Final Report

The Green Deal Glow-Up: Do the EU's Emission Rules Hit Different Inside and Outside the Union?

By Shravani Survase, Palash Gajbhiye & Kankon Sen

1. Introduction

While carbon dioxide (CO_2) is the most commonly addressed greenhouse gas, it is worth noting that nitrous oxide (N_2O) is actually one of the most potent long-lived greenhouse gases, with a global warming potential nearly 300 times that of CO_2. Agricultural soils account for the majority of anthropogenic N_2O emissions, primarily through nitrogen fertiliser application and soil microbial processes. As a result, persistent nutrient surpluses, intensive cropping systems, and uneven fertilizer-use efficiency throughout Europe have made agricultural N_2O mitigation a central component of climate and environmental policy in recent years.

Given the EU's strong sustainability ambitions and its long standing role in shaping environmental standards, an important question is how the region is responding to agricultural emissions. In 2020, the European Commission launched the Farm-to-Fork Strategy (F2F) as part of their Green Deal, introducing a coordinated framework for transitioning toward more sustainable agricultural practices. F2F set ambitious 2030 targets, including reducing nutrient losses by half and reducing fertilizer use by at least 20 percent. Although these targets extend into the future, the 2020 introduction represents a clear policy shift, marking the beginning of a new regulatory environment and revised expectations for producers, firms, and national policymakers.

In line with this, our research question asks: Did EU countries experience differential changes in agricultural N_2O emissions after the introduction of the Farm-to-Fork Strategy, compared to non-EU European countries not subjected to this policy?

We construct a panel of European countries for 2014–2022 and estimate a Difference-in-Differences (DiD) model with country and year fixed effects. This design compares within-country changes over time between EU and non-EU countries, netting out time-invariant national characteristics and shocks common to all countries such as the COVID-19 pandemic, global fertilizer price spikes, and macroeconomic disruptions, each of which is absorbed by year fixed effects.

Our research's contribution is two fold. First, we provide one of the earliest quasi-experimental assessments of the Farm-to-Fork Strategy's short-run environmental impact. Second, we document important data and measurement challenges surrounding cross-country N O emission reporting, fertilizer-use statistics, and agricultural land definitions. Together, these findings strengthen policy discussions around the feasibility of early-stage outcomes from climate-agricultural interventions.

2. Background

In order to explore our research question and incorporate the relevant controlled variables, it is crucial to understand how N_2O emissions actually arise. Agricultural N_2O emissions arise primarily from nitrification and denitrification processes in soils when nitrogen inputs exceed plant requirements for the same nutrients. The IPCC's inventory guidelines describe how factors like soil moisture, temperature, and nitrogen

availability impact these biochemical processes. In the EU's specific context, high fertiliser application rates, intensive cropping systems, and large livestock operations have been identified as contributors to the region's elevated emissions.

The Farm-to-Fork Strategy represents the EU's central roadmap to address these elevated emissions. Introduced in 2020, F2F outlines long-term quantitative targets, including:

- 50 percent reduction in nutrient losses;
- 20 percent reduction in fertiliser use;
- 25 percent organic agricultural area by 2030;
- expanded soil monitoring and precision agriculture technologies.

Thus, we understand that the F2F could influence emissions through several pathways:

- Reduced nitrogen fertiliser application, lowering direct soil N_2O generation;
- Improved nutrient-use efficiency, limiting nitrogen surpluses;
- Adoption of low-input or organic production systems;
- Changes in crop choice, rotations, and soil management;
- Investment in precision agriculture supported by CAP incentives.

Although implementation was phased in gradually, 2020 represents a clear policy onset year, as member states formally incorporated F2F goals into their Common Agricultural Policy Strategic Plans. This regulatory environment may influence behaviour and investment decisions even before direct compliance mandates occur - a mechanism widely discussed in climate-policy signaling literature. Consequently, 2020 becomes our research question's key marker for establishing a difference-in-differences (DiD) model.

Non-EU European countries including Norway, Switzerland, the UK, Iceland and Albania serve as the comparison group because they share climatic and agricultural characteristics but are not subject to F2F mandates. Thus, they also serve as a critical component of our difference-in-differences (DiD) model. However, it is worth noting that differences in data coverage and agricultural structure across countries require careful interpretation of comparative trends.

3. Data Description

Our empirical analysis uses a balanced panel of European countries from 2014 - 2022, combining agricultural emissions, fertiliser-use measures, climatic variables, and structural indicators. This section outlines our data sources, variable construction, sample definition, and limitations.

A. Data Sources

We integrate information from multiple harmonised international datasets commonly used for environmental and agricultural policy research:

- Agricultural N_2O emissions/ha: From the FAOSTAT Emissions - Agriculture database

- Fertiliser use (nitrogen): FAOSTAT Fertilizers by Nutrient dataset (kg of nitrogen per hectare), representing synthetic nitrogen application intensity. We divide this fertilizer use data by agricultural land data to form our independent variable, fertilizer use/ha.
- Agricultural land: FAOSTAT Land Use Indicators, used to normalize fertilizer use by land area.
- Climate variables: Annual precipitation (mm) from the World Bank Climate Change Knowledge Portal.
- Structural variables: Agriculture value added as a share of GDP and urban population share from the World Development Indicators.
- Policy classification: EU membership status, based on official documentation from the European Commission.

Together, these datasets provide broad European coverage with standardized measurement, though with varying degrees of completeness across countries and years.

B. Sample Definition and Treatment Classification

Our sample consists of data from: 27 EU member states (treated group): Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden

5 non-EU European countries (control group): Albania, Iceland, Norway, Switzerland, and the United Kingdom

We define our treatment indicator following the canonical DID formulation:

$$D_{it} = EU_i \times Post2020_t,$$

where Post2020_t = 1(t >= 2020)

EU membership is time-invariant over the study period. The comparison group includes high-income agricultural exporters (e.g., Norway, Switzerland, UK) and one upper-middle-income country (Albania). These countries are not subject to the Farm-to-Fork Strategy but provide a relevant counterfactual due to their geographic proximity and shared exposure to European market and climate conditions.

We acknowledge that having only 5 non-EU European countries in our control group poses limitations to our investigation. As a result, our DiD design faces two constraints:

- Reduced statistical power: With group-level fixed effects, having only five comparison units can produce wide confidence intervals and unstable estimates.
- Potential structural imbalance: Agricultural systems in Norway or Switzerland differ substantially from those in Southern and Eastern EU member states, which may affect comparability.

