# All that glitters is not green: an analysis on the energy consumption of organic and eco-friendly farming practices in Italy

**Abstract**

In this research, we offer a quasi-experimental estimation of the energy use consumption linked to the shift from conventional to organic and agro-environmental climate (AEC) farms in Italian crop farms from 2014 to 2021. By employing staggered difference-in-differences, we examine the influence of environmentally friendly practices on energy use over various years. Our results suggest that switching to organic methods does not significantly alter energy use per unit of land. However, when considering the energy consumption per unit of production (represented by total revenue), we notice a rise in energy costs. On the other hand, AEC methods do not show a statistically significant difference in energy use, whether per hectare or in relation to total revenue. These findings underscore the intricate relationship between farming methods and energy use. While the beneficial impact of environmentally friendly practices on biodiversity is unquestionable, the shift to such practices does not seem to reduce energy consumption, and, in the case of organic, this could even increase energy consumption per unit of production. These results suggest that fostering the shift to such practices does not contribute to reducing energy consumption in the EU farm sector.

# 1 Introduction

The European Green Deal aims to shift the European Union's (EU) agricultural sector towards a more sustainable system, especially through more environmentally friendly farming practices. The Common Agricultural Policy (CAP) 2023-2027 plays a crucial role in promoting organic practices (ORG) and agro-environment climate (AEC) measures[1], subsidising farms switching to these two alternative practices (Article 28 of Regulation 1305/2013). Indeed, at least 35% of EU rural development funds (administrated at country-level) are dedicated to preserving climate, biodiversity, environment and animal welfare. In line with the Farm to Fork strategy, the CAP supports the overarching objectives such as reducing nutrient losses by at least 50%, decreasing fertiliser usage by 20% and minimising reliance on chemical pesticides by half before 2030; furthermore, the land devoted to organic farming shall be increased to 25% by 2030. These targets demonstrate the EU's commitment towards a sustainable food system and mitigating its environmental and climate impacts (Münch *et al.*, 2023). Outside the agricultural sector, the strategy designed within the Energy Efficiency Directive 2023/1791 tackles the sensitive environmental issue of energy consumption in the EU economy, aiming at its reduction in all sectors by 32.5% at least.

Farming uses energy, both directly and indirectly (Zentner *et al.*, 1998, 2004). Direct energy consumption refers to the use of machinery (fuel, lubricant), water, and energy for heating and electricity; indirect energy is defined by the use of certain inputs, such as fertilisers and agrochemicals, for crop protection, hence the energy needed for their production.

The shifting from conventional to environmentally friendly practices has been found to cause a reduction in the use of chemical products, such as fertilisers (Hole *et al.*, 2005; Reganold and Wachter, 2016), although whether this also entails a reduction in direct energy consumption is not clear yet. This poses the question of whether environmentally friendly practices reduce overall energy consumption (i.e., direct and indirect).

This paper aims to measure the effect on energy consumption the auspicated shift entails, considering farms that abandoned conventional farming for either the organic or AEC one.

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[1] The term environmentally-friendly practices is used throughout the manuscript referring to both ORG and AEC altogether.

Our analysis seems particularly timely since results will shed more light on the issue, unveiling potentially conflicting policy objectives, hence enlightening future policymaking in this respect and providing relevant insights for the current political and sectoral turmoil, with farmers' protests spreading all around the EU.

We add to the existing literature under three main points: i) first, since the controversial and mixed results of the current literature, our results will give a more clear-cut message regarding the impact of switching to ORG in terms of input use, particularly the indirect energy uses reliant on pre-existing soil nutrients (Zentner *et al.*, 2004); ii) to the best of our knowledge, there are no empirical studies assessing how AEC impacts the farms' energy consumption; iii)finally, the empirical applications are often based on experimental studies referring to limited samples of farms and specific crop activities, and often focus on the direct energy consumption only.

From the methodological perspective, while most of the literature uses the unit of cropped land (i.e., energy per hectare) as the basis for comparison (Bertilsson, Kirchmann and Bergström, 2008); however, the reliance on environmentally-friendly practices entails a reduction in yields, hence the production volume per unit of land. Use the unit of production (i.e., total revenues), evaluated at constant conventional prices, as an additional basis of comparison. Finally, empirical application evaluate the impact of switching just after it occurs on the farm. Nevertheless, conversion to AEC and ORG is not an immediate process, as it requires more than one year and a gradual adaptation of farm practices such as crop rotation. Likewise, soil quality needs time to be shaped by the new farming practice, as well as the (potential) spread of weeds and pests, factors that undoubtedly influence crop productivity. To account for the dynamic and long-term nature of the conversion process, we apply a multi-period analysis (Bertilsson, Kirchmann and Bergström, 2008), also accounting for the process complexity, which carries endogeneity issues in input use and the presence of selection bias (Devilliers, Möhring and Finger, 2023).

We use the unique and large microeconomic farm database on harmonised bookkeeping principles, the Italian Farm Accountancy Data Network (FADN), focusing on field crop farms (Types of farming 1 – field crops, 2 horticultural and 3 permanent crops) for the period 2014 to 2021. This includes more than 49,000 observations referring to 37,087 conventional farms, 8,819 organic farms, and 4,927 AEC farms.

To estimate the causal effect of the conversion to both environmentally friendly practices on the farms' total energy consumption, the Difference-in-Differences (DiD) estimator is used in a longitudinal dataset for comparing the average change over time in the energy consumption between the converted and conventional farms.

The staggered DiD estimator developed by Callaway and Sant'Anna (2021) is applied to address dynamic and multi-period conversion and endogeneity issues. This methodological approach accounts for the different timing of the switching and the post-switching period(s), disentangling the time evolution of the effect. Furthermore, the double robust method and clusterisation of the error term are used to reduce the selection and omitted variable bias.

Interestingly, our results contrast with those delivered by the literature; particularly, when measured per area of production, the reduction in energy consumption is not significant for organic farms when compared to their conventional counterpart. The use of energy is even higher for organic farms when measured in terms of monetary unit of the production value. AEC farms do not show a statistically significant decrease in energy consumption for both area- and monetary-related measures.

These results suggest that while the conversion reduces the environmental impact of farming on the environment due to the reduction of agrochemicals, this is not maintained when energy consumption is at stake.

The results are expected to fuel the civil and political debate regarding the role of CAP in contributing to the overarching environmental goals of the EU.

