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FISCAL RESPONSE IN COVID-19 CRISIS – CASE OF THE EUROZONE

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ABSTRACT

Aim: The paper makes two important contributions to the fiscal policy literature during the COVID-19 pandemic, analyzing the way Eurozone countries responded with fiscal expansion or restriction as a means to manage the pandemic crisis. This research investigates the national governments' fiscal policies introduced to manage the COVID-19 pandemic within economic, political and institutional contexts, focusing on European countries that are part of the Eurozone. It demonstrates similarities and heterogeneity in three dimensions of fiscal policy responses to COVID-19 (the size of fiscal spending, the type and targets of fiscal policy responses) across 19 Eurozone countries, in the period effective from the pandemic until January 2022. **Methods:** A Cross-Country Analysis and Statistical Analysis in 19 Eurozone Countries was applied. **Results:** Eurozone countries with strong economies (Germany, France) implemented fiscal expansion directly to cope with the pandemic while weaker economies (Estonia, Spain) responded late. Additionally, the business sector was supported first, instead of the health sector, by governments. **Conclusions:** The paper makes two important contributions to the fiscal policy literature during the COVID-19 pandemic. The original contribution of this research is that it is one of the first comparative analysis studies to focus on the European region regarding national fiscal policy responses to the COVID-19 pandemic. Existing studies on COVID-19 policy responses have primarily focused on public health measures.

Key words: fiscal policy, COVID-19, cross-country; comparative analysis, Eurozone

JEL codes: E42, E52, E63, F15, F42, O38, P5

INTRODUCTION

The new form of crisis that most governments had to face, the COVID-19 pandemic, created a new burden for many countries around the world, including the European ones. There is not much evidence in the literature on how pandemic-type crises, such as COVID-19, can affect short-term output dynamics [Barišić and Kovač 2022]. Additionally, the political, economic and institutional systems were challenged by this new form of crisis. All the past crises, as well as the new one (the pandemic), highlight the importance of the national fiscal policy response in boosting employment levels, raising the living standards of people and maintaining social capital and economic development [Cottarelli et al. 2014]. In tandem, it is argued that fiscal policy should be assigned a crucial role that is more systematically beneficial to respond in times of crisis. For example, as Kominek and Stiglitz [2022] state, a well-tailored fiscal policy response of modestly increasing taxes on high-earners and delaying non-urgent fiscal expenditures would be more efficacious than locating the crisis response only within monetary policy tools. Each country needs to adopt fiscal policies that are appropriate to its unique contexts and circumstances. The European Commission rescinded its strict

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rules on state aid (March 2020), allowing EU member states to channel needed funds through aid schemes to help them face the COVID-19 crisis [Anderson et al. 2020], although, concerns have since been raised that richer, less indebted member countries have the fiscal capacity to help their businesses more [Anderson et al. 2020], which is exactly the case in Eurozone countries (see Fig. 1). The primary goal of this research paper is to make a timely cross-country comparison of Eurozone countries on their fiscal policy responses to the COVID-19 pandemic. Given the important economic links between Eurozone countries, one of the key factors for ensuring that a fiscal stimulus is effective will be for it to occur in a coordinated manner [Alvaro 2020]. It is widely documented that a fiscal stimulus in one euro area country generates positive externalities in the rest of Europe's economies [Dabla-Norris et al. 2017].

Our main research questions are the following:

- What kinds of fiscal policies were introduced by Eurozone countries in response to the COVID-19 crisis?
- How did governments' fiscal policy responses vary across Eurozone countries?

Geared toward answering these specific research questions, we used a Eurozone comparative perspective to analyze 19 countries' fiscal policies for the whole period of the COVID-19 outbreak, to provide a view of the different ways these countries managed the crisis, emphasizing the fiscal policies, perspectives, sectors and stages. The COVID-19 crisis, in fiscal terms, was comparable with a war, taking into account that the budgetary cost in some countries, like in the United States, was nearly equivalent to what they spent on war production in 1943 [Gillian 2019]. Additionally, we wanted to check if the Eurozone fiscal response to the COVID-19 crisis followed the results of the worldwide cross-country comparison of Chen et al. [2021].

The paper makes two important contributions to the fiscal policy literature during the COVID-19 pandemic. One primary contribution of this research is that it is one of the first studies on the comparative analysis that focus on European region regarding national fiscal policy responses to the COVID-19 pandemic. Existing studies on COVID-19 policy responses have primarily focused on public health measures [e.g. Ferguson et al. 2020, Flaxman et al. 2020, Chen et al. 2021].

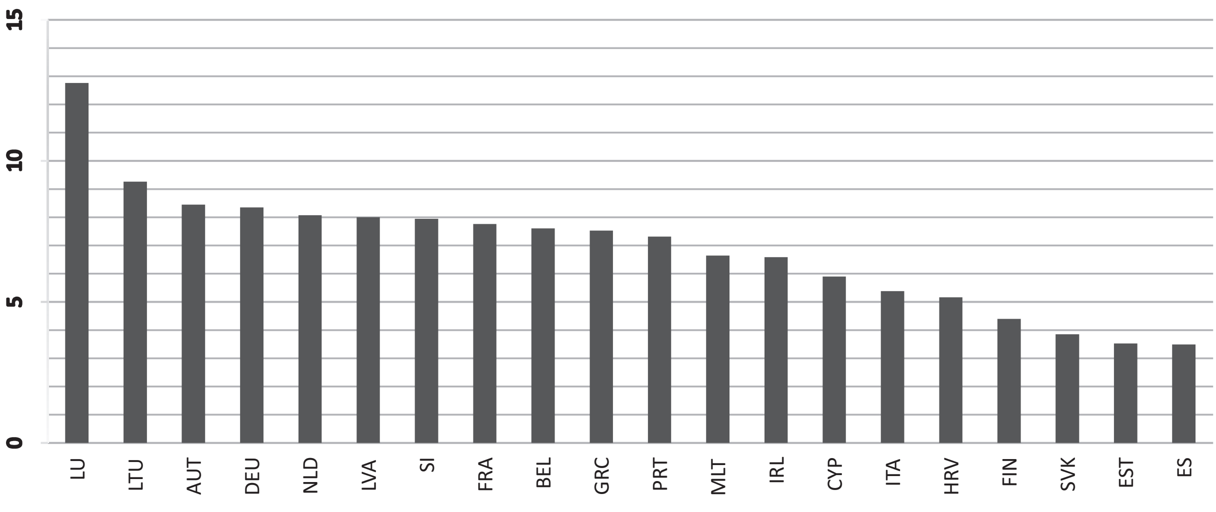

Fig. 1. Eurozone Fiscal Spending in the Pandemic [% of GDP]

Notes: The figure reports estimates of additional discretionary fiscal spending and foregone revenue during 2020 as a share of GDP. These numbers are calculated as the sum of "health", "non-health" and "accelerated" spending above the line categories. The abbreviations mean: LU – Luxembourg, LTU – Lithuania, AUT – Austria, DEU – Germany, NLD –Netherlands, LVA –Latvia, SI – Slovenia, FRA – France, BEL – Belgium, GRC – Greece, PRT – Portugal, MLT – Malta, IRL – Irland, CYP – Cyprus, ITA – Italy, HRV – Croatia, FIN – Finland, SVK – Slovakia, EST – Estonia, ES – Spain.

Source: IMF Fiscal Policy Database.

However, there has been little research using a cross-country comparative study of national fiscal policies during the COVID-19 pandemic, including the paper on which we based our study. Secondly, this study proposes a three-dimensional theoretical scheme [the size of fiscal policy spending, fiscal policy targets and fiscal policy tools] to inform and compare fiscal policy making and decisions when dealing with an extreme crisis such as COVID-19. On the other hand, some researchers analyzed both macro and micro levels of fiscal response in the pandemic crisis, with the aim of evaluating policy making success or failure and the spillover effect in firms [Gourinchas et al. 2021]. Overall, when analyzing the characteristics and the policy focus of the countries in fiscal spending in specific sectors (e.g. health or business sector), with the intention of expanding their fiscal abilities, it is useful to check the effectiveness of these policies or to confirm the possible waste of public money. As Romer [2021] stated, in the paradigm of the United States, it seems that the fiscal response to the pandemic was largely ineffective and wasteful, as it concentrated the response in sectors that were not overly important for the economy.

SCHEME AND METHOD OF COMPARATIVE POLICY ANALYSIS

This study advances an ad hoc three-dimensional scheme to guide a comparative analysis of fiscal policy responses to COVID-19. This scheme is consolidated in Table 1. The first dimension comprehends the size of the COVID-19-related fiscal spending. Moving forward, the rest of the dimensions outline the fiscal policy adoption.

Almost every country's economy has been affected

Table 1. Scheme of comparative policy analysis of fiscal responses to COVID-19

Dimensions	Policy focus of each dimension	Key indicators/sectors/tools
First dimension	Size of fiscal policy spending	Total COVID-19-related fiscal policy spending (2019 US dollars)
		Total COVID-19-related fiscal policy spending as a share of GDP (%)
Second dimension	Fiscal policy targets	Health sector
		Business sector
Third dimension	Fiscal policy tools	Direct government spending[1]
		Direct government cash transfers[2]
		Debt and contract relief[3]
		Tax benefits, cuts & exemption[4]
		Tax deferral & social security contribution delay[5]
		Government credit assistance (loans & loan guarantees)[6]
		Government subsidies to business[7]

[1] Government direct spending refers to the direct spending on goods and services purchased by governments [such as medical supplies and equipment].
[2] Direct government cash transfers mean government cash payments for poor families and unemployment insurance payments. In these cases, governments are not doing the actual spending.
[3] Debt contract and relief means the government is freezing financial obligations during the COVID-19 pandemic, such as stopping loan repayments, preventing services like water from stopping supplies.
[4] Tax benefits, cuts and exemptions indicate offering tax benefits and cuts for people or businesses and adding tax exemptions.
[5] Tax deferral and social security contribution delay involves extending tax filing and payment deadlines and delaying business social security payments.
[6] Government credit assistance includes loan guarantees to support businesses.
[7] Government subsidies for business refers to government cash subsidies for the business sector.

Source: [Chen et al. 2021].

by the spread of the coronavirus [Chen et al. 2021]. The IMF's fiscal policy tracker [2020] conveys that some Eurozone countries took unprecedented fiscal actions with expansive fiscal spending (Germany, France) to cope with the pandemic and economic downturn, while other Eurozone countries with smaller economic capacity [Estonia, Spain] had very limited fiscal policy responses and related public spending. There is a strong discussion among policymakers, central banks and political leaders, that economies with heavy debts should not, also cannot, stimulate fiscal expansionary policy, in any case, due to their diminished economic capacity [Kannan

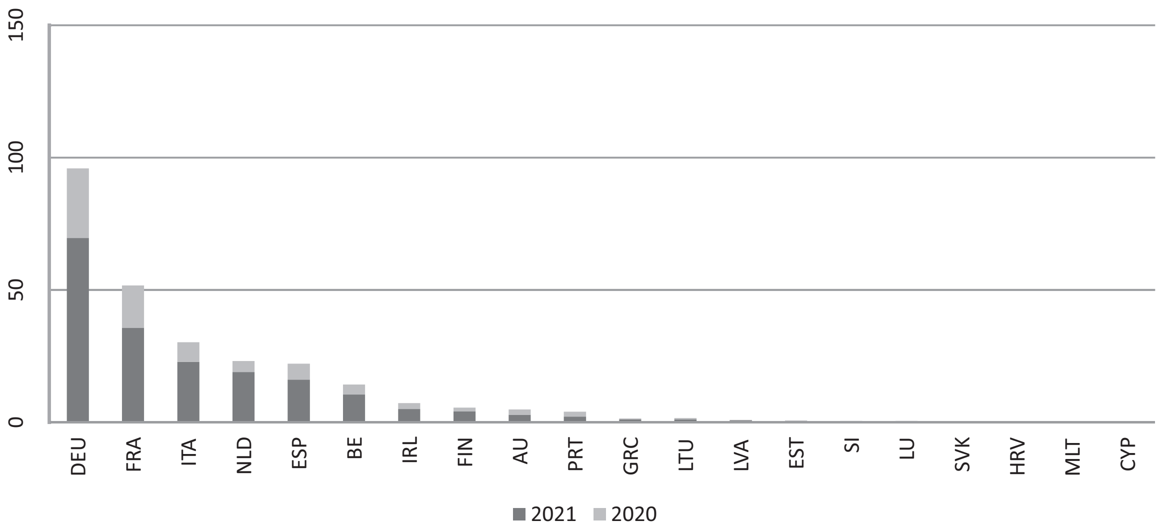

Fig. 2. Fiscal Spending on Health Sector in Eurozone

Note: The figure reports estimates of total direct government spending in USD billion during 2020 and 2021. These numbers are calculated as the sum of "health" above the line categories. Abbreviations of country names as in Figure 1.