We address these issues through careful descriptive analysis, transparent reporting of sample size, and discussion of identification assumptions.

C. Outcome Variable Construction

Our dependent variable captures the intensity of agricultural emissions, defined as:

$$Y_{it} = \log\left(\frac{N_2O_{it}}{\text{Agricultural Land}_{it}}\right)$$

We made the decision to transform our outcome variable in this manner for a range of reasons: ' - Normalisation: Dividing emissions by agricultural land area produces an emissions-intensity measure, reducing scale bias across heterogeneous agricultural systems.

- Skew reduction: N_2O emissions exhibit a right-skewed distribution because a small number of locations, farms, soils, or events generate disproportionately high emissions, while most areas emit relatively little. The log transformation mitigates extreme values.
- Interpretability: Coefficients can be interpreted as approximate percentage changes - a standard in environmental DiD research.
- Model fit: Log-linear models improve homoscedasticity and reduce leverage issues.

D. Control Variables

Using literature to evaluate the range of factors affecting emissions, we settled on the controlled variables as follows. While these do not necessarily address every factor impacting emissions in different countries, they do cover the essential economic, environmental and socioeconomic angles that drive nitrous oxide emissions.

- Rainfall (mm): Higher rainfall increases soil moisture, which limits oxygen availability and accelerates denitrification, a microbial process that produces nitrous oxide.
- Agriculture share of GDP: A higher agriculture share of GDP typically indicates more intensive farming activity, which increases fertilizer use, manure management, and soil disturbance - all major sources of nitrous oxide emissions.
- Urban population share: A higher urban population share generally corresponds to less agricultural land use, which reduces direct soil-based nitrous oxide emissions from farming.

E. Panel Construction, Missing Data, and Final Sample Size

Across 32 countries and 9 years, the dataset contains a maximum of 288 country-year observations (32×9). However, transparency about missing values and sample restrictions is essential given the small comparison group and was explicitly noted in our presentation feedback. Consequently, it is worth noting our instances of missing values: - Albania: intermittent gaps in fertilizer reporting

- Iceland: incomplete N_2O and land use reporting in some years
- Norway and Switzerland: occasional missing structural indicators
- Precipitation data: inconsistent in early years for select countries

These missing values are denoted as "NA".

F. Variable Definitions

Table 1: Variable Definitions

Variable	Definition	Source
log(N2O/hectare)	Log of agricultural N2O emissions per hectare	FAOSTAT
EU_i	1 if country is an EU member	European Commission
Post2020_t	1 for years over 2020	Constructed
D_it	EU × Post2020	Constructed
Rainfall	Annual precipitation (mm)	World Bank
AgGDP	Agriculture share of GDP (%)	World Development Indicators
Urban share	Urban population (%)	World Development Indicators
Fertiliser (kg N/ha)	Fertiliser use per hectare	FAOSTAT

G. Measurement Limitations

It is crucial to acknowledge the limitations in our formed panel dataset due to measurement shortcomings from the raw data. Studying the methodologies of our raw data sources, we note the following:

- FAOSTAT emissions rely on IPCC Tier 1 default emission factors, which may not reflect country-specific soil or climate characteristics.
- Fertiliser statistics vary in reporting quality across countries and years.
- Land-use definitions differ slightly across countries, potentially affecting denominator consistency.
- Small-sample noise is amplified because only five countries form the comparison group.

These issues reinforce the importance of cautious interpretation of estimated treatment effects.

4. Descriptive Statistics

This section describes key patterns in N_2O emissions and related variables. The descriptive analysis helps evaluate the plausibility of the empirical assumptions that underlie the identification strategy.

To aid interpretation, all time series graphs include a vertical line at the year 2020, which marks the introduction of the Farm to Fork Strategy. This line identifies the beginning of the post policy period in the Difference in Differences framework. Visual inspection of trends before and after this point provides preliminary insight into whether EU and non EU countries follow similar pre policy trajectories and whether any divergence appears following the policy announcement.

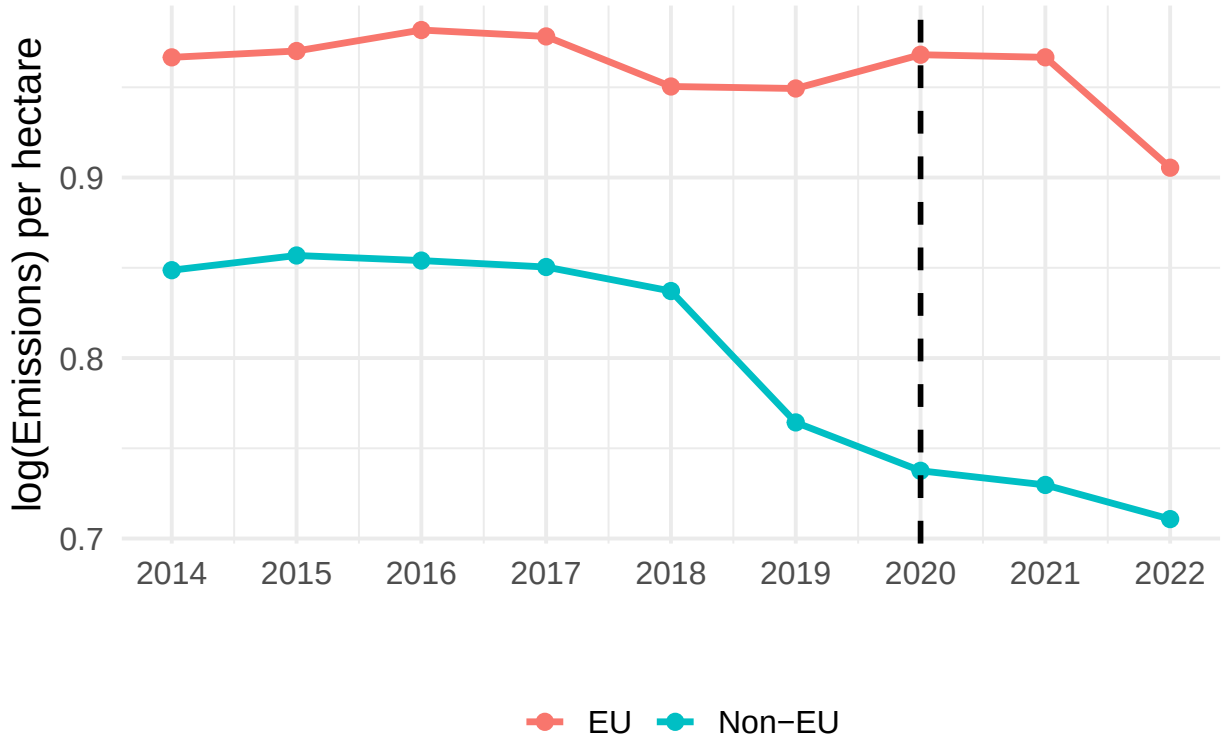
A. Trends In Emissions Intensity

Figure 1 plots the log of average N_2O emissions per hectare for EU and non EU countries, with a vertical line marking the introduction of the Farm to Fork Strategy in 2020. Before 2020, both groups move broadly in the same direction, which offers preliminary support for the parallel trends assumption required for a Difference in Differences design. The trends are not perfectly parallel, however. Non EU emissions start declining around 2018, before the policy.