The remainder of this article is as follows: Section 2 outlines the background. Section 3 describes our data. Section 4 discusses the identification strategy and how it can solve multiple issues deriving from the research questions. Section 5 reports the outcomes and the effects of participation in organic or AEC farming types and comments on the results. Section 6 concludes.

## 2 Background

### *2.1 The importance of environmentally friendly production*

Agricultural energy consumption represents, on average, 3% of the total energy use by the whole EU economy for the analysed period. Italy is, on average for the analysed period, the fourth energy consumer concerning in the agricultural sector, with an approximate use of 2.7 thousand tonnes of oil equivalent per year, representing the 10% of the whole EU agricultural energy consumption. Particularly, looking at the trends in energy use in the agricultural sector (see Figure 1), the consumption is increasing at the EU-27 level (16% increase in 2021 with respect to 2014), with Italy increasing approximately by 9%.

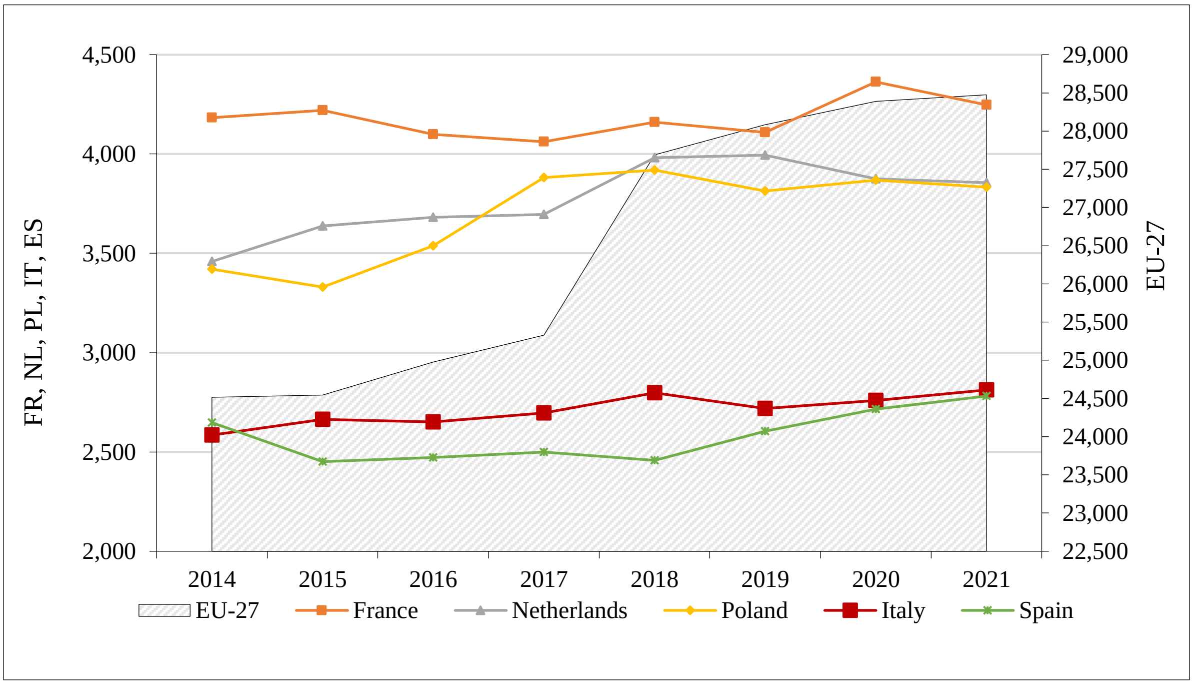


**Figure 1 - Agriculture and forestry energy consumption in thousand tonnes of oil equivalent. EU-27 and major 5 M.S.s, 2014-2021.**

***Source: Eurostat (Simplified energy balances - nrg_bal_s).***

Since this trend gives rise to concern, especially in light of the recent political efforts to reduce the environmental impact of agriculture, enahncing the relevance of this assessment. Energy is consumed directly via the use of machinery (e.g., fuel for tractors, electricity for irrigation or automated machinery) and buildings (e.g., heating of livestock stables and greenhouses) as well as indirectly, through the use of agrochemicals, farm machinery and buildings. The latter is significant and may even overcome the consumption of direct use (e.g., considerable volumes of natural gas are burnt for producing inorganic nitrogen fertilisers). However, these indirect uses of energy are not covered by the statistics presented in Figure 1, hence underestimating the true energy consumption by the farming sector.

In terms of public expenditures, the topic gains even more relevance; since 2016, the CAP incentivises significantly environmental sustainable practices, with the ‘greening’ payments accounting for a significant share of direct payments (around 284 billions euro the total spending of direct payments); the current 2023-2027 CAP is devoting approximately 45 billion euros to the Eco-Scheme (24% of total direct payments), while 30 billion euros from the Pillar 2 are allocated to investment in the environment and climate, the development of woodland and improving the viability of forests, ‘agri-environment-climate’ measures, organic farming, and Natura 2000 payments.

With regards to the organic agriculture, Italy is the first EU MS in terms of operators, representing approximately 21% of the total EU agricultural organic operators (i.e., with more than 75 thousand agricultural operators), and the sixth in terms of organic area, with almost 14% of the total UAA as organic (see Figure 2).