Source: IMF Fiscal Policy Database.

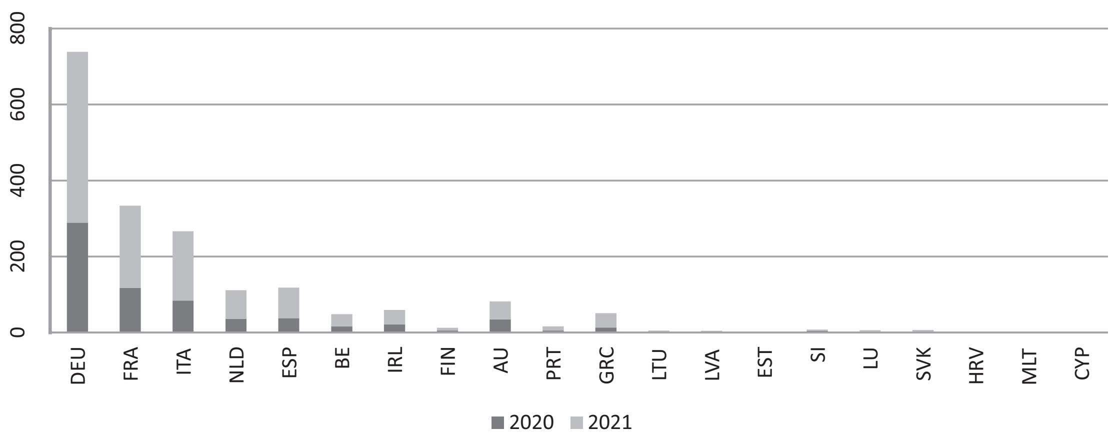

Fig. 3. Fiscal Spending in Non-Health Sector in Eurozone

Note: The figure reports estimates of total direct government spending in USD billion during 2020 and 2021. These numbers are calculated as the sum of "non-health" above the line categories. Abbreviations of country names as in Figure 1.

Source: IMF Fiscal Policy Database.

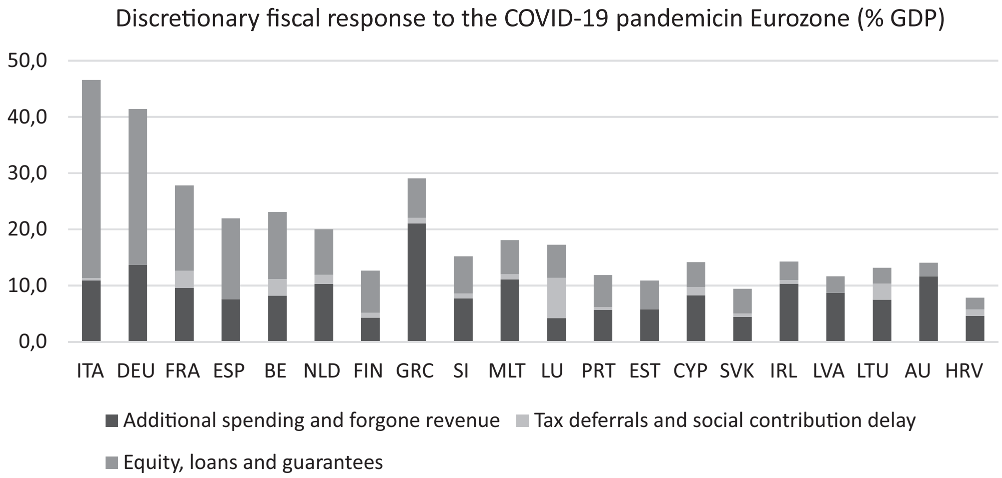

Fig. 4. Discretionary fiscal response to the COVID-19 pandemic in Eurozone [% GDP]

Note: Estimates as of 5 June 2021. Percentages of GDP are based on the July 2021 World Economic Outlook Update. Abbreviations of country names as in Figure 1.

Source: IMF, Database of Country Fiscal Measures in Response to the COVID-19 Pandemic.

et al. 2009, Nickel and Tudyka 2013]. Eichengreen [2020] argues that in the fight against the COVID-19 pandemic, "all appropriate tools" implies "no matter the debt" while the importance of fiscal policy is to underline the importance, instead of monetary policy, of facing the COVID-19 crisis, instead of monetary policy, to face the COVID-19 crisis [Eichengreen 2022].

In general, countries spent money to deal with the COVID-19 pandemic. It would also have been desirable to reallocate some fiscal spending to relax supply constraints in specific sectors [i.e. firms] to reduce future inflation [Korinek and Stiglitz 2022]. In the same line of thinking, Krugman [2020] strongly proposed the adoption of a sustained, productive program of stimulus in place, instead of implementing short-term measures every time a crisis unfolds.

The second dimension is comprised of the targets of fiscal policy responses. Fiscal policies were originated to assist different sectors across countries [OECD 2020]. At first stage, COVID-19 consisted of a health crisis, but then the problem affected the global economy, as financial assistance was needed to help the affected private firms, households, individuals, etc. The third dimension of our scheme shed light on the adopted fiscal policy tools. Governments reacted to the pandemic using a broad variety of fiscal policy tools [Cavallo and Cai 2020]. The function of fiscal policies mainly focused on transposing taxes and fiscal spending. The key tools adopted for the third dimension were recommended by OECD [2020] and IMF [2020].

Fiscal policy measures taken by governments globally to mitigate the negative effects of the pandemic tried to mitigate the economic shock after the outbreak of the pandemic and the shutdown of economies. Policymakers, political leaders and economists reached their decisions aiming to protect employment, contain the fall in private consumption and support disposable income [Anastasatou and Anyfantaki 2023]. Each country was affected differently by the pandemic and responded in different ways [Dimitropoulou and Theofilakou 2021]. Measures taken included direct budget-relevant measures, benefits, tax and social security contribution deferrals, job retention schemes, plus support both for businesses and households. Furthermore, fiscal measures were taken that did not impact the budget directly, such as loans, public guarantees, government loans, liquidity and capital injections to the business sector (e.g. to airline companies) [Anastasatou and Anyfantaki 2023].

There is significant cross-country heterogeneity within the Eurozone area in terms of both the amount and the composition of such measures (see Fig. 3). The International Monetary Fund (IMF) created a Fiscal Monitor [IMF 2021] to monitor fiscal policy responses during the pandemic, where measures were classified into two categories: a) above-the-line support and b) below-the-line measures. Above-the-line measures included public spending on the health sector and on the "non-health" sector, grants, and tax and social security contributions deferrals. Following that, the second category included measures such as state-guaranteed loans, liquidity support and government guarantees. The composition of measures adopted by each Eurozone country were different. Large Eurozone economies, such as Germany, France, Italy and Spain, gave support through government loans and guarantees to a greater extent (measures below-the-line) than above-the-line support (Fig. 3). On the contrary, Greece ranked first in the above-the-line measures, with overall measures accounting for 17.5% of 2020 GDP [Anastasatou and Anyfantaki 2023].

METHODS AND DATA: A COMPARATIVE POLICY ANALYSIS PERSPECTIVE

We accumulated data about national fiscal policy responses from the International Monetary Fund's Tracker of Policy Responses to COVID-19. Additionally, each country's economic, social, political and institutional background was outlined from the World Bank Open Data and Eurostat. Data regarding the COVID-19 cases and deaths were gathered from the University of Oxford's COVID-19 Government Response Tracker and from the COVID-19 Dashboard at John Hopkins University. We limited our data to the 19 countries that participate in Eurozone because we wanted to demarcate the characteristics of this specific area and to draw attention to the long pathway that the European Union has to follow to achieve European Integration. It should be mentioned that the creation of the Economic and Monetary Union of the European Union was a big step toward European integration but a lot still remains to be done regarding the absence of a Common Fiscal Policy in the European Union. Furthermore, the sample size in this study covers the whole population of the Eurozone and represents a broad variation in income levels, economic circumstances, geographical variation, government composition, political structure, and fiscal capacities, highlighting the gravity of the COVID-19 outbreak. The study period was limited to between January 2020 (when the official outbreak of COVID-19 infected all Eurozone countries) and January 2022 (when the crisis was mostly over and effectively managed).

MIXTURE OF FISCAL POLICY RESPONSES TO COVID-19 AMONG EUROZONE COUNTRIES

Figure 4 depicts an ascending trend of the COVID-19 infection rate in the Eurozone area in 2020 and a bigger one in 2021. Additionally, the COVID-19 death rate was rising, but compared to the infection rate, the death rate was meaninglessly low. The rate of fiscal spending was expected to follow the infection rate, but according to Figure 4, the fiscal capacity could not follow the health sectors' needs. So, we see that in 2021, the fiscal capacity accelerated more than in 2020, when there was the first outbreak of the COVID-19 crisis. In addition, it is depicted that Eurozone countries with strong economies more easily extended their fiscal capacity than countries with smaller economic capabilities.

More explanatory, our statistical analysis shows that, direct government spending reached its peaks in July 2020 [896.1%], October 2020 [937.4%], and February 2021 [940.5%], while the highest fiscal expansionary policy was seen in April 2021 [943.0%] for the whole period examined. Fig. 4 presents an upward trend of the COVID-19 infection rate in the Eurozone area in the first seven months of 2020. The first peak of COVID-19 infections was reached in May 2020 in the Eurozone, with a total of 1,061,000 cases. Following that, in the next few months, the numbers decreased until August 2020, when the cases started increasing faster, reaching the highest peak in January 2022.

As for cases of death, the COVID-19 death rate peaked in June 2020, with a total of 29,846 deaths in the Eurozone. Then the death rate declined, rising again in September 2020 and reaching its highest peak two years later, in January 2022. Along with the growing number of cases, governments' fiscal spending followed, quickly increasing its capacity and reaching a peak in July 2021.

A formal pairwise correlation test was performed to show that the COVID-19 infection rate is statistically correlated with the size of the COVID-19-related fiscal spending [0.637] at a 1% significance level. For some Eurozone countries, the line of government spending follows the rising effect of COVID-19 infection cases (Fig. 2). Along with the growing number of cases, governments' fiscal spending rose quickly, but particularly in Eurozone countries that have stronger economies, such as Germany and France, while the expansionary fiscal spending in medium-sized economies (Greece, Portugal) was low and in smaller economies (Malta, Estonia), it was found below medium.

Our statistical model that was extracted from the correlation analysis is:

$$\text{Eurozone Fiscal Spending} = \\ = 0.637 \cdot \text{COVID-19\_Infections} + u^{*}$$

* 1% significance level

where u – is random variable meaning that Eurozone Fiscal Spending could be affected by any other factor, which cannot be foreseen, as well as the model has been built to a normal distribution with SE 5%.

DIFFERENTIATION ON FISCAL POLICY RESPONSES TO COVID-19 ACROSS EUROZONE COUNTRIES

Elaborating the proposed three-dimensional scheme, this study executes a variation analysis of the three dimensions of fiscal policy responses to COVID-19 by taking the pandemic prevalence, political establishment, and fiscal state of affairs into account. Two-sample t-tests were performed to determine if statistical significance exists between the two types of country groups (i.e. high vs low) regarding the average dissimilarity in fiscal spending. By the same token, Table 2 displays the outcome of the two-sample t-tests for the size of public spending.