This earlier decline likely reflects factors unrelated to the strategy. Possible explanations include country specific environmental regulations, fertiliser price changes, and structural differences in agricultural systems such as livestock intensity or crop composition. Climatic variation may have contributed as well. Since these factors differ across countries and are not fully observable at the annual level, they raise concerns about omitted variable bias.

The pattern may also reflect sample composition bias. The non EU group is small and heterogeneous, so shocks in a single country can pull the group average. After 2020, EU emissions stabilise while non EU emissions continue to fall. Although this divergence may seem consistent with a policy effect, descriptive evidence cannot establish causality. These observations underline the importance of fixed effects to control for unobserved differences and the need for formal Difference in Differences estimation to evaluate whether the post 2020 divergence reflects the Farm to Fork Strategy or contemporaneous external influences.

Figure 1: Log of Emissions Over Time: EU vs Non-EU



Event Study Analysis:

To examine pre treatment comparability more rigorously, we estimate an event study that measures the annual difference in log N_2O emissions between EU and non EU countries relative to 2020 and provides confidence intervals for each estimate (Fig. 2). The pre treatment coefficients are small and statistically indistinguishable from zero. For instance, the estimates for event times -6 (2014), -5 (2015), and -4 (2016) are approximately -0.067, -0.072, and -0.057, with p values above 0.15 in all cases. The confidence intervals for every pre-policy year include zero and the coefficients do not exhibit statistical significance or any systematic pattern.

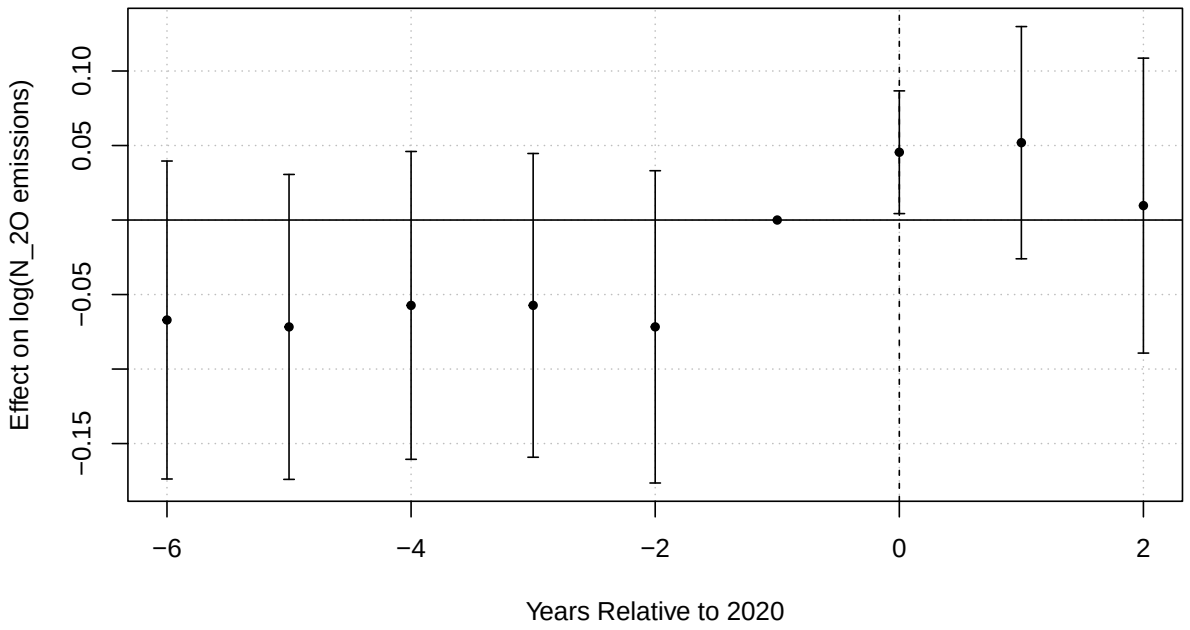
This indicates that EU and non EU countries followed broadly comparable emissions trajectories before the Farm to Fork Strategy, which supports the parallel trends assumption required for the Difference in Differences design. Formal econometric estimation is still necessary to determine whether the divergence observed after 2020 reflects the policy or the influence of external shocks during this period.

```
## OLS estimation, Dep. Var.: log_N2O
## Observations: 288
## Fixed-effects: country: 32,  year: 9
## Standard-errors: Clustered (country)
##                     Estimate Std. Error   t value Pr(>|t|)
## event_time::-6:eu -0.067089   0.052307 -1.282612 0.209136
## event_time::-5:eu -0.071724   0.050166 -1.429725 0.162797
## event_time::-4:eu -0.057285   0.050641 -1.131187 0.266652
## event_time::-3:eu -0.057262   0.049969 -1.145940 0.260589
## event_time::-2:eu -0.071689   0.051375 -1.395390 0.172815
## event_time::0:eu   0.045501   0.020189  2.253805 0.031423 *
## event_time::1:eu   0.051909   0.038206  1.358648 0.184063
## event_time::2:eu   0.009680   0.048521  0.199505 0.843171
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## RMSE: 0.047803     Adj. R2: 0.994012
##                   Within R2: 0.118272
```

Table 2: Event Study Regression Results

term	estimate	std.error	statistic	p.value
event_time::-6:eu	-0.067	0.052	-1.283	0.209
event_time::-5:eu	-0.072	0.050	-1.430	0.163
event_time::-4:eu	-0.057	0.051	-1.131	0.267
event_time::-3:eu	-0.057	0.050	-1.146	0.261
event_time::-2:eu	-0.072	0.051	-1.395	0.173
event_time::0:eu	0.046	0.020	2.254	0.031
event_time::1:eu	0.052	0.038	1.359	0.184
event_time::2:eu	0.010	0.049	0.200	0.843