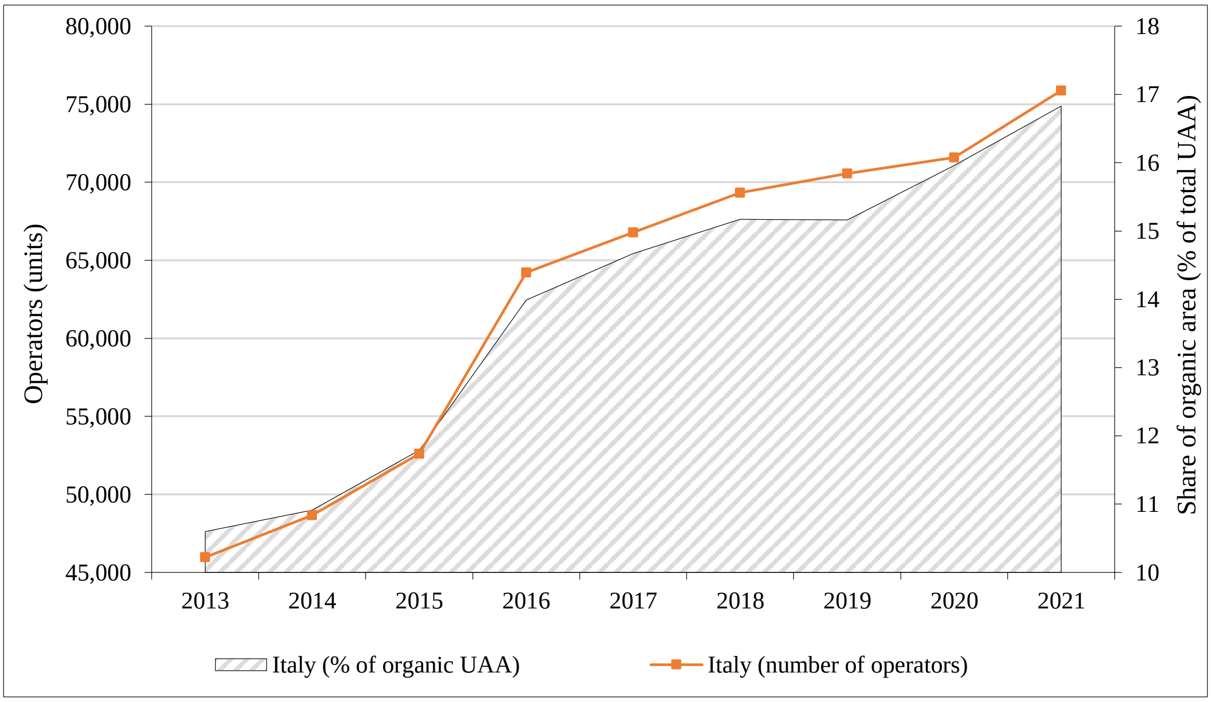


**Figure 2 - Percentage of Organic UAA on the total and number of operators in Italy from 2013-2021**

***Source: FiBL.***

*2.2 Comparison between the eco-friendly and conventional farms: what are the issues?*

Whether or not the CAP should subsidiezed environmentally economic practices stimulated a broad public and scientific debate (see among others (Trewavas, 2001; Kirchmann *et al.*, 2008; Palmer, 2012;

Muller *et al.*, 2017; Ritchie, 2017), delivering very mixed results.

Earlier reviews (Gomiero, Paoletti and Pimentel, 2008; D. Lynch, MacRae and Martin, 2011; Smith, Williams and Pearce, 2015) showed that organic agriculture embeds a lower energy usage and greenhouse gas emissions, on a per hectare basis. This studies also found that net energy production varied more when presented per kilogram of product, with conventional production having the highest levels.

An interesting strand in the literature (De Souza Filho, Young and Burton, 1999; Burton, Rigby and Young, 2003; Dadi, Burton and Ozanne, 2004; Defrancesco, Gatto and Mozzato, 2018) assesses the effect of adoption eco-friendly practices using “duration analysis” that allow to consider early and late adapter stressing the importance of time in the farms’ results. It is important to carry out a dynamic evaluation of the adoption of eco-friendly practices so as to show any change in impact during the implementation period. Adherence to eco-friendly practices conditions operations in pest, disease and weed control, and this conditions energy use. (Swetnam *et al.*, 2004; Riley, 2016; Prager and Schmitt, 2019)

An extended multi-year assessment, beyond the initial year of adoption, provides an understanding of the role of crop rotations and the impact of nutrients or agricultural practices (i.e., the decision to switch has a strong influence on the quality and quantity of inputs or crops in the immediately preceding years) (Bertilsson, Kirchmann and Bergström, 2008; Tuomisto *et al.*, 2012; Kirchmann, 2019; Wilbois and Schmidt, 2019). The design of crop rotation results be a complex issue, and the analysis of only one crop can be misleading (Pimentel *et al.*, 2005; Pimentel and Burgess, 2014; Fess and Benedito, 2018; Redlichová *et al.*, 2021).

A multiple years evaluation is also necessary to take into account that farmers operate according to long-term profit maximisation (Bergström, Bowman and Sims, 2005), in particular when we consider that eco-friendly practices benefit from CAP payments which, in turn, influence the economic performance, hence the agronomic practice and, necessarily, the consumption of energy (Sidhoum *et al.*, 2022).

In summary, to accurately compare the energy use of environmentally-friendly and conventional farms, several aspects need to be considered. These include:

i. Comparing the energy consumption per unit of land and per unit of product.
ii. Evaluating both direct and indirect energy use.
iii. Accounting for the different and staggered timing of the conversion to environmentally-friendly practices.
iv. Considering geographic factors that may impact energy consumption.
v. Comparing data over multiple years and multiple crops.

## 3 Data

In order to address the considerations set out in Section **Error! Reference source not found.**, it is n ecessary to rely on granular data providing energy consumption data, land and farm characteristics, and a panel structure to assess the time dynamics of the farming practices investigated and their implementation at the farm level, hence considering multiple crops.

The Italian FADN is used, allowing for the set of data and characteristics described above. We investigate the 2014-2021 period as per the uniform application of the CAP, considering both the organic and AEC farming practices, besides including the last released FADN data point. The homogeneous application of the CAP within the studied period ensures the conditions hold equal for the whole policy programming period. The choice to use Italy as a case study comes from its importance in terms of agricultural producers and, hence, energy consumption within the EU, as well as its large number of organic operators and the area devoted to organic production.

In terms of agricultural production, the analysis focuses on crop farms exclusively, hence excluding those specialised in animal and mixed production. Since the technology of production, hence the production function strongly influences the consumption of energy, the lesser the difference between farming types, the more robust the estimates– as the lesser the potential bias. Indeed, we assume that farms specialised in arable crops, horticulture and permanent crops (using the 8-Class Farm Type Classification (ToF) corresponding to ToF 1, 2 and 3, respectively) rely on similar production technology. However, the inclusion of individual fixed effects ensures that any time-invariant specific factor is accounted for in the estimation strategy.

The energy consumption, either direct or indirect, is measured in monetary terms (i.e., the farm's expenses), deflated by input-specific deflators to account for price trends (see Appendix for more details). Furthermore, we account for the total farm expenses in energy inputs, hence considering multiple products, as farmers make their choices based on product mix and crop rotations (McCormack, Thorne and Hanrahan, 2020; Aragón, Oteiza and Rud, 2021; Diewert, 2021), and given the fact that organic farms cannot have conventional production processes, we are comparing the overall farm's energy consumption on its total area of production and revenues.