Table 2 shows the percentage distributions of fiscal policies in two dimensions – fiscal targets and tools – for the Eurozone countries. Focusing on fiscal policy targets, it was found that Eurozone countries

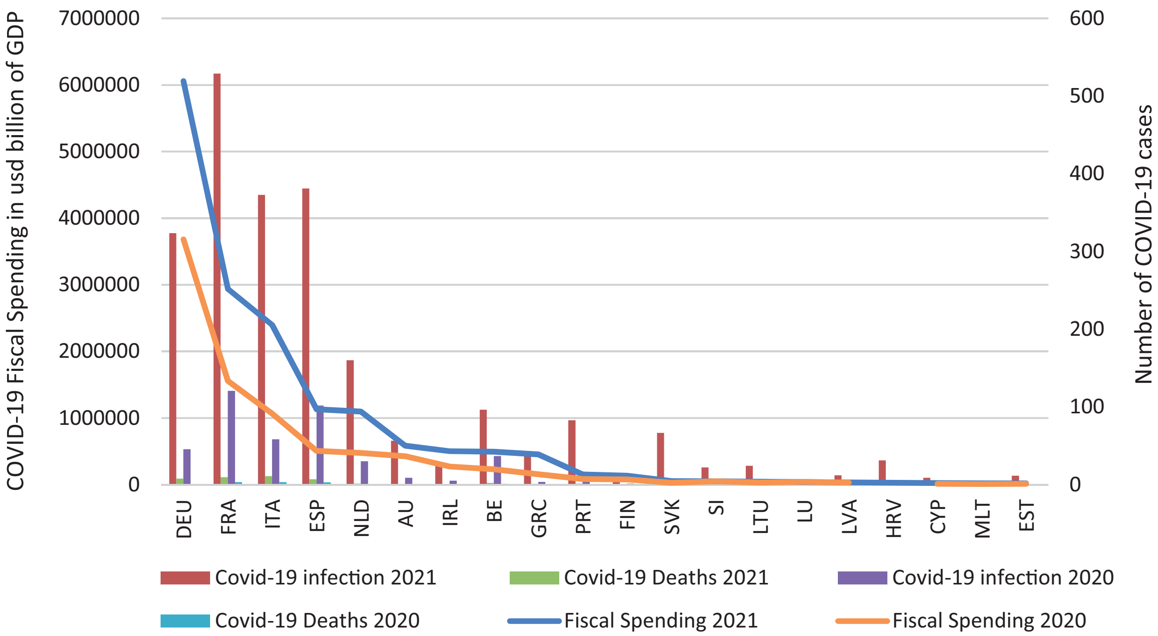

Fig. 5. Outbreak of the COVID-19 and Fiscal Spending Response in Eurozone in billion USD [2020, 2021]

Notes: The infection rate is measured by the COVID-19 cumulative cases standardized per 1 million population. The death rate is measured by dividing the COVID-19 cumulative death number by the cumulative confirmed cases. The data are the accumulative value at the end of July. Data sources: Johns Hopkins University's Coronavirus Resource Center and University of Oxford's COVID-19 Government Response Tracker

Source: Author's calculations

gave priority mostly to the business sector (43.34) over the health sector (5.74), no matter its relevance to the nature and impacts of the COVID-19 crisis. This can be explained, firstly, by the instant impact of the pandemic on the Eurozone economies, so simultaneously, the countries' fiscal policy first contributed to mitigating the negative effects on the economies. Additionally, turning our focus to fiscal policy tools, we find that debt and contract relief (103.50) was the most popular fiscal tool, with government subsidies to business (37.75) following. The smallest numbers are calculated on tax benefits (2.57), tax deferral and social contribution delay (12.70), and government credit assistance in loans and loans guarantees (5.61), where the mean is very low.

Table 2. Percentage distributions of fiscal policy targets and fiscal policy tools in Eurozone

Eurozone	Mean [billion USD]
Fiscal Policy targets	
Health Sector	5.74
Business Sector	43.34
Fiscal policy tools	
Direct government spending	49.08
Direct government cash payment	103.66
Tax benefits, cuts, and exemptions	2.57
Tax deferral and social security contribution delays	12.7
Debt contract and relief	103.5
Government credit assistance (loans & loan guarantees)	5.61
Government subsidies to business	37.75

Note: Data are cumulative values at the end of July (*N* = 105 observations).

Source: Author's calculations based on the University of Oxford's COVID-19 Government Response Tracker data

Chen et al. [2021] supported that there is a significant association between countries with higher income and fiscal expansion, while Wang et al. [2022] support that this is not the case, as fiscal expansion is the remedy for future economic growth, no matter the country's income level.

We can conclude that in the Eurozone economies, the focus was on fiscal response based on securing the economies from the crisis first (measures that support the private sector are higher) and then responding to the health crisis and rising expenses related to health crisis management.

PANDEMIC PREVALENCE

A higher prevalence of the pandemic is expected to have had more adverse effects on the economy and thus to have triggered stronger fiscal policy responses [Alberola et al. 2020]. This paper analyzes the short-term effects of the fiscal policy measures undertaken in the Eurozone during the COVID-19 crisis, expecting the same results as Barišić and Kovač [2022], in the short-term, and determines that the fiscal measures were generally effective.

We found that countries with a higher level of COVID-19 infection had higher fiscal spending. Specifically, Eurozone countries with a higher COVID-19 infection rate announced expansionary fiscal policies that amount to 62.5% of GDP, as compared to 19.10% in Eurozone countries with a lower infection rate. Also, the same significant differences in fiscal policy responses applied between Eurozone countries with high and low levels of COVID-19 deaths but in higher fiscal spending expansion rates (87.50% of GDP). This outcome stands in contrast to the findings of Chen et al. [2021], who showed that there were no significant differences in fiscal policy responses between countries with high and low levels of COVID-19 death rates.

Political leaders in democratic countries are more likely to expand their fiscal policy quicker in times of crisis [Chen et al. 2021]. The majority of Eurozone countries are Centralized Republics, except for Austria and Germany, which are federal, and Luxembourg and the Netherlands, which are constitutional monarchies. This study finds that the size of the fiscal spending is much higher in non-federalist countries (93.26%), according to the results of Table 3, which can be explained by the above-mentioned three different forms of constitutions (Federal Democracy, Constitutional Monarchy and Centralized Republic). To be more consistent, this finding implies an association between federalism and fiscal policy targets of subnational governments [Chen et al. 2021]. It was expected that political leaders in democratic countries are more likely to take active fiscal actions in times of a national health crisis [Chen et al. 2021]. This study summarizes that countries with a federalist system announced fiscal spending that amounted to 75% of GDP, as compared to 93.26% in non-federal countries, which followed a pattern of more limited fiscal spending. This outcome comes in contrast to what Auerbach et al. [2020] found, that the federal government and states skyrocketed their fiscal spending in response to the COVID-19 crisis, but this was the case for the USA. Our results regarding the role of government structure come in contrast to the findings of Chen et al. [2021], the evidence of whom proved an association between the level of democracy and fiscal policy targets, as fiscal spending was much higher in highly democratic countries than in less democratic countries. Additionally, this contrast can be explained by the political and institutional differences between the USA vs Eurozone vs OECD areas; the first is a federalist union, while the second is far from a federalist union of countries and the third constitutes a mixture of different types of countries in the global economy.

Compared to Europe, the USA was more likely to offer direct cash assistance to households, whereas European governments were more likely to support the business sector with loan guarantees [Durante 2022]. As shown in Table 2, the business sector was strongly supported by governments (mean 43.44) while they gave lean aid to the health sector (mean 5.74). The size of the difference between those two sectors is very significant, in the fiscal targeting in the Eurozone.

The extent to which each country can expand its fiscal policy or not is an important factor which is interconnected with its income level. Countries with a higher income level and stronger fiscal capacity expand their public expenses quicker and easier, implementing fiscal expansionary policies, while instrumenting external funding in parallel [Alberola et al. 2020]. Regarding the economic and fiscal conditions, the income level picked as a variable where we find that low-income countries had a low level of fiscal spending in the Eurozone, which amounted to 76.40% of their GDP. In general, the capacity and space of the fiscal policy is an important factor [Chen et al. 2021]. It was expected that countries with higher income levels have stronger fiscal capacities and would mobilize resources more easily and directly, leading to fiscal expansion [Benmelech and Tzur-Ilan 2020]. The World Bank assigns the world's economies into four income groups, high, upper-middle, lower-middle, and low, but in our research, which is focused on the Eurozone area, we are using only two income level groups – high and low – to simplify our research.

Regarding the concern that richer, less indebted member countries had the fiscal capacity to help their businesses more [Anderson et al. 2020], in contrast to other weaker Eurozone countries, this was not the case in the Eurozone. Solidarity among EU countries worked, economic funds and help pacts were instituted in all Eurozone countries from the EU's common treasury, leaving aside the rule of Northern vs Southern countries. Additionally, as shown in Figures 3 and 4, the fiscal capacity in the Eurozone countries was extended relative to the outbreak of COVID-19 infections, no matter the debt capacity of each country.

Concerning the way fiscal policy tools were adjusted to the needs of each country, in the Eurozone example, direct government cash payments (103.66) and relief of debts (103.50) concerned mostly state aid to targeted sectors. Direct government spending was a fundamental tool, too, but with smaller impact (49.08). It was expected that tax benefits, deferrals and social security contribution delays would have attracted bigger attention by governments, but the mean numbers of our research make us conclude that they were not a priority in health crisis management. The mean numbers in Table 3 show that primary attention was given in helping businesses cope with the COVID-19 crisis, associated with our analysis findings, explaining the need of business sector for instant cash in order to keep their liquidity balanced and avoid unexpected bankruptcies, plus the mean of government subsidies to the business sector states this idea (37.75).

Table 3. Comparison of COVID-19 fiscal spending [%GDP] by Eurozone countries

Comparison of COVID-19 fiscal spending [%GDP] by Eurozone countries					
Dimension			**Size of fiscal spending**		
Country groups [cross-sectional data *N* = 105]			**Mean**		**Difference**
	[1]	[2]	[1]	[2]	[1]–[2]
Pandemic Prevalence			High	**Low**	
COVID-19 infections [%]	High [*n* = 19]	Low [*n* = 89]	62.50%	19.10%	43.40%
COVID-19 deaths [%]	High [*n* = 16]	Low [*n* = 89]	87.50%	19.10%	68.40%
Political institutions and government structures					
Federal	Yes [*n* = 16]	No [*n* = 89]	75.00%	93.26%	–18.26%
Economic and fiscal condition					
Income level	High [*n* = 16]	Low [*n* = 89]	75.00%	76.40%	–1.40%

Note: The data are the cumulative values at the end of July [sectional data: *N* = 105]. If a country is above the median value, the study characterizes the country as high, where there are high numbers of COVID-19 infections, deaths, government policy response index, federal government structure, and income level capacity.

Source: Author's calculations based on Data sources: Johns Hopkins University's Coronavirus Resource Center, University of Oxford's COVID-19 Government Response Tracker, IMF Fiscal Monitor, Freedom House and World Bank's Open Data.

EUROZONE AND FISCAL RESPONSE TO COVID-19 CRISIS

According to Figures 2 and 3, Germany, as expected – characterized as the strongest economy in Europe and thus in the Eurozone – was the first to follow fiscal expansionary policy, both in 2020 and in 2021. The federal government of Germany adopted three supplementary budgets to combat the COVID-19 crisis: EUR 156 billion (4.7% of GDP) in March 2020, EUR 130 billion (3.9% of GDP) in June 2020, and EUR 60 billion (1.7% of GDP) in March 2021. Measures taken include expenses for healthcare equipment, hospital capacity and R&D (vaccines), public expenditure to secure jobs and income both for the active population and unemployed people, while 50 euro billion was given as grants to small business owners and self-employees persons in accordance with tax deferrals. The stimulus package in June 2020 included a temporary VAT reduction, grants for SMEs, expanded credit guarantees for exporters and export-financing banks, and subsidies in green energy and digitalization [IMF 2021].

In addition to the federal government's fiscal package, many local governments provided support with their own measures to stimulate their economies. The new wave of infections in 2021 made the government correspond with additional fiscal measures to support families, young workers and businesses, including revenue compensation, extended access to grants, apprenticeship subsidies, public loan guarantees, tax loss carryback and additional support for the health sector.

In France, the authorities introduced four amending budget laws during March – November 2020, increasing the fiscal capacity to cope with the health crisis, valued at approx. 180 euro billion. Additionally, a handsome package of public guarantees was introduced for bank loans and credit reinsurance schemes (more than EUR 315 billion). Fiscal support measures included boosting health insurance for vulnerable people and their caregivers, spending on health supplies, social security and tax payments deferrals for companies, accelerated refunds of tax credits (i.e. VAT), wage support for workers, financial support for SMEs, self-employed persons and low-income households, deferrals for rent and utility payments for SMEs, an additional allocation for equity investments of companies in difficulty, extensions of expiring unemployment benefits, preservations of rights and benefits of disabled people and people in need, and support measures for difficult sectors such as the automotive and aerospace industries, with the aim of promoting a greener economy with new investments [IMF 2021].