Figure 2: Event Study: Dynamic Effects of Farm-to-Fork on log(N2O)

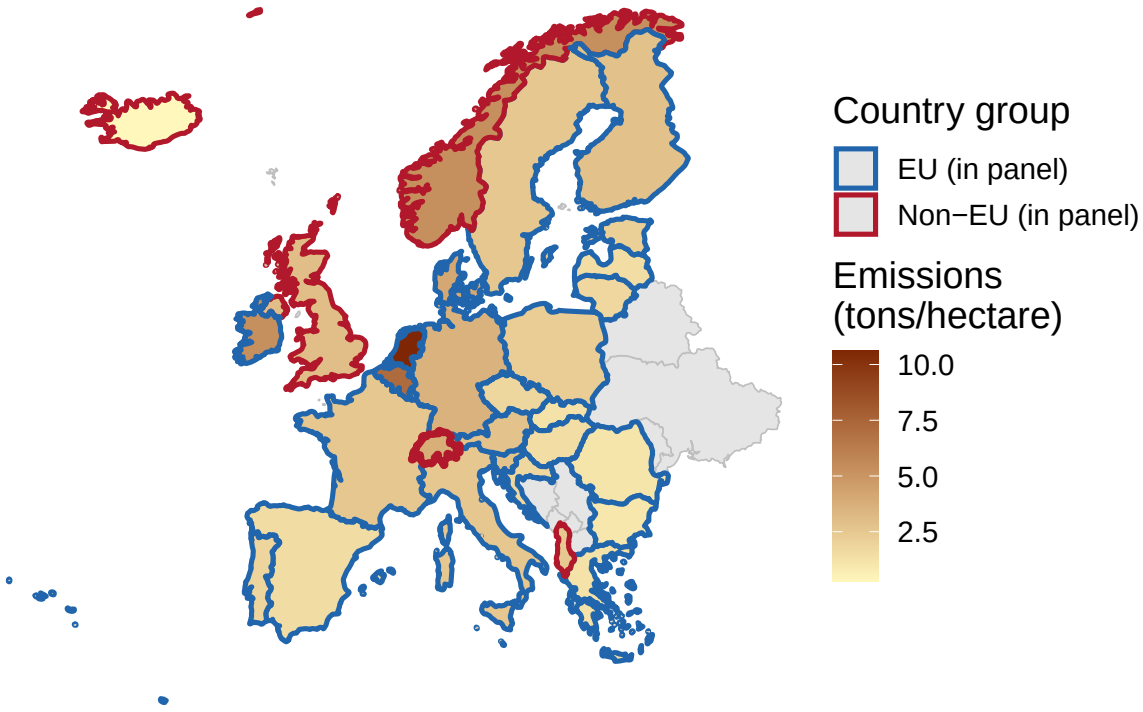


B. Spatial Patterns In Emissions

Figure 3 presents a map of emissions intensity across Europe in 2019. The map shows substantial spatial variation in emissions per hectare across countries. Several Northern European non EU countries such as Iceland, Norway, and Switzerland exhibit relatively high emissions intensity, while many EU member states display a wider range of values, including both higher intensity regions in Central Europe and lower intensity regions in parts of Southern and Eastern Europe. These descriptive differences reflect the diversity of agricultural systems, land use patterns, and ecological conditions across the region.

Because the figure represents a single cross sectional snapshot, it is used only to describe how emissions are distributed in the data. These baseline differences do not inform any conclusions about policy effects or temporal dynamics. They are largely time invariant and will be absorbed by the country fixed effects in the empirical model. The substantial spatial variation observed here further highlights why a causal study is needed, since raw cross sectional differences cannot isolate the effect of the Farm to Fork Strategy from long standing structural differences across countries.

Figure 3: N_2O Emissions in Europe in 2019

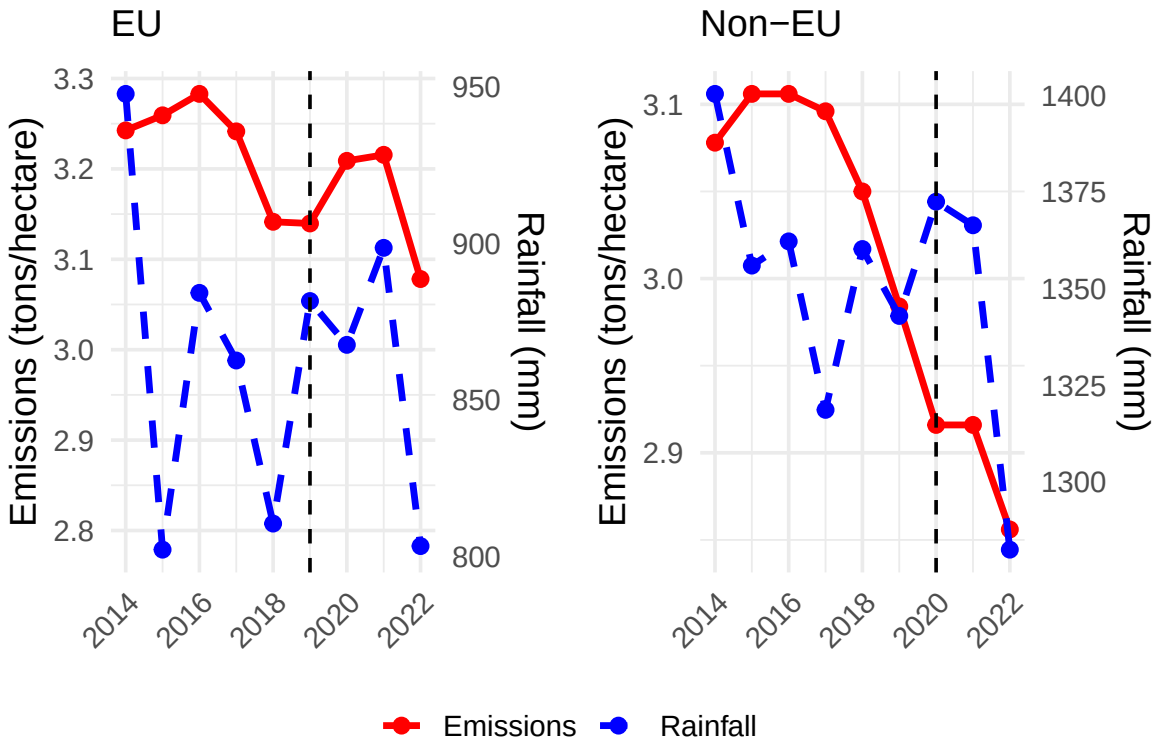


C. Emissions and Rainfall

Figure 4 presents trends in emissions intensity alongside annual precipitation for EU and non EU countries, with a vertical line marking the introduction of the Farm to Fork Strategy in 2020. Rainfall influences soil nitrogen processes by regulating soil moisture and the conditions under which nitrification and denitrification occur. Because these biological pathways are sensitive to changes in precipitation, rainfall can generate short term variation in N_2O emissions that is unrelated to policy.