As pointed out by the literature, different energy measurements prevent any comparisons between studies, besides representing two different perspectives (van der Werf et al., 2007). On the one hand, expressing the energy consumption in terms of area units (e.g., hectares of land) highlights the contribution of environmentally friendly farms as providers of non-market goods (e.g., biodiversity); on the other hand, when expressed in product units (e.g., kilograms or per monetary unit value), it emphasises the role of farms as providers of market goods, such as food and fuel (Cherubini and Strømman, 2011; Foresight, 2011). These two different types of measurements often yield opposite results (Smith, Williams and Pearce, 2015).

When evaluating the economic performance of organic farms a crucial caveat arises: organic products benefit from the market price premium, which renders direct comparisons of total revenue misleading and requires a more nuanced approach.

First, we found the relationship between the prices of organic and conventional using the Fisher Price Index for each year. In a few words, with this mode, we can determine how many times organic prices are greater or lower than conventional farms. We use the inverse of this index with the organic total revenue to report these values at conventional price levels. Finally, we use the Fisher Price Index between years to build an index to rebase the price in 2015 (to maintain the base price using other inputs at the same time).

By considering the prices of conventional products as a common price indicator bet, we can isolate the true impact of production practices on total revenue (Rao, O'Donnell and Ball, 2002; Hill, 2004; Coelli *et al.*, 2005; Baldoni, Coderoni and Esposti, 2021) (for more detail about this procedure, see the Appendix).

Another issue concerns the definition of direct and indirect energy consumption. According to (Zentner *et al.*, 2004), this distinction is crucial when comparing energy consumption between environmentally friendly and conventional farming practices. For example, relying heavily on machinery to control pests instead of using natural alternatives like green manure might increase overall energy consumption despite lower fertiliser and pesticide use.

In the present study, energy consumption is measured using two different denominators. The first is the amount of land (i.e., UAA); hence, indicators of energy use are expressed on a hectare basis. The second is the overall amount of production in monetary terms, that is, the total revenue generated by the farm. In this latter case, energy consumption is expressed per monetary unit value (in percentage terms). The energy costs are considered as total energy costs, as well as direct and indirect energy costss.

The average total energy cost per unit of land differs between conventional and eco-friendly farms (ORG and AEC) (Table 1). The average level of this indicator is way lower in these latter two groups of farms, being around 40% of the level observed in conventional farms. However, note that a very high level of heterogeneity exists within each group. It appears that there are significant differences among farms based on various factors related to productivity and structure. For instance, farms belonging to the AEC group tend to be larger on average compared to the other two groups, as shown in the upper part Table 1 shows some farm characteristics, one of which is worth mentioning: AEC farms are, on average, larger than the farms of the other two groups. This suggests that the comparison between groups should explicitly account for such heterogeneity to address potential selection bias.

The cost of energy per unit of production (TotEnerg/TR) is relatively high across all three groups. These costs represent at least 21% of total farm revenues (as shown in Table 1), indicating that energy costs have a significant economic impact on farming, and an increase in energy costs could negatively affect farm economic performance. Although the indicator is similar for both conventional and AEC farms, it is significantly higher for ORG farms, reaching around 25%.

The total energy cost incurred in agriculture is the combination of two energy components. Among these, the indirect component holds more significance than the direct component. In fact, the indirect component contributes to more than half of the total energy cost, as shown in Table 1. Therefore, it is crucial to address energy issues in agriculture and not just focus on the direct component. It has been observed that the importance of direct energy costs is similar in the conventional and AEC farms, which is around 38%. However, in ORG farms, the share of direct energy consumption is higher, reaching an average of 46%. Therefore, ORG farms rely more on direct energy than indirect energy compared to other farms. This could be due to the fact that ORG farms do not use chemical fertilisers. Therefore, they have to rely more on direct energy like fuel. Additionally, ORG farming may require more mechanical operations, such as controlling weeds and plant diseases, than conventional and AEC practices, which could also contribute to the higher direct energy consumption.

The dynamic of conversion years between conventional farms in ecofriednly pratice ( treated farms) is reported both for ORG (Table 2) and AEC (Table 3).

For the ORG and AES, we note a non-homogenous trend in adhesions. The dynamic is similar due to the fact that both the agricultural systems can be indemnified by the 2nd pillar of CAP.

Considering that the CAP is divided into programming periods that, in this specific case, embrace the period after 2014 until 2022 (this last year is not available on FADN yet) in the first year of a programming CAP period, the number of applications is higher than the least period.

This effect is due to high levels of resources being available in the first years in comparison with a decrease in the next years.

This stimulated the application requests during the first years of the CAP Program for Pillar 2. In the next period, the application becomes more selective, with more stringent requests to adhere to payment schemes.

Finally, we can note that the AEC's adhesions before 2015 are absent; this is because this scheme was activated in 2015, during the first year of the programming period of the CAP.

| Acronyms | Variable | Conventional Farms 37087 observations | | | Organic Farms 8819 observations | | | AEC Farms 4927 observations | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Standard Deviation | Median | Mean | Standard Deviation | Median | Mean | Standard Deviation | Median |
| TR | Total revenue [€] | 101922.68 | 240516.25 | 44257.24 | 88501.98 | 237372.81 | 36173.63 | 143834.68 | 250477.77 | 69732.32 |
| UAA | Utilised Agricultural Area - UAA [Ha] | 23.94 | 44.35 | 10.36 | 28.30 | 55.26 | 13.50 | 40.53 | 65.05 | 19.10 |
| K | Total Capital [€] | 522311.19 | 2318795.96 | 229992.00 | 550557.69 | 1347193.47 | 239216.00 | 732693.59 | 1715425.89 | 337323.00 |
| Labour | Labour [hours] | 3743.84 | 4578.18 | 2500.00 | 4280.66 | 5949.81 | 2900.00 | 4333.77 | 5052.49 | 2880.00 |
| TotEng | Total energy [€] | 18724.53 | 35648.50 | 8317.00 | 15233.23 | 41957.12 | 6505.00 | 27922.48 | 46011.11 | 12382.00 |
| Dir_Eng | Direct Energy [€] | 7113.09 | 13882.18 | 3247.00 | 7004.37 | 17055.75 | 3429.00 | 10685.15 | 18983.30 | 4884.00 |
| InDir_Eng | Indirect energy [€] | 11611.43 | 24657.06 | 4691.00 | 8228.84 | 29512.57 | 2514.00 | 17237.33 | 31516.71 | 6862.00 |
| TotEng/TR | Total Energy/Total Revenue [%] | 0.22 | 0.20 | 0.20 | 0.25 | 0.79 | 0.18 | 0.21 | 0.12 | 0.19 |
| TotEng/UAA | Total energy/UAA (Euro/ha) [€/Ha] | 2443.84 | 9354.83 | 757.03 | 961.69 | 4357.36 | 495.91 | 985.83 | 1255.39 | 662.22 |

