x, y) represent the dataset[4] that contains n pairs of (x_i, y_i) where $xi = (x_i^1, \ldots, x_i^k)$ are the exogenous parameters and y_i are the endogenous responses. Thus, the simulation model is referred to as:

$$F^{SIM}(y_i, x_i) \equiv 0 \qquad i = 1, \ldots, n. \tag{7.2}$$

Furthermore, with x_i and y_i, we can t a metamodel which can be formulated as:

$$\hat{y}_i = f^{meta}(x_i) \qquad i = 1, \ldots, n, \tag{7.3}$$

where f^{meta} represents the metamodel that we utilize to approximate the relationships of the underlying simulation model and $\hat{y}_i$ is the predicted values of the outputs using x_i.

In the following we briefly describe how metamodels can be derived from complex scientific models. Basically, this derivation entails three steps: selection of metamodel types, DOE, and model validation (Kleijnen and Sargent, 2000).

Metamodel Types

Metamodels are classified into parametric and non-parametric models (Rango et al., 2013). Parametric models, such as polynomial models (Forrester et al., 2008; Myers et al., 2016), have explicit structure and specification. Examples of non-parametric models include of Kriging models (Cressie, 1993; Yildizoglu et al., 2012; Kleijnen, 2015), support vector regression models (Vapnik, 2013), random forest regression models (Breiman, 2001), artificial neural networks (Smith, 1993), and multivariate adaptive regression splines (Friedman et al., 1991).

In this paper, we focus on the use of polynomial and Kriging models in our policy optimization framework.

4 The dataset is also called the training sample.

Polynomial Models

The polynomial model has polynomials of various orders. A second-order polynomial model is given as follows:

$$y = \beta_0 + \sum_{h=1}^{k} \beta_h x_h + \sum_{h=1}^{k} \sum_{g \geq h}^{k} \beta_{h,g} x_h x_g + \epsilon, \tag{7.4}$$

where $x_1,\ldots,x_k$ are the k factors of the model and ϵ is the error term. The corresponding coefficients β are usually estimated through a linear regression based on least squares estimation.

Compared to other metamodel types second-order polynomial models have the following advantages: (1) they have a simple specification, which is easy to understand and manipulate; (2) compared to other types they require the lowest computational effort; In spite of these advantages, there are some limitations in using polynomial metamodels for complex responses (i.e. highly nonlinear or irregular I/O relationships).

Kriging Models

The Kriging models include Ordinary Kriging, Universal Kriging and Stochastic Kriging (see Kleijnen 2015 for their specific features). A commonly used Universal Kriging has the following form:

$$y = f(x) + N(x), \tag{7.5}$$

where x represents the factors of the model and $f(x) = \beta' x$ is the global trend of the model. $N(x)$ is a stochastic process that refers to the localized deviations of the model from the global trend and is assumed to be a weakly stationary process with mean 0 and covariance matrix $\Sigma = \tau^5 R$ where τ^2 is the process variance and R is the correlation matrix whose (i,j) element is the correlation between points x_i and x_j^2, namely, $R = Corr[N(x_i),N(x_j)]$. In Kriging, the correlations are determined by the distances between the points, that means, the closer the points x_i and x_j are to each other, the higher the correlation between them is. This idea is represented by the following correlation function which computes the correlation of points x_i and x_j using a Gaussian kernel:

$$Corr[N(x_i), N(x_j)] = exp(-\frac{1}{2} \sum_{h=1}^{k} \frac{1}{\psi_h^2} (x_{i,h} - x_{j,h})^2), \tag{7.6}$$

where h represents the h^{th} *factor* of each point and ψ_h quantifies the relative importance of this factor meaning that a higher ψ_h represents a higher contribution of factor x_h to the correlation between the points, in other words, a higher importance of factor x_h to the output.

The Kriging models use a linear predictor and predict the new point x_0 as a linear function of the n old points.

$$\hat{y}_{x_0} = \sum_{i=1}^{n} \lambda_i y_i, \tag{7.7}$$

where $y_i = F^{SIM}(x_i)$ is the simulation outputs of the i^{th} old point x_i and λ_i refers to the weight of it. The Kriging model is often called a spatial estimator because λ_i decreases as the distance between the new point x_0 and the old point x_i increases. To determine the optimal weights λ_i^*, it uses the BLUP as a criterion which minimizes the mean squared error of the predictor:

$$min \quad MSE[\hat{y}_{x_0}] = min \quad E[\hat{y}_{x_0} - y(x_0)]^2. \tag{7.8}$$

Following the derivations in the paper (Kleijnen, 2015), we can obtain:

$$\hat{y}_{x_0} = f(x_0) + \sigma(x_0)^{\intercal}\Sigma^{-1}(y - f(x_0)), \tag{7.9}$$

where we have unknown parameters β (in the trend function), ψ and τ^2 that are estimated using the maximum likelihood method:

$$\begin{aligned} l(\mu, \tau^2, \psi) = \; & -\ln[(2\pi)^{n/2}] \\ & -\tfrac{1}{2}\ln[\det(\tau^2 R(\psi))] - \tfrac{1}{2}(y - f(x)1)^{\intercal}[\tau^2 R(\psi)]^{-1}(y - f(x)) \quad with \quad \psi \geq 0, \end{aligned} \tag{7.10}$$