Moving our interest to the wounded south of Europe, from the previous economic crisis of 2008, Greece's government implemented a fiscal package of measures valued at about 13.7% of GDP in 2020. These measures included loan guarantees, which were financed both from national and EU resources. Fiscal support measures concerned spending in the health sector for hiring additional staff in hospitals (doctors, nurses), procurement of medical supplies, bonuses for staff in health sector, cash stipends, pensions and benefit payments for vulnerable people, the unemployed and people in need, additional cash benefits for workers in business sectors that were hit hard by the crisis and the self-employed, support for SMEs, household loans, paid leave for parents with children that were not going to school, liquidity support for firm sectors that were closed because of the lockdowns, rent reductions, loan guarantees, refundable advance payments, deferrals for tax and social security contributions, VAT rate reductions for products that were critical for COVID-19 protection, and support for the sectors of research, transportation and hospitality. The extension of the COVID-19 crisis until March 2021 made the government extent its fiscal policy to about 8.5% of GDP in 2021 [IMF 2021].

Italy adopted a 25 euro billion [1.6% GDP] stimulus package on March 2020 to support the public health care system and civil protection policy. It also took measures to preserve jobs and stabilize income for workers and self-employed people. The business sector was supported with deferrals in tax and utility bill payments in the most affected municipalities, while measures to support credit supply were also taken. Italy passed the most stimulus packages to support its economy, among the economies of southern Europe. In the same manner as the previous countries, Italy also supported its health care system, workers, jobless people, vulnerable persons, families and the business sector, with the aim of kickstarting the economy from the financial spillover of the pandemic [IMF 2021].

Spain expanded its fiscal policy to the extent of 7.4% of GDP, including budget support from the contingency fund to the Ministry of Health, transfers to the regions to support the health system, additional healthcare expenses and support for R&D related to COVID-19, unemployment benefits, and support for social services, education and business sector. Likewise, self-employed persons were financially supported, seasonal employees who were affected by economic activity suspension, sick-payments for COVID-19 infections, rental assistance for vulnerable renters, state contribution to the contribution to the State Housing Plan 2018-21, social contribution deferrals, reduction of the VAT rate for surgical disposable masks, zero VAT for essential medical material, deferral of social security debts for companies in industries that were negatively affected by the COVID-19 crisis, and tax incentives and reductions (income tax, digital publications) [IMF 2021].

Estonia stimulated its economy in anticipation of the damage caused by the COVID-19 economic crisis, with packages that supported the healthcare system, workers and firms. Besides this, the stimulus package included business loans, guarantees for bank loans, liquidity support, support to local authorities, investments loans for companies and compensation for direct costs of canceled cultural and sporting events. As the second wave of COVID-19 increased, the Estonian government took more measures to support education, culture, and businesses in specifically affected regions, i.e. in Ida-Viru and Harju [IMF 2021].

Another small economy of the Eurozone, Malta, followed the same manner of fiscal measures to support its economy and mitigate the negative consequences of the health crisis, spending millions (4% of GDP) to support the healthcare sector, firms and households. Tax deferrals, income security for the unemployed and people in need, injections to the business sector to transition to teleworking experience, vouchers, cash grants, rent extensions and electricity subsidies were among the fiscal measures taken until June 2021 [IMF 2021].

Cyprus also responded to the COVID-19 crisis, but with a smaller impact (3.9% of GDP), supporting the health sector, households and businesses. Businesses were supported to maintain jobs, while a two-month deferral of VAT payments was managed and a temporary VAT cut to stimulate the hospitality sector, which plays a significant role in this country. Loan guarantees, subsidy schemes, and unemployment benefits were also among the fiscal measures adopted until April 2021 [IMF 2021].

The Slovak Republic introduced fiscal measures that included wage compensation for firms and self-employed people, subsidies for people without an income, unemployment, sickness and nursing benefits, a social security contributions delay for some months, deferral of payroll and corporate tax payments for businesses in line with the decline in revenues (>40%), rental subsidies, and higher medical spending. In addition, liquidity support was given to individuals, the self-employed and SMEs, while deferrals of loan payments were also included in the state-guarantee scheme [IMF 2021].

CONCLUSIONS

As Alberola et al. [2020] stated, high COVID-19 infection rates in accordance with high death rates negatively affected all economies worldwide. As a direct consequence, strong fiscal responses were observed by countries in pursuance of coping with the new form of crisis, a hygienic one, which also created a new chronicle of economic crisis.

In this paper, we support that Eurozone countries, which have a common characteristic – the euro – had the ability to expand public expenses, individually, while still maintaining their fiscal sovereignty, in the absence of a Fiscal Union in the EU. Additionally, in expanding public expenses, countries were expected to support citizens throughout the COVID-19 crisis, by supporting the health and business sectors, granting them tax benefits, cuts and exemptions, tax deferrals and social security contribution delays, debt reliefs, loans and loan guarantees, etc. Countries that participate in the Eurozone do not have the same income capacity level, so we aimed to investigate the hypothesis that countries with a lower GDP capacity expanded their fiscal policy conservatively. This hypothesis was proved by the statistical analysis of the data collected and analyzed (Table 3).

It is remarkable that Eurozone countries first expanded their fiscal spending, supporting the business sector during the COVID-19 crisis and only then turned their attention to the health sector. This can be explained by the fact that Eurozone countries have their foundation in the business sector; if business had failed, all other sectors would have collapsed too, through the domino effect, so they chose to secure the foundation of their economy first. The same conclusion was also drawn by other researchers analyzing a different group of countries [Chen et al. 2021]. OECD countries were found to support their business sectors by expanding their fiscal expenses first during the outbreak of the COVID-19 crisis and then their business sectors. In this way, policymakers first tried to overcome the economic crisis that followed and then deal with health crisis management.

The findings demonstrate similarities in the types and targets of fiscal policy responses, driven by the extent of COVID-19 infections as the pandemic expanded. However, different characteristics of the countries' political structures and income capacities do seem to have affected the size of the fiscal expansion accordingly. To be more specific, non-federalist countries in the Eurozone adopted expansionary fiscal spending slowly and at low rates. In terms of income capacity, low-income countries also kept their fiscal spending low. The argument of Kannan et al. [2009] is not proved, though, as we found that there was a statistical correlation between the fiscal expansion policy and COVID-19 infections in all Eurozone countries, including those that are heavily in debt (i.e. Greece).

We also found that all Eurozone countries focused on helping two basic sectors – health and business – but the most significant attention was given to the business sector, as the economy is based on it. This finding follows the argument of Korinek and Stiglitz [2022] that countries reallocated their fiscal spending in order to relax supply constraints in specific sectors (i.e. firms) to reduce future inflation.

To sum up, this study opens the dialogue about fiscal policy responses to the COVID-19 pandemic, making an important contribution to the comparative analysis about national fiscal policy making in the Eurozone area during the COVID-19 crisis.

In general, there is not one specific fiscal policy that all countries can adopt, so this research explains the practical policy implications in times of crisis. The fact that each Eurozone country made its own decisions and fiscally responded differently proves that European integration still has a long to go. Strong economies may have adopted large fiscal stimulus packages, globally, but this is not the case for every economy, and thus, in the Eurozone area. Every country should adopt the policy that fits its own characteristics (income level, political institutions, government structure, fiscal condition, debt capacity). In the case of the Eurozone area, where countries still maintain their fiscal sovereignty, policy making happens at the state level, and this seems to have been beneficial during COVID-19 crisis, which was well-managed after all as the crisis petered out. "All appropriate tools" were applied (i.e. fiscal tools), no matter the debt of each Eurozone country, resulting in the good management of the health crisis, proving the arguments of Eichengreen [2022] to be correct.

To conclude, the need of a Common Fiscal Union is stronger than ever, following the remarks of Krugman [2020], for the adoption of a sustained, productive program of stimulus in place, regarding the fact that in the last decades, the Eurozone has been hit by many unique crises, and responded late, adopting short-term measures. In order to come closer to European Integration, in the nearest future, the creation of a European Fiscal and Tax Union is strongly recommended.

REFERENCES

Alberola, E., Arslan, Y., Cheng, G., Moessner, R. (2020). The fiscal response to the COVID-19 crisis in advanced and emerging market economies. Retrieved from https://www.bis.org/publ/bisbull23.htm [accessed: 20.01.2022].

Alvaro, L. (2020). The fiscal response to COVID-19 in Europe: will it be enough? International Economy Focus, CaixaBank Research. Retrieved from https://www.caixabankresearch.com/sites/default/files/content/file/2020/09/15/34454/im09_2`6-ei-ue-focus-4-en.pdf [accessed: 20.01.2022].

Anastasatou, M., Anyfantaki, S. (2023). COVID-19 Pandemic: Overview of the fiscal policy response and macroeconomic developments in the Euro Area and the United States, Economic Bulletin, Bank of Greece, 57, 47–65.

Anderson, J., Papadia, F., Véron, N. (2020). Government – guaranteed bank lending in Europe: beyond the headline numbers. Peterson Institute for International Economics. Retrieved from https://www.piie.com/blogs/realtime-economic-issues-watch/government-guaranteed-bank-lending-europe-beyond-headline [accessed: 20.06.2022].

Auerbach, A.J., Gale, W., Lutz, B., Sheiner, L. (2020). Fiscal effects of COVID-19, Brooking Papers on Economic Activity. Fall, 228–278. Retrieved from https://www.brookings.edu/wp-content/uploads/2020/09/Auerbach-paper.pdf [accessed: 20.06.2022].

Barišić, P., Kovač, T. (2022). The effectiveness of the fiscal policy response to COVID-19 through the lens of short and long run labor market effects of COVID-19 measures, Public Sector Economics, 46(1), 43–81.

Benmelech, E., Tzur-Ilan, N. (2020). The determinants of fiscal and monetary policies during the COVID-19 crisis. National Bureau of Economic Research, Working Paper 27461. Retrieved from https://www.nber.org/system/files/working_papers/w27461/w27461.pdf [accessed: 20.06.2022].

Brunet, G. (2019). After the war: wartime saving and postwar housing investment, 1946–1950. Retrieved from http://conference.nber.org/conf_papers/f127354.pdf [accessed: 20.06.2022].

Chen, C., Shi, Y., Zhang, P., Ding, C. (2021). A cross-country comparison of fiscal policy responses to the COVID-19 global pandemic. Journal of Comparative Policy Analysis: Research and Practice, 23(2), 262–273. https://doi.org/10.1080/13876988.2021.1878885

Cavallo, A.F., Cai, T. (2020). HBS COVID-19 global policy tracker. Retrieved from https://www.hbs.edu/COVID-19-business-impact/Insights/Economic-and-Financial-Impacts/Global-Policy-Tracker [accessed: 20.01.2022].

Cottarelli, C., Gerson, P., Senhadji, A. (2014). Post-Crisis Fiscal Policy. The MIT Press, Cambridge.

Dabla-Norris, E., Dallari, P., Poghosyan, T. (2017). Fiscal spillovers in the Euro Area: letting the data speak. IMF Working Paper, WP/17/241.

Durante, A. (2022). U.S. Fiscal Response to COVID-19 among largest of industrialized countries. TaxFoundation. Retrieved from https://taxfoundation.org/blog/us-COVID19-fiscal-response/ [accessed: 20.01.2022].

Dimitropoulou, D., Theofilakou, A. (2021). Explaining the cross-country differences in the economic fallout during the COVID-19 pandemic crisis. Economic Bulletin Bank of Grece, 53, 29–48.

Eichengreen, B. (2020). Coronanomics 101, Project Syndicate. Retrieved from https://www.project-syndicate.org/commentary/limits-macroeconomic-tools-coronavirus-pandemic-by-barry-eichengreen-2020-03 [accessed: 20.01.2022].