**Table 1 - General Statistics of the sampled farms subdivided by conventional, ORG and AEC farms.**

Note: Values per farms other in the case of Total energi per unit of land and over total revenues.

| Year | Conventional | Year of transition to ORG | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Before 2015 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| **2014** | 4611 | 707 | 56 | 44 | 49 | 12 | 14 | 8 | 11 |
| **2015** | 3839 | 450 | 308 | 53 | 61 | 16 | 18 | 9 | 13 |
| **2016** | 3866 | 373 | 221 | 292 | 74 | 20 | 23 | 9 | 16 |
| **2017** | 4070 | 334 | 209 | 186 | 307 | 24 | 30 | 11 | 21 |
| **2018** | 3948 | 272 | 167 | 141 | 241 | 241 | 44 | 12 | 32 |
| **2019** | 3940 | 228 | 117 | 135 | 213 | 195 | 272 | 18 | 43 |
| **2020** | 3902 | 207 | 106 | 123 | 192 | 165 | 239 | 158 | 43 |
| **2021** | 4036 | 188 | 104 | 111 | 174 | 146 | 210 | 123 | 231 |

**Table 2 – Table of farmers with the year to transition in organic production**

| Year | Conventional | Year of transition to AEC | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Before 2015 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| **2014** | 4611 | 0 | 84 | 349 | 117 | 83 | 54 | 30 | 33 |
| **2015** | 3839 | 0 | 116 | 409 | 135 | 85 | 57 | 32 | 33 |
| **2016** | 3866 | 0 | 75 | 564 | 152 | 100 | 83 | 41 | 38 |
| **2017** | 4070 | 0 | 69 | 491 | 259 | 125 | 93 | 43 | 49 |
| **2018** | 3948 | 0 | 47 | 408 | 201 | 260 | 122 | 56 | 68 |
| **2019** | 3940 | 0 | 38 | 331 | 162 | 208 | 238 | 72 | 76 |
| **2020** | 3902 | 0 | 34 | 312 | 151 | 191 | 206 | 135 | 87 |
| **2021** | 4036 | 0 | 36 | 334 | 151 | 190 | 179 | 106 | 202 |

**Table 3 – Table of farmers with the year to transition in AEC production**

# 4 Identification strategy

The causal analysis between environmentally friendly and conventional farming practices, to assess the impact on energy consumption, needs to account for the different timing of conversion (i.e., when exactly the farm enters into the specific environmentally friendly regime).

Recent empirical researches shed light on innovative approaches for determining causal impacts in panel data contexts, with a significant portion focussing on the DiD estimator, particularly in the field of economics and environmental science (Arkhangelsky and Imbens, 2023).

The DiD estimator estimate is determined by the difference in the change of the outcome of interest (i.e., the energy consumption) before and after a specific treatement (i.e., the farmer enrolling in environmentally friendly agricultural practices) in the group that received the treatment compared to the group that did not receive it, the control group:

$$\left(\bar{y}_{TREAT}^{POST} - \bar{y}_{TREAT}^{PRE}\right) - \left(-\bar{y}_{CONTROL}^{POST} - \bar{y}_{TCONTROL}^{PRE}\right) \qquad (1)$$

Where $\bar{y}$ is the outcome, POST and PRE suffixes indicate the period after and before the treatment, respectively, TREAT defines the treated group while CONTROL the control group.

However, farmers engaging in environmentally friendly agricultural practices are included in the treated group once they adopt these practices, with the timing of such treatment varying between them. According to (Arkhangelsky and Imbens, 2023), this resembles a particular type of DiD, which requires overcoming the canonical two-way fixed effect (TWFE) estimators (Goodman-Bacon, 2021), which may deliver biased estimates, with the staggered DiD. The latter resembles a more robust estimator, better accounting for omitted variables and selection biases that often affect the DiD estimators (Abadie, 2005; Sant'Anna and Zhao, 2020). In light of this, we apply the recent staggered DiD estimator developed by (Callaway and Sant'Anna, 2021).

As the first step, it is crucial to define the treated group for testing the Conditional Parallel Trend Assumption (CPTA) (see Assumption 4 and 5 in (Callaway and Sant'Anna, 2021)). The two alternative assumptions introduced by Callaway and Sant'Anna (2021) are to use two groups as the basis for the CPTA: defining the "never-treated" group as those farms that are never treated in the analysed period, the authors posit that the average outcome for this group and that representing those initially treated has to display a parallel trend in the absence of treatment, while within the “Not-Yet-Treated” group (i.e., those farms that are not treated in the initial period but will receive the treatment further on) it is assumed that the CPTA is fulfilled (i.e., farms that are not yet treated but will be treated afterwards fulfill the CPTA between these two moments in the panel).

Since not all farmers have the propensity to join ORG or AEC, we have ruled out using “Never Treated” groups because the comparison is made using farmers who, by definition, either do not want or cannot change their production in eco-friendly. When considering the group of “Never-Treated” farms, these may maintain the same outcome trend for the whole period, in contrast to the treated group, which may have different trends in the periods before and after the treatment, thwarting the CPTA. As suggested by Callaway and Sant’Anna (2021), we adopt the “not yet treated” as the control group, overcoming the issue; indeed, it allows to account for the conversion period, i.e. an intermediate period of treatment in which the converting farms are not yet fully treated.

## 5 Results and Discussion

The results of our analysis do not allow us to conclude on any significant difference in energy consumption—be it direct, indirect, or total—per unit of agricultural area (UAA) for both environmentally friendly agricultural practices (see Figure 3 and Figure 4).