The figure shows that rainfall fluctuates over time in both EU and non EU countries, but the timing and magnitude of these fluctuations differ across the two groups. These descriptive patterns underscore the scientific need to control for rainfall in the empirical model. Without doing so, changes in emissions could partly reflect climatic variation rather than behavioural responses to the Farm to Fork Strategy. Including rainfall as a covariate helps isolate policy related changes from environmentally driven ones.

Figure 4: Emissions and Rainfall

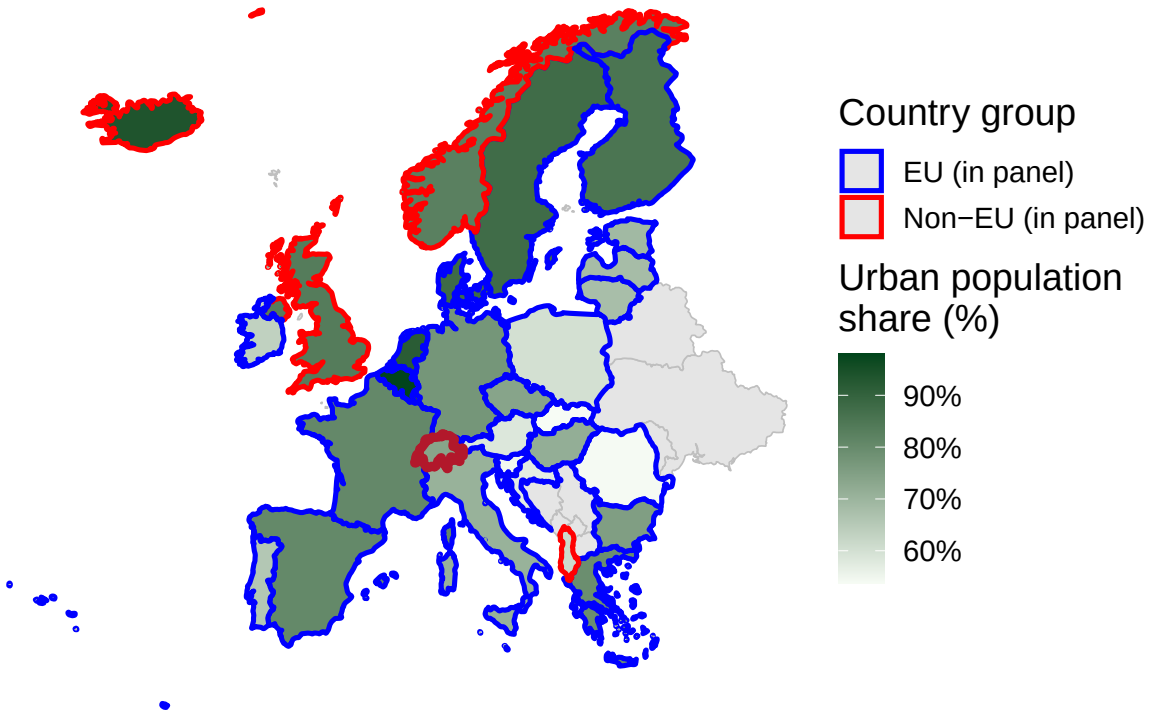


D. Urban Population Patterns

Figure 5 illustrates the spatial distribution of urban population shares in 2019. Non EU countries such as Iceland, Norway, Switzerland, and the United Kingdom have very high levels of urbanisation. EU countries display more variation, with a mix of highly urbanised and more rural member states.

Urbanisation reflects long term demographic and land use patterns that may influence agricultural structure and emissions. Because these features change slowly, they are effectively controlled by the country's fixed effects. The variation shown in the map reinforces the value of comparing within country trends rather than raw differences across groups.