Eichengreen, B. (2022). COVID and the outlook for emerging markets. Journal of Policy Modeling, 44(4), 820–

826. https://doi.org/10.1016/j.jpolmod.2022.09.008

Ferguson, N., Laydon, D., Nedjati-Gilani, G., Imai, N., Ainslie, K., Baguelin, M. et al. (2020). Impact of non-pharmaceutical interventions [NPIs] to reduce COVID-19 mortality and healthcare demand. https://doi.org/10.25561/77482

Flaxman, S., Mishra, S., Gandy, A., et al., 2020, Estimating the effects of non-pharmaceutical interventions on COVID-19 in Europe. Nature, 584, 257–261. https://doi.org/10.1038/s41586-020-2405-7

IMF (2021). Policy responses to COVID-19. Retrieved from https://www.imf.org/en/topics/imf-and-covid19/policy-responses-to-covid-19 [accessed: 20.01.2022].

Kannan, P., Scott, A., Terrones, M. (2009). From recession to recovery: how soon and how strong? [In:] S. Claessens, A. Kose, L. Laeven, F. Valencia (eds), Financial crises, causes, consequences, and policy responses. International Monetary Fund. https://doi.org/10.5089/9781475543407.071.ch008

Korinek, A., Stiglitz, J.E. (2022). Macroeconomic Stabilization for a post – pandemic world: revising the fiscal – monetary policy mix and correcting macroeconomic externalities. Hutchings Center Working Paper, 78, Hutchins Center on Fiscal & Monetary Policy, Brookings. Retrieved from https://www.brookings.edu/research/macroeconomicstabilization-for-a-post-pandemic-world/ [accessed: 20.01.2022].

Krugman, P. (2020) The case for permanent stimulus, in mitigating the COVID economic crisis: act fast and do whatever it takes. CEPR Press, London.

Nickel, C., Tudyka, A. (2013). Fiscal stimulus in times of high debt: reconsidering multipliers and twin deficits. ECB Working Paper, 1513.

International Monetary Fund Tracker of Policy Responses to COVID-19 (2020). Retrieved from https://www.imf.org/en/Topics/imf-and-COVID19/Policy-Responses-to-COVID-19 [accessed: 20.01.2022].

OECD (2020). Tax and fiscal policy in response to the Coronavirus crisis: Strengthening confidence and resilience. Retrieved from http://www.oecd.org/ctp/tax-policy/tax-and-fiscal-policy-in-response-to-thecoronavirus-crisis-strengthening-confidence-and-resilience.htm [accessed: 20.01.2022].

Romer, C.D. (2021). The fiscal policy response to the pandemic. Brooking Papers on Economic Activity. Retrieved from https://www.brookings.edu/wp-content/uploads/2021/03/15872-BPEA-SP21_WEB_Romer.pdf [accessed: 20.01.2022].

Wang, T., Gao, K., Wen, C., Xiao, Y., Bingzheng, Y. (2022). Assessing the nexus between fiscal policy, COVID-19, and economic growth. Environmental Science and Pollution Research, 29, 65289–65303. https://doi.org/10.1007/s11356-022-20358-z

REAKCJA FISKALNA NA KRYZYS COVID-19 – PRZYPADEK STREFY EURO

STRESZCZENIE

Cel: Artykuł wnosi dwa istotne wkłady do literatury dotyczącej polityki fiskalnej podczas pandemii COVID-19, analizując sposób, w jaki kraje strefy euro zareagowały ekspansją lub ograniczeniami fiskalnymi jako sposobem radzenia sobie z kryzysem związanym z pandemią. Zbadano, jakie polityki fiskalne rządów krajowych zostały wprowadzone w celu zarządzania pandemią COVID-19 w kontekście gospodarczym, politycznym i instytucjonalnym, koncentrując się na krajach europejskich będących częścią strefy euro. Wskazano na podobieństwa i heterogeniczność w trzech wymiarach reakcji polityki fiskalnej na COVID-19 (wielkość wydatków fiskalnych, rodzaj i cele reakcji polityki fiskalnej) w 19 krajach strefy euro w okresie od początku pandemii do stycznia 2022 roku. **Metody:** Zastosowano analizę przekrojową i analizę statystyczną w 19 krajach strefy euro. **Wyniki:** Kraje strefy euro o silnych gospodarkach (Niemcy, Francja) przeprowadziły reakcję fiskalną bezpośrednio, aby poradzić sobie ze skutkami pandemii, podczas gdy słabsze gospodarki (Estonia, Hiszpania) zareagowały późno. Ponadto rządy w pierwszej kolejności wspierały sektor biznesowy, a nie sektor zdrowia. **Wnioski:** Artykuł wnosi dwa istotne wkłady do literatury dotyczącej polityki fiskalnej w czasie pandemii COVID-19. Oryginalność tego badania polega na tym, że jest to jedno z pierwszych badań dotyczących analizy porównawczej, które skupiają się na gruncie europejskim w zakresie reakcji krajowej polityki fiskalnej na pandemię COVID-19. Istniejące badania dotyczące reakcji politycznych na COVID-19 skupiały się przede wszystkim na środkach w zakresie zdrowia publicznego.

Słowa kluczowe: polityka fiskalna, COVID-19, przekrojowe; analiza porównawcza, strefa euro acta_oeconomia.sggw.pl

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PROSUMER DILEMMA: DOES CHOOSING NET BILLING LOWER HOUSEHOLD ELECTRICITY COSTS?

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ABSTRACT

Aim: The study generates information about the expected electricity costs under several scenarios including PV panel and storage battery additions using the case of a rural prosumer operating a micro-PV installation and faced with a decision to switch to the new net-billing (NB) system or continue with net-metering (NM) (given the new subsidy for a storage battery). **Methods**: The benchmark data about prosumer electricity production and use and predicted electricity prices for the 15-year period serve to calculate future changes in electricity costs under alternative scenarios, including a household without a micro-PV installation. The prosumer cost for electricity used is calculated using the Levelized Cost of Electricity (LCOE) and the modified LCOEC accounting for consumption (LCOEC). **Results**: The average electricity price is estimated at 2.33 PLN/kWh in 2037 (almost three times more than in 2022). A similar increase is calculated for prices using the G12 tariff applied to households. The prosumer flexibility in electricity self-consumption determines the advantage of a storage battery, but the subsidy for a micro-PV installation is crucial. Without the subsidy, having a micro-PV installation with a storage battery in the NB system would not lower the LCOEC as compared to the NB scenario without storage. **Conclusions**: The NB system is associated with higher electricity bills than the NM system, although owning a micro-PV installation still lowers electricity costs as compared to a household without it. The adoption of micro-PV installations by households is likely to continue, albeit at a slower rate than in recent years.

Key words: prosumer, micro-PV installation, net-billing, net-metering, electricity generation

JEL codes: Q28, Q42, Q47

INTRODUCTION

Electricity and fossil fuel prices have increased since the spring of 2020 [Nyga-Łukaszewska and Aruga 2020, Chomać-Pierzecka et al. 2022a, b, Zasuń and Derski 2022] and the Russian-Ukrainian war further affected energy markets [Michiyuki and Shunsuke 2023, European Council and Council of the European Union 2023, Antosiewicz et al. 2022]. Higher fossil fuel prices translated into a substantial electricity price increase in Poland, where coal accounts for 83% of domestic energy production [Polskie Sieci Elektroenergetyczne 2022]. Efforts to protect households from sudden electricity price increases included freezing rates for a limited volume of consumed electricity [Dz.U. 2022 poz. 2127, Dz.U. 2022 poz. 2243]. The anticipated termination of the electricity rate freeze in the summer of 2024, the continuing threat of energy

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insecurity, and the welfare-affecting higher electricity prices are increasing household interest in becoming a prosumer, i.e., a producer of electricity from renewable energy sources (RES) with the option to supply the excess to the grid.

The EU climate policy implementation encompassing the GHG emission reduction, air quality improvement, and reduction of fossil fuel use have been driving household adoption of renewable energy source (RES) utilization for space heating [Klepacka et al. 2018, Klepacka and Florkowski 2019, 2021] and micro-PV installations [Siudek et al. 2020] in Poland. The invasion of Ukraine by Russia and the EU-imposed sanctions on energy imports from Russia propelled the already rising energy prices, dramatically increasing household electricity bills. The unexpected invasion coincided with revisions in EU regulations stemming from the drive to further lower emissions and changes in the pricing of electricity in all member countries.

The revised "Poland's Energy Policy until 2040" (PEP2040) [M.P. 2021 poz. 264] lists the acceleration of RES development [Kancelaria Prezesa Rady Ministrów 2022] to reduce dependence on imported fossil fuels and increase energy security. A larger share of RES in Poland's energy mix could insulate households from electricity bill increases. The Levelized Cost of Electricity (LCOE) generated by solar farms is already lower than that of power plants using fossil fuels [International Renewable Energy Agency 2022]. In Poland, the PV sector has been the fastest developing RES since 2018 [Instytut Energetyki Odnawialnej 2022] and the annual growth rate of installed PV capacity was three times higher than the average in the European Union (EU) in 2022 [Instytut Energetyki Odnawialnej 2023].

The growth rate was due to household investment in micro-PV equipment, which accounted for 75% of the installed PV capacity in the first quarter of 2022. The growth was spurred by the government's "My Electricity" (Mój Prąd or My Electricity) program that targets household installations of 2kW–10kW PV capacity. By early 2023, the program accepted another 413,000 applications totaling 2.38GW of PV capacity [Ministerstwo Klimatu i Środowiska 2023] and subsidized prosumer investment costs. Besides sheltering households from electricity price increases, the program supports the national goal of a 23% RES share in electricity consumption by 2030 and the climate policy goal of reducing CO_2 emissions associated with electricity generation by 30% compared to 1990 [M.P. 2021 poz. 264].

In April 2023, the government announced yet another subsidy program ("My Electricity 5.0 – MP5") for micro-PV and heat pump installations. The program incentivizes household self-consumption of generated electricity to reduce supply to the grid. The new government subsidy program requires a prosumer to adopt the new net billing (NB) settlement system, implying the termination of prosumer participation in the existing net-metering system (NM) [Ministerstwo Klimatu i Środowiska 2022]. The NB system effectively lowers the rate paid for the electricity a prosumer supplies to the grid [Dz.U. 2015 poz. 478].

The two decades of implementing the energy and climate policy in the EU ultimately affect households. The considered case is placed in the context of historical institutionalism and its recent applications to the shift in feed-in tariffs. The replacement by the EU of the feed-in tariffs with an auctioning system will introduce competitiveness to the electricity market that involves prosumers. The effort seems an afterthought following years of EU-designed programs promoting the utilization of RE by offering generous subsidies that created the uncompetitive environment in the first place. The current study examines the case of a prosumer household already operating a micro-PV installation subsidized by earlier editions of the "My Electricity" program, offsetting a large portion of the investment but facing the possible choice between two billing systems due to this new wave of regulatory changes. The household is composed of three adults residing in a detached house in the predominantly rural Mazursko-Warmińskie Voivodeship in north-eastern Poland. The average per capita income in the Mazursko-Warmińskie Voivodeship is 70.9% of the national average [Chinowski 2023] and influences the households' ability to self-finance investments in micro-PV equipment. The region also typically receives less solar radiation than other regions [Lorenc 2005], limiting the volume of generated electricity. A review of the regional distribution of the "My Electricity" program funds does not overlap with the most favorable solar radiation conditions. The Mazursko-Warmińskie Voivodship received only 2.4% of the available funds, placing it 13th among all 17 voivodeships [Instytut Energetyki Odnawialnej 2023]. The area has a low density of grid connections and piped heat from a central power station is unavailable, which motivated households to invest in PV equipment to operate a heat pump to secure heating of the living space and other electricity uses. The prosumer considered in this study is only one of two micro-PV installation operators in the area and, as a result, currently faces a low risk of being disconnected because of the grid's inability to store oversupplied electricity during sunny weather.

The current case study complements earlier research on the use of net-metering (NM) and net-billing (NB) settlement systems in Poland and other EU countries [Trela and Dubel 2022, Kurz and Nowak 2023] following recent regulatory changes and the implementation of the new billing options. The current case illustrates a choice of a prosumer who has already invested in micro-PV equipment: Would they switch from the NM to the NB system, settling for the electricity supplied and purchased from the grid? Under Poland's climatic conditions, especially for prosumers residing in a region with less than average solar radiation, the need to heat the living space is a common driver of investment in equipment utilizing solar radiation. The study accounts for the most recent changes using projected electricity prices. Because the prosumer has already invested in micro-PV equipment, the pre-investment considerations are omitted. However, the provided scenarios include the expansion of the already owned PV installation and the addition of a storage battery. The frequent and abrupt changes in the law and regulations affecting RES utilization, especially the use of solar radiation, poses the risk of slowing micro-PV installation expansion [Instytut Energetyki Odnawialnej 2022]. The regulatory uncertainty discouraged household investment in RE utilization in the past [Klepacka and Pawlik 2018, Trela and Dubel 2022, Kurz and Nowak 2023].