While a big chunk of the applied literature (Lampkin, 1999; Gomiero, Paoletti and Pimentel, 2008; IFOAM, 2008; D. H. Lynch, MacRae and Martin, 2011; Smith, Williams and Pearce, 2015; Meemken and Qaim, 2018) finds a net decrease in energy consumption when shifting from conventional to organic farming, when considering the staggered and dynamic nature of the conversion to organic, such negative balance does not seem to be significantly different from zero.

The analysis of the Total Energy consumption in terms of UAA (Figure 3c) - indicates a reduction only after the first years of the transition. The increase of variability in the results that can derive, for example, from different meteorological conditions, and does not allow to maintain such negative difference as statically significant in time.

The assessment of conventional farms in the AEC transition reveals that the total energy consumption in terms of UAA follows a similar trend to that of ORG. However, unlike ORG, the energy consumption becomes statically negative (i.e. less energy is required) at the end of the mandatory adhesion period (after five years).

The evaluation of total energy in relation to total revenue (Figure 4c) shows a pronounced consumption in ORG compared to conventional farms. This difference remains consistently high even after the conversion period. This is not in contrast with the results for total energy consumption in terms of UAA: the (non-statically) lower energy use per hectare does not correspond to a lower energy use per unit of produced revenue.

In contrast to ORG, the transition in AEC has no particular impact on total energy consumption in terms of total revenue.

This result is interesting: the two eco-friendly measures show different energy consumption trends in comparison with the conventional: ORG has an increase in terms of total energy consumption per total energy obtained, while AEC has no differences.

The analysis of direct and indirect energy consumption per UAA in ORG adhesion (Figure 3a and Figure 3b) shows how the positive trend in energy consumption stems from both of these energy sources. The higher energy use is primarily driven by the greater reliance on energy-intensive fuel sources[2] in organic farming, which may be caused by the fact this requires more mechanical operations to compensate for the impossibility to use chemical controls for weeds and pests even reported in (D. H. Lynch, MacRae and Martin, 2011; El-Hage Scialabba, 2013; Smith, Williams and Pearce, 2015).

Regarding (private and public) market good production, conclusions are again controversial; the slogan of the CAP for a greener agricultural system seems not to be efficient for the Italian case study. Consumers are willing to pay a premium price for organic, hence 'greener' or more sustainable products, although such enhanced sustainability seems not to happen: at constant conventional prices, organic production consumes more energy than its conventional counterparts, although the indirect energy use (i.e., fertilisers and agrochemicals for plant protection) do not show any significant difference. All in all, the environmentally friendly agricultural practices subsidised through the CAP seems not to be more parsimonious in their energy consumption when evaluated at their monetary

[2] The analysis of the different components of direct and indirect energy is not reported in this paper for lack of space but is available upon request.

outputs. Although besides the objective of this study, such non-significant reduction of energy use per hectare and the even increased use of energy inputs in terms of monetary output signal that these may have a null to even negative effect on the sustainability of the EU farming system: the indirect effects on GHG emissions may be controversial – e.g., a non-significant effect on indirect energy use hinder the reduction of GHG emissions of organic production methods, as well as a heavier use of machinery for weed control.

Nevertheless, it is fundamental to note how we are focussing on energy expenses, not considering other indicators and externalities (e.g., biodiversity, soil and water quality) of both AEC and organic farming. Therefore, this is not an overall assessment of the net welfare effect of such transitions, as it would be reductive and misleading (Greene *et al.*, 2011), but anyway, an important insight for policymakers and for further research on the issue of energy consumption, which may have been under-scrutinised in the policymaking and which deserve more thorough thinking and analysis.