Figure 5: Urban Population Share in Europe in 2019

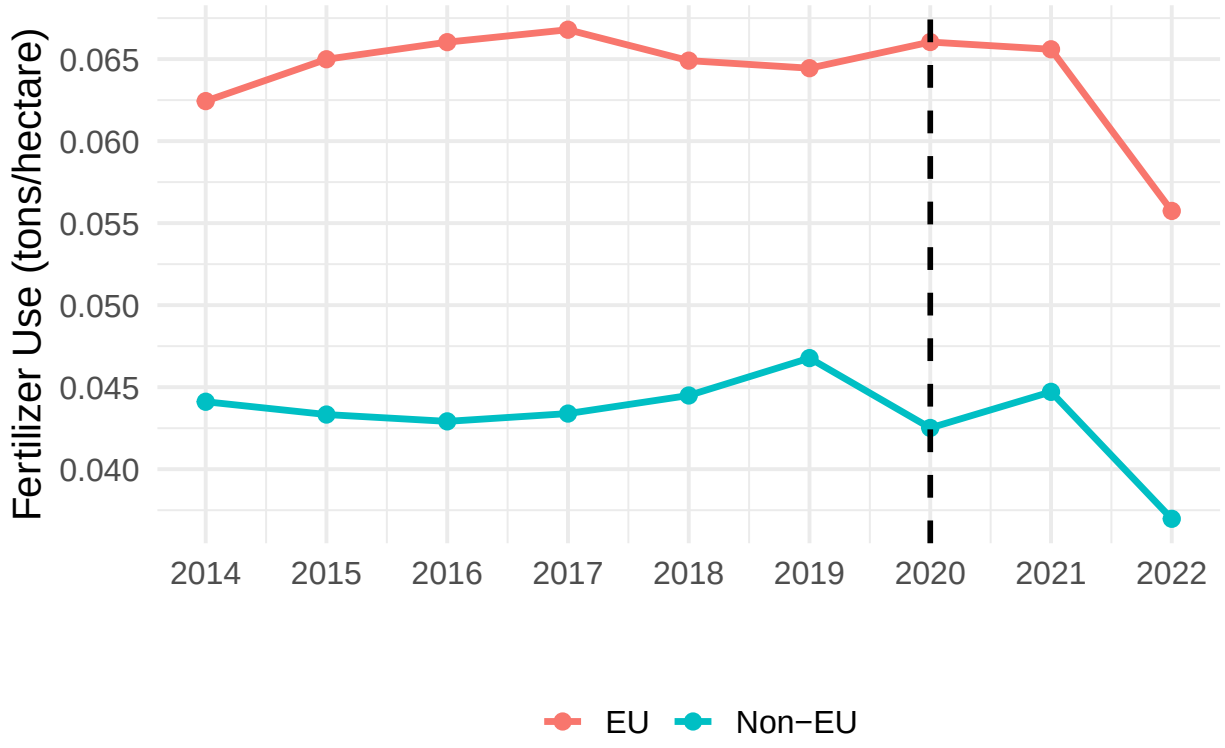


E. Fertiliser Use Per Hectare

Figure 6 shows fertiliser use per hectare for EU and non EU countries, with a vertical line marking the introduction of the Farm to Fork Strategy in 2020. Prior to 2020, fertiliser use in both groups follows a broadly similar pattern, with small fluctuations and no clear divergence. This similarity in pre policy movements supports the type of parallel trends that motivate the use of a Difference in Differences framework.

Fertiliser use is directly linked to N_2O emissions through the role of nitrogen inputs in soil nitrogen cycling. The descriptive trends therefore provide important background for interpreting the emissions patterns discussed earlier. After 2020, fertiliser use does not show a sharp or immediate change in either group, and both display a noticeable decline only in the later years of the sample. These descriptive trends align with the inclusion of fertiliser use per hectare as a key explanatory variable in our regression model, since it remains one of the primary determinants of variation in emissions across countries and years.

Figure 6: Fertilizer Use per Hectare: EU vs Non-EU



5. Empirical Strategy

Our model uses the following population regression function (PRF):

$$\log(N2O_{it}) = \delta(EU_i \times Post2020_t) + \beta_1 Fertiliser_{it} + \beta_2 Rainfall_{it} + \beta_3 AgGDP_{it} + \beta_4 Urban_{it} + \alpha_i + \gamma_t + \varepsilon_{it}$$

Whereby: $\log(N2O_{it})$ = the log of agricultural nitrous oxide emissions per hectare

$EU_i \times Post2020_t$ = treatment (Farm-to-Fork exposure for EU countries, after 2020)

β variables = fertiliser use per hectare, rainfall, agriculture GDP share, urbanization

α_i (country FE) = controls for unobserved, time-invariant country characteristics

γ_t (year FE) = controls for global shocks and region-wide trends

δ = DiD estimate, i.e., the short-run impact of the Farm-to-Fork Strategy on N O emissions

As noted earlier, our empirical approach follows a difference in differences (DiD) framework with country and year fixed effects, i.e., two way fixed effects, illustrated by our PRF above. The DiD model with two way fixed effects enables us to isolate whether EU countries experienced differential post-2020 changes in N_2O emissions relative to non-EU countries, following the implementation of the Farm-to-Fork Strategy in 2020.

The country fixed effects α_i allow us to capture time-invariant characteristics such as geography, soil type, and institutional factors, while the year fixed effects γ_t (gamma t) control for common shocks affecting all

countries, such as global fertilizer-price changes or the COVID-19 pandemic. In this manner, the model enables us to exclude broader global and regional trends which may influence nitrous oxide emissions (N_2O) across our sample's countries. Meanwhile, the δ (delta)coefficient in the PRF provides an estimate for the average change in agricultural N O emissions for EU countries after 2020 relative to non-EU European countries.

6. Findings

This section presents the results from two Difference-in-Differences (DID) specifications estimating the short-run impact of the Farm to Fork Strategy on agricultural nitrous oxide (N_2O) emissions. Model 1 includes only the treatment interaction and fixed effects, while Model 2 extends this specification to include key explanatory variables related to fertiliser use, climatic variation, and economic structure.

Both models incorporate country fixed effects to absorb time-invariant structural differences and year fixed effects to account for shocks common to all countries, such as the COVID-19 period or global fertiliser price increases.

Model 1:

$$\log(N2O_{it}) = \delta(EU_i \times Post2020_t) + \alpha_i + \gamma_t + \varepsilon_{it}$$

The estimated coefficient on the treatment interaction EU × Post2020 is 0.08987, with a standard error of 0.0541 and a p-value of 0.1069.

Because the dependent variable is in logarithms, this coefficient can be interpreted as an approximate 8.99 percent increase in emissions for EU countries after 2020 relative to non-EU countries.

This estimate is not statistically significant at the 10 percent level, reflecting relatively high uncertainty when observable covariates are not included. The within R^2 of 0.091 is typical for a simple DID specification without explanatory and control variable.

```
## OLS estimation, Dep. Var.: log_N2O
## Observations: 288
## Fixed-effects: country: 32,  year: 9
## Standard-errors: Clustered (country)
##             Estimate Std. Error t value Pr(>|t|)
## eu:post2020 0.089871   0.054127 1.66039  0.10692
## ... 2 variables were removed because of collinearity (eu and post2020)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## RMSE: 0.048529     Adj. R2: 0.994004
##                  Within R2: 0.091303
```

Dependent Variable:	log_N2O
Model:	(1)
Variables	
eu × post2020	0.090
	(0.054)
Fixed-effects	
country	Yes
year	Yes
Fit statistics	
Observations	288
R^2	0.99484
Within R^2	0.09130

Clustered (country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 3: Raw Coefficient Output for DID Without Controls

Term	Estimate	Std Error	t value	p value
eu:post2020	0.09	0.054	1.66	0.107

Model 2:

$$\log(N2O_{it}) = \delta(EU_i \times Post2020_t) + \beta_1 Fertiliser_{it} + \beta_2 Rainfall_{it} + \beta_3 AgGDP_{it} + \beta_4 Urban_{it} + \alpha_i + \gamma_t + \varepsilon_{it}$$

The full DID specification includes fertiliser use per hectare, rainfall, agricultural share of GDP, and urbanisation. The coefficient on EU × Post2020 is 0.0976, with a standard error of 0.0189 and a p-value of 4.77 × 10 , making it statistically significant at the one percent level.