The EU energy policy has been intertwined with the domestic energy policy of Germany, especially since 2014. The explanation of the energy transformation initiated in Germany has been interpreted in the context of historical institutionalism [Leiren and Reimer 2018]. The feed-in tariff underlying the NM system benefited early investors in household--installed micro-PV equipment. Those households benefited from the long-term (multi-year) contracts paying for electricity supplied to the grid. Those early investors in Germany, as those later in Poland, also received generous subsidies for the purchase and installation of PV panels on the roofs of their detached houses. But, as noted in the literature, the early prosumer-households burdened the non-participants with the maintenance fees because they did not pay for access to the grid. Under the concept of institutional change, those who did not benefit from the system would push for a change. The theory of gradual institutional change suggests gradual displacement, as those who benefit from the system (here the NM system) are unable to thwart the shift to new rules (here the NB system) [Mahoney and Thelen 2010].

The NM system encouraged households to become prosumers in order to utilize RE that would not have been economically feasible otherwise due to the inherit risks, such as the seasonality of solar radiation in Poland and northern Europe. Once the number of prosumers grew, the subsidy scheme costs rose, making it unsustainable, leading to auctioning and the NB system. Although it has been argued that the NM system (feed-in tariff) was not competitive, therefore justifying the auctioning system, the actual operating system is not truly competitive. A description of the system being implemented in Poland is provided later in this paper.

Coincidentally, the fundamental change in the EU and Germany's energy policy took place in the year of the Ukraine Crimea region's annexation by Russia. The feed-in tariffs offering prosumers above-the-market prices for electricity generated from RES in Germany were replaced in 2016 by the auctioning system following a pilot program started in 2014 [Leiren and Reimer 2018]. The auctioning system replaces the direct participation of households, reflecting participatory democracy by favoring large corporations, which are the key players in the new system. Households, as small providers of electricity, are placed at a disadvantage and further constrained by the 50 kW size of a household PV installation. The 2014 European Commission decision changed the guidelines recommending the auctioning system, which is incompatible with the NM (feed-in tariff) system. Since the change of the system has not occurred under demands from non-prosumer households burdened with their electricity purchase bill but also grid access fees, the theory of gradual institutional change does not fully capture the realities. As rightly noted by Leiren and Reimer (2018), the EU has been the external force, an endogenous change-agent, imposing the change from the top down. Table 1 shows the selected documents originating from various European institutions within the EU and links some of them to specific events ("critical junctures" [Leiren and Reimer 2018]) such as the annexation of Crimea and the invasion of Ukraine, giving weight to the distinctly different policy change explanation emphasizing triggering events as disruptive to the period of stability and offering an opportunity for a change.

The list of documents in Table 1 illustrates why the process of increasing the utilization of RE can be viewed as chaotic from the household perspective. Each of the listed documents required EU-member countries to develop or later modify their domestic policies, all eventually affecting households through their electricity bills. The case study in this paper is an illustration of a path of adapting to the rapidly changing regulatory regime affecting the access, availability, and cost of an essential household good: electricity.

Background: recent geopolitical events, solar radiation utilization, and tariff systems

In the case of Poland, household electricity consumption initially increased, driven by COVID-19-imposed restrictions forcing remote work and schooling in 2020. The unprecedented interest in investing in micro-PV installations recently has been driven by the advance of energy prices, including electricity prices, since 2021. The 2022 Russian invasion of Ukraine resulted in elimination of natural gas imports from Russia, increasing domestic natural gas prices. Natural gas was used primarily for cooking and heat-

Table 1. Timeline of major policy decisions affecting household electricity use

Directive/Document	Date	Stated goal(s)
European Parliament Directive 2012/27 changing directives from 2009 and 2010 and annulment parliament directives from 2004 and 2006[1]	December 2012	Reduce energy by 20% by 2020
European Parliament "Clean energy for all Europeans"[2]	December 2016	Primary and final energy use reduced to 32.5% by 2030 using forecast from 2007
European Parliament[3]	July 2021	"Fit for 55" revised energy efficiency goal for 2030 using 2020 forecast
European Parliament[4]	May 2022	Further revision in additional reduction of energy efficiency; increased support for solar radiation utilization
European Parliament[5]	May 2022	Revised share of RE to 42.5% by 2030 (desired level, 45%)
European Parliament Directive[6]	October 2023	Revised goal of primary and final use to 11.7% by 2030 using forecast from 2020
European Parliament, several documents[7]	December 2024	10- year energy and climate national plan for the period 2021–2030; Poland's target of RE share is 23.8% in 2030

Source: [1] Directive 2012/27/EU; [2] Communication from the Commission… COM/2016/0860 final; [3] Communication from the Commission… COM/2021/550 final; [4] Communication from the Commission… COM/2022/230 final; [5] Communication from the Commission… COM/2022/221 final; [6] Directive (EU) 2023/1791; [7] Ministerstwo Klimatu i Środowiska, 2024.

ing water, and, to a lesser degree, for heating the living space for households with access to piped gas [GUS 2023]. Only 1.9% of households used electricity as the main space heating source in 2021 (before the start of the Russia-Ukraine war) because of the already high cost of this energy type [GUS 2023]. Coal, in various forms, was the most common energy type used in space heating, often with the addition of biomass. The start of the war increased the prices of all energy types in Poland and coincided with the implementation of the new EU electricity pricing regulations as well as the continuation of the "My Electricity" program and the planned new version of the program for 2023. In the first half of 2023, household electricity bills increased by about 30% [Derski 2023]. The increase in electricity prices changed the expectations of prosumers who had invested in micro-PV installations.

The past EU policy and support programs for solar energy utilization subsidized thermal solar panel installations [Kaya et al. 2018] and required local governments to initiate the application and recruit the households planning to invest in thermal panels. Individual households were excluded from early programs. Solar farms producing electricity suffered from low profitability, while changes in the law created uncertainty [Klepacka and Pawlik 2018]. The PV panels were installed by public entities and businesses off-grid because regulations were lacking. Since 2016, the regulation stimulated the adoption of micro-PV panels rather than earlier installed thermal panels used to heat water. The early PV-support adopters, applying for investment grants through local governments, were enabled to supply the grid with unrestricted volumes of electricity.

The effects of regulations on the electricity billing systems were subject to earlier studies. Trela and Dubel [2022] conducted a sensitivity analysis on the return of two alternative space heating and electricity supply systems in a detached house accounting for the NM and NB systems. The study conducted before the implementation of the NB system in April 2022 was motivated by the perceptions of the new system's benefits vs. the NM system operating at that time. Their study compared the return on investment in a natural gas-fired boiler and the purchase of electricity from the grid and an air/water heat pump powered by electricity from PV panels. The combination of a micro-PV installation and an air/water heat pump, with an investment subsidy, offers an alternative, especially in areas lacking piped heat or natural gas. The study omitted storage batteries because of the negligible presence of such technology in prosumer households at the time the study was conducted and the inadequate regulations [Adamska 2021]. The authors concluded that the regulatory changes in billing systems introduced in 2021 would reduce the rate of return and new investments in the PV installations.

Kurz and Nowak [2023] noted that the boom of investment in micro-PV installations by households in Poland was instrumental in reaching the installed capacity of RES-utilizing equipment by mid-2022, set originally for 2040 under EU policy. The strong household response in the utilization of solar radiation to increasing electricity and energy prices prompted the decision to change the billing system from NM to the NB forced by the EU regulations. The change slowed household decisions to invest in additional micro-PV equipment [Kurz and Nowak 2023].

An energy netting study of Danish households was motivated by the 80% share of taxes in the final electricity bill [Ziras et al. 2021]. The NM system introduced in Denmark in 2010 led on the one hand to a decrease in tax revenues, and on the other hand was unfair to households without capabilities to generate their own electricity but bearing the cost of grid access fees. The study viewed the NB system as a special case of the NM system, where the netting, i.e., the calculation of the balance between electricity supplied and purchased from the grid, is performed in very short intervals. The study focused on a case of a typical prosumer with a 6 kW PV system and showed that the NB increased self-consumption, reduced purchase from the grid, and, under Danish conditions, generated slight annual savings.

The continuously rising electricity prices negatively impact consumers and encourage simulations exploring the economic benefits of operating a micro-PV and battery storage system (BSS) [Chatzigeorgiu et al. 2023]. BSS assures household energy security and reduces electricity bills. It also limits the frequency with which the grid is accessed, improving its performance [Chatzigeorgiu et al. 2020], especially in countries with favorable solar radiation conditions like those in the Mediterranean region. Chatzigeorgiu et al. [2023] indicate that the consideration of NB shows intercountry discrepancies. The existence of differences across countries limits universal applicability of the results and warrants the examination of country-specific cases.

The "My Electricity 5.0" program subsidizes the purchase of batteries for storing the electricity generated by micro-PV installations in Poland. Storage reduces the risk of disconnecting the household from the grid in periods of oversupply of electricity. Storage also increases the flexibility of self-consumption and lowers purchases from the grid. The average living space of a rural house in Poland is about 63% larger than the living space of an average urban household, implying greater heating needs. The average electricity consumption is also nearly 55% higher in rural households [GUS 2023], which also commonly use more outside lights than urban households, increasing their utility bills.

The current study uses real data from a prosumer operating in a substantially changed environment of accelerated electricity price increase since 2021, an elevated risk of energy supply due to the Russian invasion in Ukraine in 2022, and the emerging system of electricity trading exchange using the readings of remotely read electricity meters. The study considers a case of a prosumer located in northeastern Poland, where solar radiation is less intense than in EU countries located in southern Europe.

Prosumer-targeting settlement systems

The difference between the NM and NB systems is the compensation households receive for sending surplus electricity to the grid. The NM system allows the prosumer to access 0.8 kW for every 1k W supplied to the grid. The remaining 0.2k W compensates the grid operator for the prosumer's access to the grid. The agreement between a prosumer and the distributor is valid for 15 years and the prosumer purchases electricity at the existing tariff without paying the distribution fee. Prosumers using the NM system have incentives to supply an unlimited amount of electricity to the grid above their own use. Under exceptionally sunny weather, which seldom covers the whole country, the prosumer-supplied electricity causes grid instability, leading to an automatic disconnection of some, especially in areas of dense detached housing operating micro-PV installations.

A prosumer using the NB system sells surplus electricity to the grid and creates a deposit used to balance the purchased electricity. The prosumer is compensated for 20% of any net balance injected into the grid accrued in the preceding 12 months. The intentionally small share is to discourage installations of micro-PV equipment capable of generating electricity exceeding the volume a household typically uses. Still, the NB system incentivizes supplying electricity when demand is high and purchasing when demand is low in response to changing prices. The NB system requires users to pay distribution fees only for the purchased electricity, not for the volume supplied to the grid. From July 1, 2022, until June 30, 2024, the surplus is set at the price for the month it was supplied (RCEm). Ultimately, the NB system will use the hourly market price (RCE) once the Central Energy Market Information System (CEMIS) starts to operate on July 1, 2024 (Centralny System Informacji Rynku Energii – CSIRE) [Ministerstwo Klimatu i Środowiska 2021a].

CEMIS processes energy market information available to all market participants, including prosumers. CEMIS collects meter readings on the volume supplied and purchased by each prosumer every hour from the mandatory remote electricity meters [Dz.U. 2021 poz. 1093, Centrum Informacji Rynku Energii 2023]. The payments for electricity sent or purchased are calculated using the meter readings [Ministerstwo Klimatu i Środowiska 2021] allowing a prosumer to manage electricity use in response to hourly price fluctuations [Ministerstwo Klimatu i Środowiska 2021b]. CEMIS shortens the period of approving the sale of electricity to a single day, verifies the electricity volume a prosumer sent or obtained from the grid, and facilitates access to electricity market price information [Polskie Sieci Elektroenergetyczne 2023a].