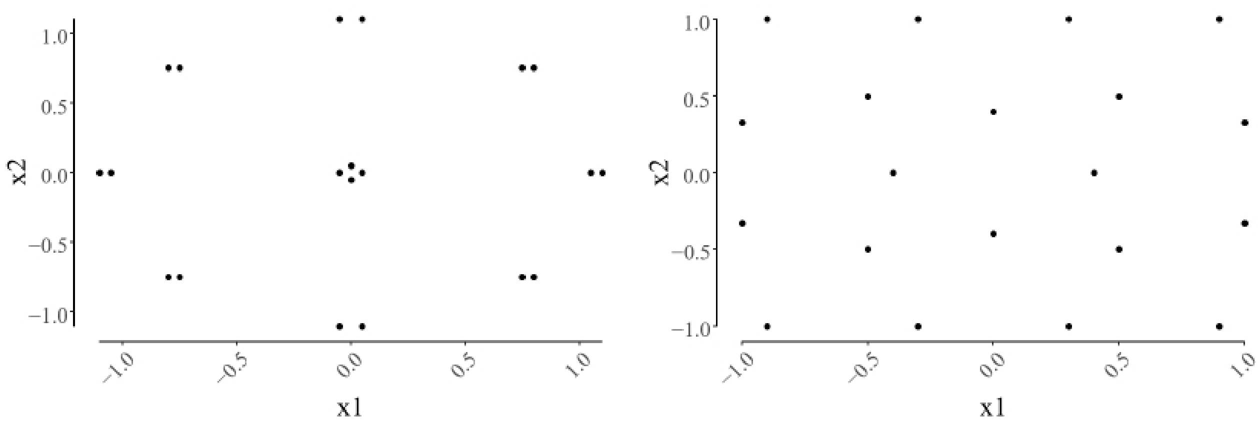
where det refers to the determination of a matrix.

Compared to second-order polynomials Kriging models are better suited to approximate nonlinear and irregular relationships. Moreover, by design they perfectly predict the training sample. However, the estimation of Kriging models can be tedious and very time-consuming as it requires the optimization of a complex maximum likelihood (Kleijnen, 2015).

Design of Experiments

To utilize metamodels, we need to estimate the corresponding coefficients. We generate the simulation sample by Design of experiment (DOE), which is a statistical method of drawing samples in computer experiments (Dey et al., 2017) and perform the estimation by entering the simulation sample into the simulation model. DOE could be set-up in two ways: the classical experimental design and the space-filling experimental design (see Figure 48). The former places the sample points at the boundaries and the centre of the parameter space to minimize the influence of the random errors from the stochastic simulation models. However, Sacks et al. (1989) have argued that this is not the case for deterministic simulation models where systematic errors prevail. Therefore, the space-filling experimental designs should be employed to replace the classical ones. Among popular space-filling designs, Latin Hypercube design enjoys great popularity due to its ability to generate uniformly distributed sample points with ideal coverage of the parameter space as well as the flexibility with the number of the sample points (Sacks et al., 1989).

Figure 48 – Classical and Space-filling Design.(adapted from Simpson et al. (2001))



7.1.3. Model Validation

Validation refers to assessing whether the prediction performances of the metamodels hold an acceptable level of quality (Kleijnen, 2015; Villa-Vialaneix et al., 2012; Dey et al., 2017). Normally, two samples are needed to assess the quality of a derived metamodel: the training sample and the test sample. The training sample is used to t the parameters of the metamodel, whereas the test sample is used to validate the trained metamodel, and the test sample must include data points that are not part of the training sample. It is important that the metamodels have good predictions while maintaining generality. For this reason, a test sample is essential because it helps us evaluate if the metamodels can be generalized and whether the simulation model can be replaced with them.

$$\begin{aligned} R^2 &= 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \\ RMSE &= \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}\ , \end{aligned} \qquad (7.11)$$

where y_i are the model responses in the test sample and $\hat{y}_i$ the predicted values of the metamodel on the test sample and $\bar{y}$ is the mean of all y_i in the test sample. The RMSE is a frequently used measure of a model's predictive accuracy and R^2 represents the correlation determination. In addition, to compare the prediction performances for dependent variables that have different scales, we introduce the AER, which is calculated by taking the absolute value of RMSE divided by the corresponding mean:

$$AER = \left| \frac{RMSE}{\bar{y}} \right|. \tag{7.12}$$

The metric gives us an idea of how large the prediction errors are in comparison to the true simulated values on average, i.e., the lower the AER values, the better the prediction performances. As we want to use the metamodels replacing the CAPRI-model in our policy optimization framework it is particularly important that metamodels have a global prediction accuracy, e.g. predict quite well relevant policy outcomes over a compact subset of policies.

7.1.4. Implementation of the framework

In order to apply our framework, six main steps are necessary, which are summarized in Algorithm 1. We implemented the individual steps in a mix of 1) R Core Team, 2022; 2) GAMS Development Corporation, 2022. Solving the different optimization models in GAMS is mostly single-threaded, therefore we structured our code to allow the usage of multiple CPU cores and high-performance computing resources. This is possible due to the independence of the individual simulations in step two, for example. Please also note, that one needs to generate two samples: The first for the derivation of the metamodels (steps one to three), and the second for the actual policy analysis (steps four to six).

Algorithm 1 Steps

1. DOE: Sample generation for metamodel derivation
2. Computing simulations
3. Estimating and validating metamodels
4. DOE: Sample generation for policy analysis
5. Identify optimal policies applying Bayesian model averaging and model selection techniques ⇒ $\gamma*$
6. Calculating political performance gaps, $L(\gamma*)$

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