In a log–level model with a binary treatment, the coefficient represents an approximate percentage change.

Thus, 0.0976 corresponds to an approximate 9.76 percent increase in emissions for EU countries after 2020 relative to non-EU countries. The R^2 rises to 0.195, indicating improved explanatory power once relevant controls are added.

```
## OLS estimation, Dep. Var.: log_emissions
## Observations: 272
## Fixed-effects: country: 31,  year: 9
## Standard-errors: IID
##                      Estimate Std. Error   t value   Pr(>|t|)
## fertilizer_use    0.000000217 0.00000100  0.216999 8.2840e-01
## rainfall_mm       0.000010231 0.00002986  0.342618 7.3220e-01
## agri_gdp_share    0.027321667 0.01229669  2.221871 2.7275e-02 *
## urban_population -0.010488270 0.00627357 -1.671818 9.5932e-02 .
## eu:post2020       0.097603015 0.01882627  5.184404 4.7739e-07 ***
## ... 2 variables were removed because of collinearity (eu and post2020)
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## RMSE: 0.043938     Adj. R2: 0.994655
##                  Within R2: 0.1951
```

Dependent Variable:	log_emissions
Model:	(1)
Variables	
fertilizer_use	2.17×10^{-7}
	(1×10^{-6})
rainfall_mm	1.02×10^{-5}
	(2.99×10^{-5})
agri_gdp_share	0.027**
	(0.012)
urban_population	-0.011*
	(0.006)
eu × post2020	0.098***
	(0.019)
Fixed-effects	
country	Yes
year	Yes
Fit statistics	
Observations	272
R^2	0.99550
Within R^2	0.19510

IID standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 4: Raw Coefficient Output for DID with Controls

Term	Estimate	Std Error	t value	p value
fertilizer_use	0.000	0.000	0.217	0.828
rainfall_mm	0.000	0.000	0.343	0.732
agri_gdp_share	0.027	0.012	2.222	0.027
urban_population	-0.010	0.006	-1.672	0.096
eu:post2020	0.098	0.019	5.184	0.000

We report two DID models to distinguish between: A simple DID model (Model 1) that captures the raw difference in post-2020 emissions between EU and non-EU countries. A fully specified DID model (Model 2) motivated by our population regression function (PRF).

Both models produce treatment effects of similar magnitude (approximately 9 percent in Model 1 and 9.76 percent in Model 2), but Model 2 is preferred because: A. The standard error is much smaller (greater precision) B. The treatment effect is statistically significant C. Explanatory power of the model increases ($R^2 = 0.195$ vs. 0.091) D. The model aligns with theoretical expectations regarding the determinants of N_2O emissions Thus, Model 2 serves as our primary specification, while Model 1 provides a robustness benchmark showing consistency in effect size.

Table 5: Comparison of the main DID coefficient (Model 1 vs Model 2)

Model	EU...Post2020.Coefficient	Std..Error	p.value	Interpretation
Model 1 (No controls)	0.0899	0.0541	0.1069000	8.9% increase, not significant
Model 2 (With controls)	0.0976	0.0189	0.0000005	9.76% increase, highly significant

Finding A) Estimated Policy Effect

Across both models, the DID coefficient indicates that emissions in EU countries increased relative to non-EU countries after 2020. The preferred specification (Model 2) estimates a 9.76 percent approximate increase in N_2O emissions following the introduction of the Farm to Fork Strategy. These results indicate that EU countries did not experience a short-run decline in agricultural N_2O emissions in the period 2020–2022; instead, emissions remained higher relative to the counterfactual trajectory represented by the non-EU comparison group.

Finding B) Positive coefficient for $EU_i \times Post2020_t$ treatment variable

We hypothesized that the EU's passing of the Green Deal would drive a more extreme reduction in emissions compared to non-EU countries. However, our regression illustrates the opposite - non-EU emissions fell dramatically, while EU emissions actually increased marginally. This gives us the positive coefficient in our regression. To break down this counterintuitive result, we did some research into the success of the Farm-to-Fork Strategy according to the European Commission, media outlets and independent researchers.

The counterintuitive result is not because the Farm-to-Fork strategy failed, but because non-EU countries faced much stronger external shocks. Foremost, global fertilizer prices tripled due to the Russia–Ukraine war, energy price shock and supply chain disruption. While EU farmers were shielded by CAP subsidies, non-EU farmers without these subsidies had to reduce fertilizer use sharply because they couldn't afford it. This alone explains why non-EU emissions fell more.

For instance, the United Kingdom's nitrogen inputs from inorganic fertilizers had fallen about 14–15% year-on-year in 2022, reaching the lowest levels recorded in decades (Gov.UK, "Soil nutrient balances UK, 2022- Statistics Notice"). This reduction was driven primarily by the global fertilizer price surge caused by the Russia–Ukraine war, energy market disruptions, and supply chain shocks, which made manufactured fertilisers prohibitively expensive for many UK farms. The import (CIF) price of NPK fertiliser in the UK peaked at approximately USD 976 per tonne in July 2022 (Indexbox, imarcgroup).

Comparatively, Netherlands presents an interesting case where national fertiliser use changed only modestly after 2020, helped in part by market access (large imports of cheaper Russian urea) and policy moves that reduced the worst of the price shock. Fertilizer use decreased by 3% year-on-year in 2021 and 13% in 2022. The European Commission also documented the huge fertilizer price spike and the policy effort to ensure availability/affordability (member-state interventions, emergency measures) that softened the impact for some farmers. Accordingly, 2022 data for the Netherlands shows the average fertiliser import price reached roughly USD 451 per tonne (Indexbox, imarcgroup). The UK's price was substantially higher than the Netherlands' import average, reflecting differences in import supply-chains, transport costs, exchange rate effects, and domestic market structure. However, this could not be captured by our research as we do not have comparable data for each of our countries across the dataset.

Countries also had specific aggressive reforms: e.g., the UK's agricultural nitrogen use declined sharply after 2019, due to their Environmental Land Management Scheme (ELMS) and stronger nitrogen pollution restrictions, which couldn't be captured by our broader grouping of non-EU countries for the regression.

We can also look at political factors. For instance, since 2023–2024, strong farmer protests, lobbying and changing political priorities have led to softer proposals and debates about watering down the policy targets. Several news outlets and analysts report the Commission shifting toward incentive-based and less prescriptive measures. This political friction could not be captured by our regression, but slowed down the progress of the policy from 2020.