Electricity market: the prosumer perspective

Contrary to intentions [International Renewable Energy Agency 2019], electricity pricing was not yet market-driven in 2023 or the first half of 2024 in Poland. The government implemented the "Wprowadzenie Rządowej Tarczy Solidarnościowej" program to protect households from electricity price volatility. The retained 2022 rates applied to three levels of annual volume of electricity used: 2,000 kWh, 2,600 kWh, and 3,000 kWh [Serwis Samorządowy PAP 2022]. A price ceiling was implemented if the purchased volume exceeded the 3,000 kWh threshold at 0.693 PLN/kWh [Serwis Rzeczpospolitej Polskiej 2023] and increased the distribution fees [Urząd Regulacji Energetyki 2023b]. In the case of prosumers using the NM system, the limit applied only to the net volume of purchased electricity. For those subject to the NB system, the annual limit applies to the total electricity volume purchased from the grid [Ministerstwo Klimatu i Środowiska 2022b]. Additionally, the 2023 VAT rate for electricity increased to 23% from 5% in 2022 [Redakcja PIT.pl 2022]. Ultimately, the NB system imposes a quasi-market price discovery applicable to prosumer-supplied electricity through CEMIS, but the purchase of electricity from the regional monopoly is at prices subject to the approval of the government agency: Urząd Regulacji Energetyki. Overall, the system has to be recognized as lacking transparency and providing a potential source of uncertainty in the future.

MATERIALS AND METHODS

The prosumer case examined in this study exemplifies households residing in detached houses in rural areas. The study examines the existing PV installation in a three-person household located in northeastern Poland. The installation has 24 PV panels (JA SOLAR 340) and has a capacity of 8.16 kW. The Fronius Symo inverter has a capacity of 7 kW. Data on the volume of electricity generated are from the monitoring system and available at Fronius Solar.web. The data on the volume of electricity sent to the grid, purchased from the grid, and the balance were from the portal of PGE, the electricity supplier contracted by the prosumer. The costs follow the G-12 tariff applied to households. Hourly readings of the volume and direction of electricity flow were obtained from the remote electricity meter (LZO in Polish), an Apator Otus 3 meter.

Calculations are for both systems, i.e., NB and NM, and include two options to increase returns: expansion of PV capacity and storage of surplus electricity in a household battery. For comparison, the third case of a household that does not have a PV installation is also considered. The analysis involves seven scenarios, each for the 15-year period that covers the expected life of the PV panels. The scenarios are: NB – net-billing system; NB+ – enlarged PV installation in the NB system; MNB – original PV capacity with the storage option in the NB system; NM – net-metering system; NM+ – enlarged PV installation in net-metering; MNM – original PV capacity with the storage option in the NM; BPV – household without a PV installation.

The micro-PV installation cost is 4,800 PLN/kW, and the subsidy obtained from "My Electricity 4" is 4,000 PLN/kW. Those costs are the same for both settlement systems. It has been assumed that an additional 19,000 PLN would be obtained from "My Electricity 5," the current program, for the investment in a storage battery and additional PV panels.

The future electricity prices supplied to the grid and purchased cover the period 2023–2037. The benchmark period is from April 1, 2022, to March 31, 2023. Returns from electricity production under the two settlement systems were calculated using the LCOE and LCOEC (the latter accounts also for the electricity consumed).

Fronius Solar.web data indicate that the PV installation in question generated 8,388 kWh between April 1, 2022 and March 31, 2023. The forecast for the next 14 years for the same period as in the benchmark assumes a 0.5% decline in the PV panels' capacity to generate electricity [Instytut Energetyki Odnawialnej 2023]. In scenarios assuming the expansion of the PV installation, the maximum capacity is 10 kW to avoid a reduction of the coefficient used in calculating the surplus sent to the grid, which is 0.8. The installed capacity increased from 8.16 kW to 9.86 kW by adding five PV panels, type JA SOLAR 340 W. The forecast for scenarios NB+ and NM+ starting on April 1, 2023, assumes the electricity generated increases under the scenarios NB and NM by 20.83%, and the annual performance decline begins on April 1, 2024.

The billing of prosumers is based on the hourly balance of electricity consumed and sent to the grid. The balance of the electricity purchased and supplied to the grid was calculated using the vector method [Polska Grupa Energetyczna 2023]. For every hour (t) in the 24-hour period, the balance is the difference between the electricity purchased (E_p) and supplied to the grid (E_o) in kWh ($E_{z,t} = E_{p,t} - E_{o,t}$). When the purchase and supply take place during the same hour, the prosumer is free of distribution charges [Fotowoltaikaonline.pl 2023].

Knowing the volume of PV-generated electricity (E_w) and the directions of electricity flows in the benchmark year, the volume of electricity consumed (E_e) in the period (t) is:

$$E_{e,t} = E_{w,t} - E_{o,t} + E_{p,t} \tag{1}$$

The prosumer consumption of electricity remains unchanged during the 14-year period. In leap years, February is assumed to have 28 days. The future volume of electricity generated (E_w), the volume purchased from the grid (E_p), supplied (E_o), and consumed (E_a) are obtained using formulas (2)–(5):

$$\begin{aligned} E'_{w,t} \geq E_{e,t} &\rightarrow E'_{a,t} = E_{e,t} \\ E'_{w,t} < E_{e,t} &\rightarrow E'_{a,t} = E'_{w,t} \end{aligned} \tag{2}$$

$$E'_{p,t} = E_{e,t} - E'_{w,t} \tag{3}$$

$$E'_{o,t} = E'_{w,t} - E_{e,t} \tag{4}$$

$$E'_{z,t} = E'_{p,t} - E'_{o,t} \tag{5}$$

As a result, it is possible to predict the balance (E_z) in the period (t), while omitting the situations of simultaneous purchase and supply of electricity.

Market price of electricity

The average electricity price (CG) is based on records, s, collected during the 24-hour session (S) and weighted by the traded volume (EG) [Dziennik Urzędowy Unii Europejskiej 2019]:

$$RCE = \frac{\sum_{s \in S} CG_s \cdot EG_s}{\sum_{s \in S} EG_s} \tag{6}$$

The monthly electricity price used for settlement with prosumers is the average market electricity price (RCE) for a given month, m, weighted by the volume of prosumer-supplied electricity (E). The price applies to the period T when the accounts were not settled [Journal of Laws of 2015 item 478. 2023]:

$$RCEm = \frac{\sum_{t \in T} RCE_t \cdot E_t}{\sum_{t \in T} E_t} \tag{7}$$

Calculation of the LCOE and LCOEC

Formula (1A) shows the calculation of the $LCOE$ for the scenarios using the NM system:

$$LCOE_{NM} = \frac{\sum \left(I_t - D_t \right)}{\sum E'_{u,t}} \tag{8}$$

where the definition of $E'_{u,t}$ varies for three scenarios: for NM: $E'_{u,t} = E'_{a,t} + E'_{a,t} + 0.8 \cdot E'_{z-,t}$, for NM+: $E'_{u,t} = E'_{aw,t} + 0.8 \cdot E'_{zw-,t}$, and for MNM: $E'_{u,t} = E'_{am,t} + 0.8 \cdot E'_{zm-,t}$. Calculations of the $LCOE$ for the scenarios using the NB system are made using the following formula (2A):

$$LCOE_{NB} = \frac{\sum \left(I_t - D_t + K_t - Z_t \right)}{\sum E'_{u,t}} \tag{9}$$

where the definition of $E'_{u,t}$ is: for NB: $E'_{u,t} = E'_{a,t} + E'_{z-,t}$, for NB+: $E'_{u,t} = E'_{aw,t} + E'_{zw-,t}$, and for MNB: $E'_{u,t} = E'_{am,t} = E'_{am,t} + E'_{zm-,t}$.

The following formula calculates the $LCOEC$:

$$LCOEC = \frac{\sum \left(I_t - D_t + R_t \right)}{\sum E_{e,t}} \tag{10}$$

where R_t is the cost of electricity in year t and is a result of the need to balance the electricity supplied to and purchased from the grid [Urząd Regulacji Energetyki 2020, Urząd Regulacji Energetyki 2023a].

Addition of electricity storage

The household was assumed to have a battery capable of storing 50% of the daily electricity consumed [Pomorski et al. 2022]. The average daily electricity consumption was 44.5 kWh, in the benchmark year. A BYD Battery-Box Premium HVM 22.1, with a capacity of 22.08 kW, serves as the model. The battery has 96% efficiency and an annual deterioration rate of 2.2%, and is capable of 6,000 charge-discharge cycles [Instytut Energetyki Odnawialnej 2023].

The battery operation involves charging with electricity (E_{dom}) intended to be supplied to the grid in a given time period (t) until it is fully charged. The volume of electricity discharged (E_{odm}) does not exceed the expected volume of electricity purchased in a given hour, assuming that for every 1 kWh sent to the grid, the volume obtained from the grid is 0.96 kWh. For the MNM and MNB scenarios, it is possible to predict the volume obtained (E_{pm}) or sent to the grid (E_{om}), and the self-consumption (E_{am}) using formulas (9)–(12):

$$E'_{am,t} = E'_{a,t} + E'_{odm,t} \quad (11)$$

$$E'_{pm,t} = E'_{p,t} - E'_{odm,t} \quad (12)$$

$$E'_{om,t} = E'_{o,t} - E'_{dom,t} \quad (13)$$

$$E'_{zm,t} = E'_{pm,t} - E'_{om,t} \quad (14)$$

The approach predicts the electricity volume needed from the grid while accounting for the storage (E_{zm}) in period (t). The prediction ignores the case of simultaneous purchase from and supply to the grid.

Forecast of market price

A series of future electricity prices is calculated to compare each scenario. RCE and RCE_m are particularly important in the scenarios using the NB system because those prices determine the value of the electricity supplied to the grid. The future prices were based on a series of hourly market prices for every hour from the PSE portal for the period January 1, 2018 to June 22, 2023 [Polskie Sieci Elektroenergetyczne 2023B].

Table 2. 24-hour factors in the calculations

Hour	Factor [–]
1	0.86
2	0.82
3	0.81
4	0.80
5	0.81
6	0.84
7	0.96
8	1.01
9	1.08
10	1.09
11	1.06
12	1.06
13	1.06
14	1.05
15	1.01
16	1.02
17	1.06
18	1.11
19	1.15
20	1.20
21	1.16
22	1.04
23	1.01
24	0.90

Source: own calculations based on data from PSE 2023B.

The prices showed a daily pattern and an increasing tendency, especially in the years 2021–2023, in average electricity prices (Fig. 1). The daily pattern showed that the average RCE values increase between 5 a.m. and 8 a.m. and between 2 p.m. and 7 p.m. The prices were set to increase annually with the exception of 2020 COVID-19 related regulations. [Derski 2021].

Seasonality is marked for each hour by averaging earlier described multipliers calculated for each hour (Tab.2). Once the seasonal effects are identified, they can be separated from the market prices by dividing RCE by the seasonality element for each hour.

Next, the calculation of trends allowed the examination of de-seasoned RCE values in relation to time. The calculations were made using the function Analysis ToolPack in Excel. Excel allowed the fitting of variables in the given function, that are statistically the closest to given values. The result was the following trend function: (15)

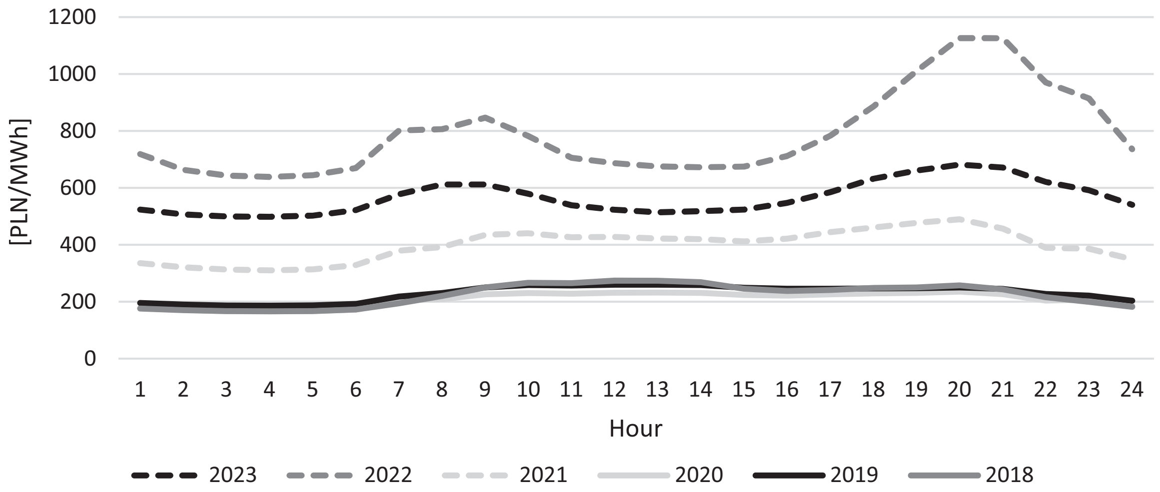

Fig. 1. Average hourly market price of electricity, 2018–2023.