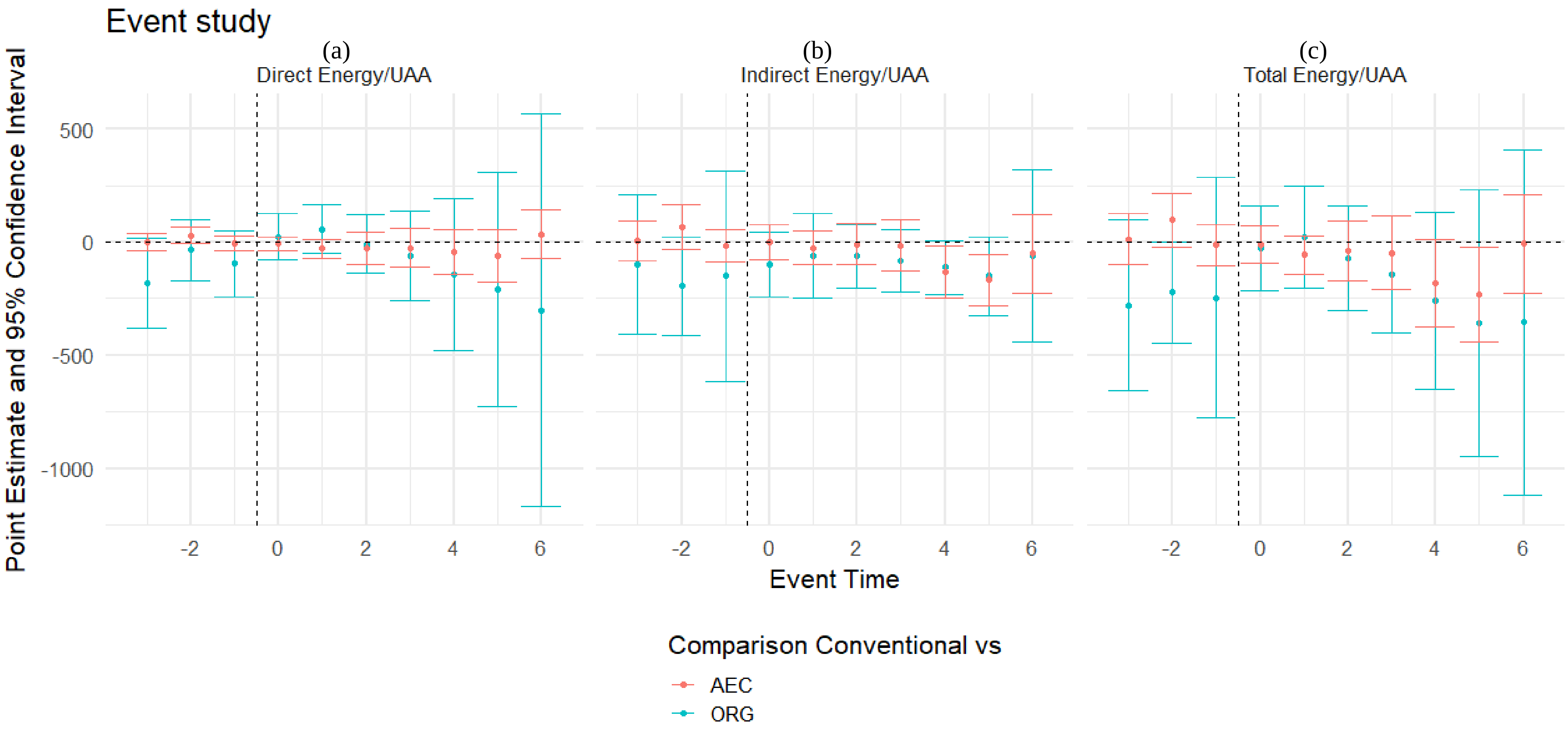


**Figure 3 - ATT of the shift to AEC and ORG from Conventional in terms of Direct, Indirect, Total energy expenses per hectare of UAA[3]**

[3] These figures plot point estimates and associated 95% confidence intervals clustered at the farm level for the impact on incidences of a shift in ORG or AEC. We have included estimation time-varying covariates to verify the conditional Parallel Trend Assumption. The robustness checks is conducted removing including or removing certain contol variable. All the estimations is robust about the parallel trend assumption at 0.05 level.

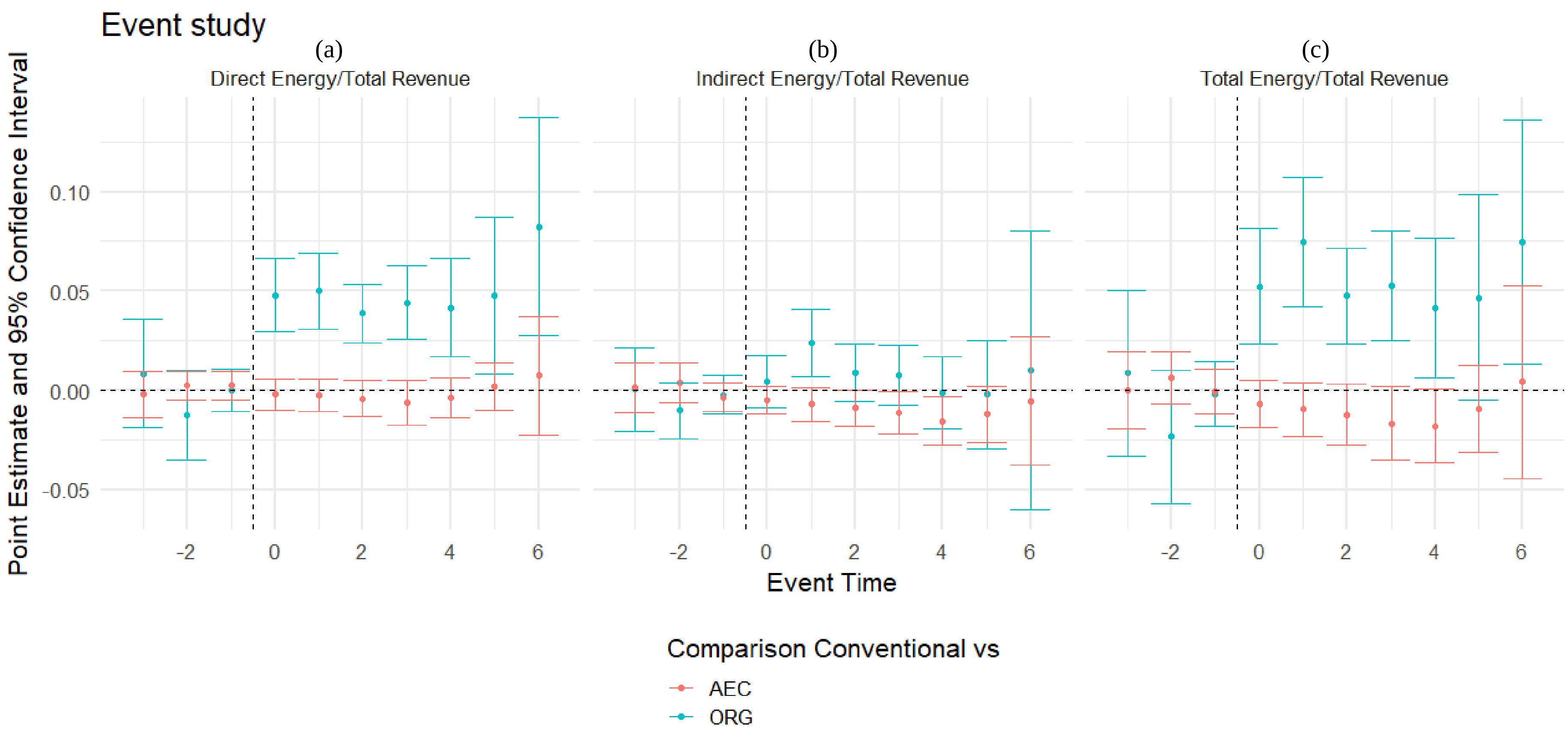


**Figure 4 - ATT of the shift to AEC and ORG from Conventional in terms of Direct,Indirect, Total energy expenses per hectare of UAA)[4]**

[4] These figures plot point estimates and associated 95% confidence intervals clustered at the farm level for the impact on incidences of a shift in ORG or AEC. The specification of estimation includes a vector of farmers' covariates to verify the conditional Parallel Trend Assumption. All the estimations is robust about the parallel trend assumption at 0.05 level.

## 6 Summary and Concluding Remarks

The relationship between energy and environmentally friendly practices represents an intricate question. A quasi-experimental design using a Difference-in-Difference estimator is adopted to disentangle how and if the energy consumption differs in the AEC and Organic farms.

To analyse the time impact during the "treatment" (i.e. the shift between conventional in Organic or AEC), we adopt a staggered DiD using the Callaway and Sant'Anna, 2021 approach to overcome self-selection bias and the bias derived from early and late adopters.

In particular, switching to organic farming methods does not significantly alter energy use per unit of land area in Italian crop farms. However, when accounting for energy consumption per unit of production (total revenue), there is an increase in energy costs for organic farms.

Agro-environmental climate (AEC) farming methods do not show a statistically significant difference in energy use compared to conventional farms, whether measured per hectare or total revenue.