Finally, the Commission's tracking metrics are also being contested. EU countries have very stable, high-quality emissions reporting whereas non-EU countries show more volatility. This can produce visually steep declines in short panels, which could have impacted our regressions too.

Finding C) Controlled variables coefficient analysis

Fertiliser use (not statistically significant): The coefficient is extremely small and not statistically significant at any conventional level. This reflects limited within-country year-to-year variation in fertiliser application and the fact that country fixed effects absorb long-run structural differences in fertiliser intensity.

Rainfall (not statistically significant): Annual rainfall totals are too coarse to meaningfully capture soil moisture dynamics that influence microbial nitrogen processes. This results in no statistically observable relationship with emissions.

Agriculture share of GDP (positive, significant at the 5 percent level): A coefficient of 0.0273 implies that each one-percentage-point increase in agriculture's share of GDP is associated with an approximate 2.7 percent increase in emissions intensity.

Urbanisation (negative, marginal significance at the 10 percent level): More urbanised countries tend to have smaller agricultural sectors, resulting in lower emissions intensity. The coefficient is marginally significant, consistent with structural transformation patterns across Europe.

7. Conclusion

Our analysis offers an early evaluation of the Farm-to-Fork Strategy's initial effects on agricultural nitrous oxide emissions. Broadly, we found that EU member states did not experience short-run reductions in N_2O emissions after 2020 relative to comparable non-EU European countries. Instead, emissions increased by 9-10 percent in the EU during the 2020-2022 period following the policy.

While it would be easy to attribute this unexpected result to the failure of the policy, further research reveals that this divergence appears driven less by shortcomings of Farm-to-Fork itself and more by external shocks - most notably the global fertilizer price surge following the Russia–Ukraine war. This pushed non-EU countries to cut fertilizer use more sharply than EU countries protected by CAP subsidies. Some non-EU governments also enacted independent nitrogen regulations during this period, reinforcing declines in their emissions. However, we were unable to account for such political nuances and price changes in our model due to data unavailability. Our research was a good exercise in understanding that the nuances of policy adoption are often not entirely captured by quantitative studies.

These early findings suggest that the Farm-to-Fork Strategy may require longer timelines and stronger incentives for nutrient management before measurable reductions in N_2O emissions emerge. They also highlight the importance of building resilience into EU agricultural policy, given the sensitivity of emissions to global input-price shocks. Strengthening data quality and harmonised monitoring across Europe would further support effective implementation and evaluation of Green Deal objectives.

As noted earlier, our research design faced several constraints. Our control group includes only five non-EU countries, limiting statistical power and comparability in our investigation. The reliance on IPCC Tier 1 emissions factors and annual aggregates also introduced measurement noise and reduced our ability to capture fine-grained biological processes that drive N_2O dynamics. Finally, the narrow post-policy window (2020-2022) overlapped with unprecedented global shocks, complicating causal attribution. Nonetheless, the Difference-in-Differences framework - combined with country and year fixed effects - gave us a transparent and credible structure for isolating relative changes across groups.

Beyond these internal validity concerns, the external validity of our findings is also limited. The results reflect only the short-run effects of Farm-to-Fork and may not generalise to longer horizons, other greenhouse gases, or different agricultural contexts. Because our comparison group is restricted to a small set of European non-EU countries with distinct institutional and agronomic structures, the estimated effects should not be extrapolated to countries outside this region. Likewise, the early implementation period may not represent the eventual steady-state response to the Strategy, particularly as EU member states continue to adjust to evolving regulatory incentives and market conditions.

Future work should extend the analysis as more post-2020 data become available and employ event-study specifications to better test dynamic effects and parallel trends. Incorporating better quality agricultural and climatic data would also deepen understanding of the mechanisms behind emissions changes. As the EU progresses toward its 2030 targets, continued monitoring will be essential to evaluating the true effectiveness of the Farm-to-Fork Strategy and guiding policy design.

8. References

Batool, M., et al. (2025). “Scenario analysis of nitrogen surplus typologies in Europe.” Nature Food.

Clean Energy Wire. 2021. “EU’s Farm to Fork Strategy impacts climate, productivity and trade.” Factsheet.

European Commission. (2020). “A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system.”

European Commission. List of EU Member States and accession dates. Publications and official documentation of the European Union, Brussels.

FAO. FAOSTAT Emissions Database – Emissions: Agriculture (IPCC Tier 1 methodology). Food and Agriculture Organization of the United Nations, Rome.

FAO. FAOSTAT Fertilizers by Nutrient Database (nitrogen fertiliser use, kg N per hectare). Food and Agriculture Organization of the United Nations, Rome.

FAO. FAOSTAT Land Use Indicators Database (agricultural land area). Food and Agriculture Organization of the United Nations, Rome.

Fertilizer Price in the Netherlands - 2025 - Charts and Tables - IndexBox. https://www.indexbox.io/search/fertilizer-price-the-netherlands/. Accessed 9 Dec. 2025.

Intergovernmental Panel on Climate Change (IPCC). 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Chapter 11: N O Emissions from Managed Soils, and CO Emissions from Lime and Urea Application.

NPK Fertiliser Price Trend, Chart 2025 and Forecast. https://www.imarcgroup.com/npk-fertiliser-pricing-report. Accessed 9 Dec. 2025.

“Soil Nutrient Balances UK, 2022 - Statistics Notice.” GOV.UK, https://www.gov.uk/government/statistics/uk-and-england-soil-nutrient-balances-2022/soil-nutrient-balances-uk-2022-statistics-notice. Accessed 9 Dec. 2025.

Tian, H., et al. (2020). “Global Nitrous Oxide Budget 1980-2020.” Earth System Science Data / Scripps Institution of Oceanography.

Turner, A. J., et al. (2017). “Nitrous oxide emissions are enhanced in a warmer and wetter world.” Proceedings of the National Academy of Sciences, 114(45).

Van der Weerden, T. J. et al. “N O emissions and product ratios of nitrification and denitrification in agricultural soils under varying management.” Soil Biology & Biochemistry.

World Bank. Climate Change Knowledge Portal – Historical Climate Data (annual precipitation). The World Bank Group, Washington, DC.

World Bank. World Development Indicators (Agriculture, value added (% of GDP); Urban population (% of total)). The World Bank Group, Washington, DC.

9. Appendices

Use appendices for more detailed data description, and supplementary tables or charts that provide supporting information that is useful but not central for the story you are telling with your data.

Figure 7: Emissions Over Time (tons/hectare): EU vs Non-EU