The results underscore the complex relationship between farming methods and energy use. While organic and AEC practices benefit biodiversity, their influence on energy use differs.

The findings suggest that current EU policies and CAP subsidies aimed at reducing energy use and emissions through environmentally friendly farming practices may not be as efficient as intended, at least for the Italian case study.

Further research is needed on the energy consumption of organic and AEC systems to inform policymakers and improve environmental performance according to EU sustainability goals.

In summary, while organic and AEC practices benefit the environment in other ways, their energy savings compared to conventional farming appear minimal based on this analysis of Italian crop farms. The higher energy use of organic farming in terms of production value is notable. Overall, the complex link between farming methods and energy requires additional scrutiny to enhance policy outcomes.

Considering the question raised by (Woodward, 1995; Connor, 2008): "Can the organic feed the world?" this could be partially re-formulated into "Can the organic feed the world with lower energy consumption?".

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## Appendix

### *6.1 Deflating methodology.*

The estimated energy consumption was based on multiple inputs that did not have the same price trend over the period considered.

For this motivation, we adopt a specific deflator for each variable as reported in the following table:

| Macro Classification | | Variable | Price index | Source | Price index |
|---|---|---|---|---|---|
| | | *Traction Fuel* | Motor fuels Price Index base 100 = 2015 | Eurostat | Price indices of the means of agricultural production, input-rebased to 2015= 100 |
| | | *Lubrifiant* | Lubricants Price Index base 100 = 2015 | Eurostat | Price indices of the means of agricultural production, input-rebased to 2015= 100 |
| | | *Heating fuel* | Fuels.for.heating - Price Index base 100 = 2015 | Eurostat | Price indices of the means of agricultural production, input-rebased to 2015= 100 |
| | **Direct Energy Costs** | *Electricity* | Electric Price Index base 100 = 2015 | Eurostat | Price indices of the means of agricultural production, input-rebased to 2015= 100 |
| **Total Energy Costs** | | *Warming* | Fuels for heating Price Index base 100 = 2015 | Eurostat | Price indices of the means of agricultural production, input-rebased to 2015= 100 |
| | | *Drinking water* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| | | *Irrigation water* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| | **Indirect Energy costs** | *Fert* | Fertilisers and soil improvers Price Index base 100 = 2015 | Eurostat | Price indices of the means of agricultural production, input-rebased to 2015= 100 |
| | | *Crop Protection* | Plant protection products and pesticides Price Index base 100 = 2015 | Eurostat | Price indices of the means of agricultural production, input-rebased to 2015= 100 |
| | | *Leasing Costs* | GDP Deflator Index base 100 = 2015 | FRED | Gross domestic product (implicit price deflator) |
| **Capital** | | *Fixed capital* | GDP Deflator Index base 100 = 2015 | FRED | Gross domestic product (implicit price deflator) |
| | | *Total Capital* | GDP Deflator Index base 100 = 2015 | FRED | Gross domestic product (implicit price deflator) |
| | | *Machinery Equipment and Plant* | Machinery and other equipment Price Index base 100 = 2015 | Eurostat | Price indices of the means of agricultural production, input-rebased to 2015= 100 |
| | | *Coupled Direct Payments* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| | | *Direct Decoupled Payments* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| | | *Rural Development Subsidies non-annual payments* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| | | *Rural Development Payments for Agri-Environmental Schemes* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| **CAP** | | *Rural Development Payments for Agri-Environmental-Climate Measures* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| | | *Rural Development Payments for Organic Measures* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| | | *Rural Development Payments for Less Favourable Areas* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| | | *Rural Development Payments fo Animal Welfare* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |
| | | *Rural Development Payments for Natura 2000 Areas* | HICP - base 100 = 2015 | Eurostat | HICP - annual data - rebased to 2015= 100 |

**Table 1 - Source of price indexes used for deflating**

### *6.2 Price comparison between organic and other farms.*

A comparison of energy consumption relied on the product, but it is necessary to take into account that farmers make their choices based on product mix and rotations. For this reason, we follow the prevalent literature about the comparison of similar to other studies (McCormack, Thorne and Hanrahan, 2020; Aragón, Oteiza and Rud, 2021; Diewert, 2021)

In order to conduct a meaningful comparison, we need to consider multiple products instead of relying on a single oneIt is important to note that, this methodology is necessary to overcome the criticisms regarding comparisons between organic and conventional farms.This allows us to overcome the problem of unit of measurement of a single product ( the yield of a hectare of sugar beet is not comparable with the yield of leguminous crops that are grown for their grain, for example, field bean ) The organic farm benefits from a different price for the output, and comparison using total revenue can generate misleading results. To solve this issue, it is necessary to use the price for organic (AEC has not this problem) using the price for conventional. We adopt a Fisher bilateral procedure similar to (Rao, O'Donnell and Ball, 2002; Hill, 2004; Coelli *et al.*, 2005; Baldoni, Coderoni and Esposti, 2021)[5]

1. $(Index\ Convert\ Laspeyres)_t = \frac{\Sigma(P_{i,t,Conv} \times Q_{i,t,Org})}{\Sigma(P_{i,t,Org} \times Q_{i,t,Org})}$ with Con is conventional , Org is Organic, i = culture and t= year
2. $(Index\ Convert\ Paasche)_t = \frac{\Sigma(P_{i,t,Conv} \times Q_{i,t,Org})}{\Sigma(P_{i,t,Org} \times Q_{i,t,Org})}$
3. $(Index\ Convert\ Fisher)_t = \sqrt{(Index\ Convert\ Laspeyres)_t \times (Index\ Convert\ Paasche)_t}$

We adopt the Fisher index, considering that it incorporates both the information of Laspeyres and Paasche index (Hill, 1999, 2004; Baldoni, Coderoni and Esposti, 2021).

This type of approach overcomes the naïve method that relied on the simple sum of the yields to compare the outputs of two farms. Summing the quantity of products to compare outputs between two farms might seem intuitive, but this approach has significant limitations while the Fisher's price index adopted allow to be adopted even in the case of i) different type of outputs, ii) different units of measures, in reason that the rational farms want to reach the optimal level of production when marginal revenue is equal to marginal cost (and not using only quantity of input and output):

Moreover, the Fisher index uses prices as weights, allowing for the aggregation of different products into a single measure that reflects both the quantity and the value of outputs

[5] The code can be obtain after request.