Source: own calculations using data from PSE 2023B.

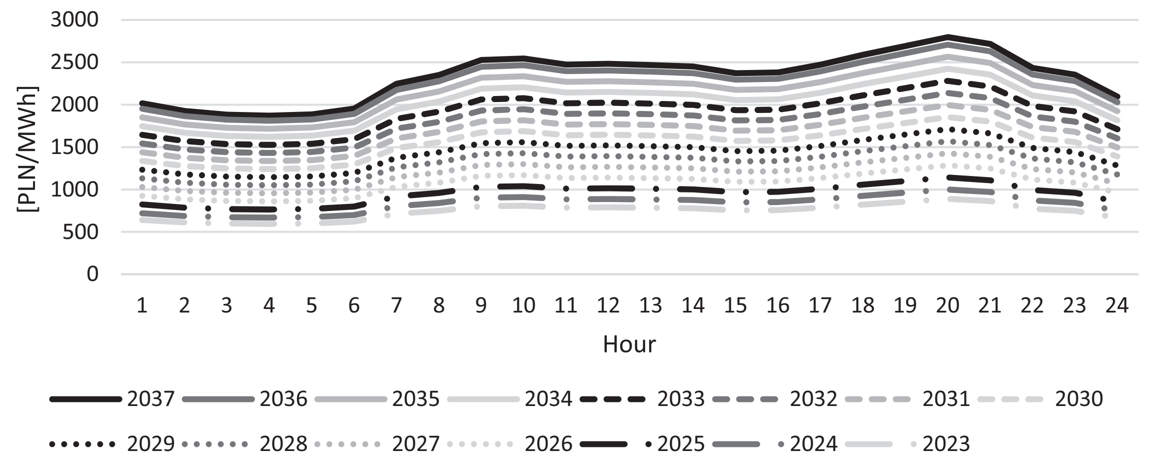

Fig. 2. Calculated average hourly market electricity prices, 2023–2035

Source: own calculations based on data from PSE 2023B.

The forecast was obtained for every hour from June 12, 2023, until March 31, 2037 (Fig. 2), by multiplying the seasonality elements (Tab. 2) by the calculated trend value obtained using formula (15).

$$f(t) = 0.013578 \cdot t + 62.134972 \tag{15}$$

The trend value multiplied by the hourly factor generates the electricity price per hour for the period June 12, 2023, to March 31, 2037 (Fig. 2). Additionally, all scenarios required the RCE_m values from June 2023 to June 2024. The monthly electricity prices resembled the average monthly *RCE* values for the period June 2022 to May 2023 and confirmed the high value of the coefficient of determination, $R^2 = 0.9136$ ($y = 0.6701x + 138.21$). The future monthly RCE_m values were obtained using the calculated trend.

The rates and fees charged by the prosumer's electricity supplier, PGE, are not published. The supplier is assumed to set next year's electricity prices

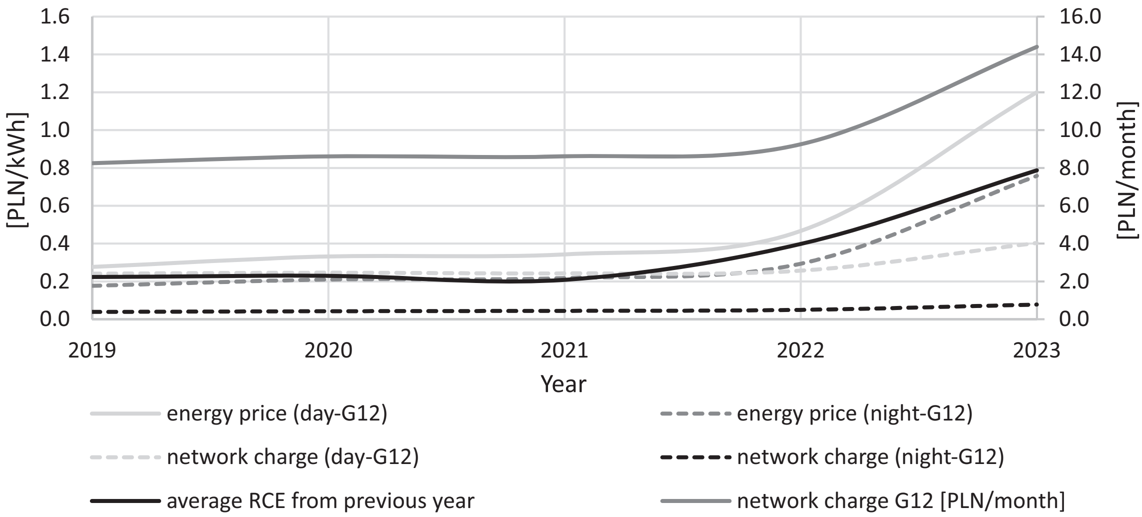

Fig. 3. Comparison of day and night rates and fees for the average RCE value in the preceding year

Source: own calculations based on data from PSE 2023B.

given current electricity market conditions, that is, the hourly records in year *N* influence prices in year *N* + 1 (Fig. 3).

This is a statement with no verb that isn't continued in the rest of the sentence so something is missing. The values of the coefficient of termination are high (R^2 >0.9) (Fig.5). The tariff fees for the preceding years. The future rates and fees are obtained for day and night rates for the G-12 tariff applied to households (Fig. 4) under the assumption of fixed transfer fees, quality fees, subscription fees, as well as *RES* cogeneration capacity fees [Urząd Regulacji Energetyki 2020], and VAT and excise taxes after 2023 because of the inability to estimate them.

The data are for electricity generated annually by micro-PV systems installed in the prosumer household, and its electricity consumption. Also included are data on the amount of electricity sent to the grid and the price of electricity purchased from the grid. The forecast is for the period 2023–2037. Returns from electricity production under two settlement systems were calculated using the *LCOE* and *LCOEC*.

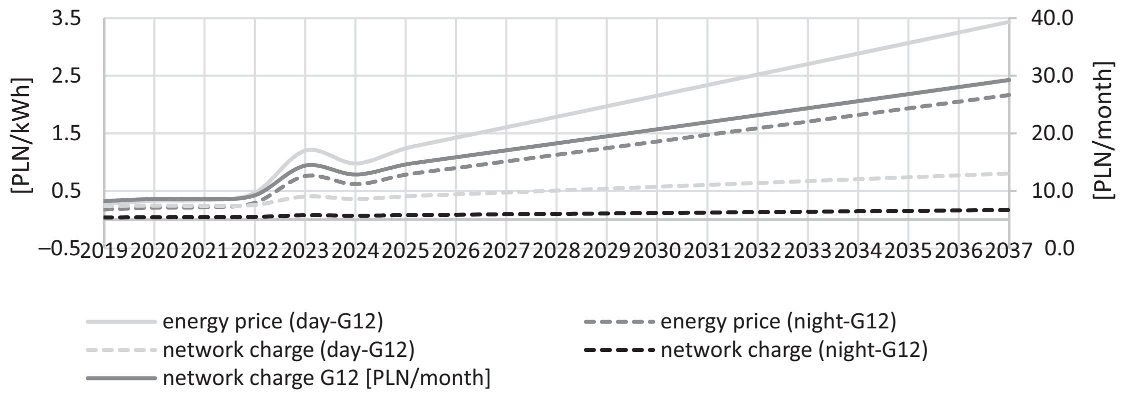

Fig. 4. Predicted rates and fees through the year 2037

Source: own calculations based on data from PSE 2023B.

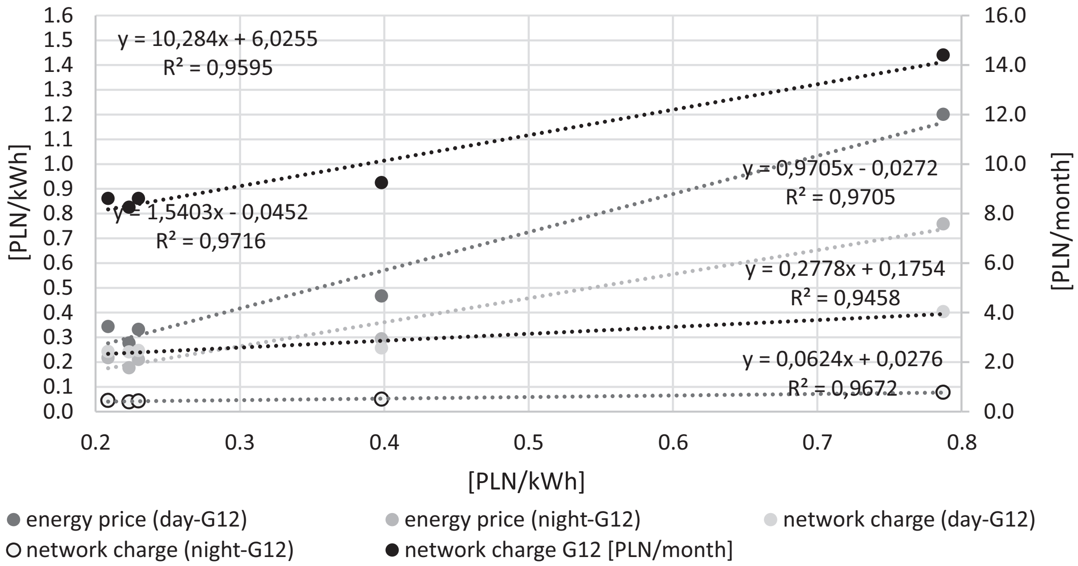

Fig. 5. Trends for day and night rates and fees for the average RCE value in the preceding year

Source: own calculations based on data from PSE 2023B.

Electricity cost calculations for the scenarios

The average cost of electricity generation, the Levelized Cost of Electricity (LCOE), is applied in calculating returns from various types of energy generating electricity [Sulewski et al. 2016]. Here, it is used to compare the returns from the PV installation under the earlier listed scenarios. The LCOE formulas vary across the scenarios because of the differences in the total cost of installation (I_t), amount of subsidy (D_t), and volume of electricity from the prosumer's perspective (*Eu*'). The formula for scenarios NB, NB+, and *MNB* include earnings from sending electricity to the grid (Z_t) and higher distribution fees (K_t) than in scenarios *NM*, *NM*+, and *NMB*. All calculations assume the constant value of the PLN.

The Levelized Cost of Electricity Consumption (LCOEC) applied in this study accounts for all costs associated with electricity purchased from the grid by the prosumer (R_t) and electricity consumed (E_e) in year *t*. The LCOEC reveals to a potential micro-PV installation investor the expected electricity bill for a period of 15 years under a given settlement system. Also, the average cost of the electricity consumed applies to scenario BPV, where a household does not have a PV installation.

RESULTS AND DISCUSSION

Benchmark period

The total prosumer electricity consumption was 16.26 MWh in the benchmark period and reflects the 8.39 MWh of electricity generated (of which 28% was consumed by the household) and the 13.89 MWH purchased from the grid. The daily pattern of electricity flows between April 1, 2022 and March 31, 2023 are averaged in Fig. 6. The micro-PV installation generated the largest volume of electricity between 11 a.m. and 2 p.m., reflecting the position of the sun and the panels. Self-consumption increases with the presence of household members and the use of home appliances. The volume of purchased electricity increases when the heat pump operates as night temperatures drop. The positive net balances (E_z+) followed the seasonal weather pattern, reflecting the purchase of electricity to supply the heat pump. The largest negative net balances (E_z–) are from May to September, when the prosumer supplied electricity to the grid. Self-consumption peaked in March and April, when the outside temperatures require the heat pump to operate to heat the living space.

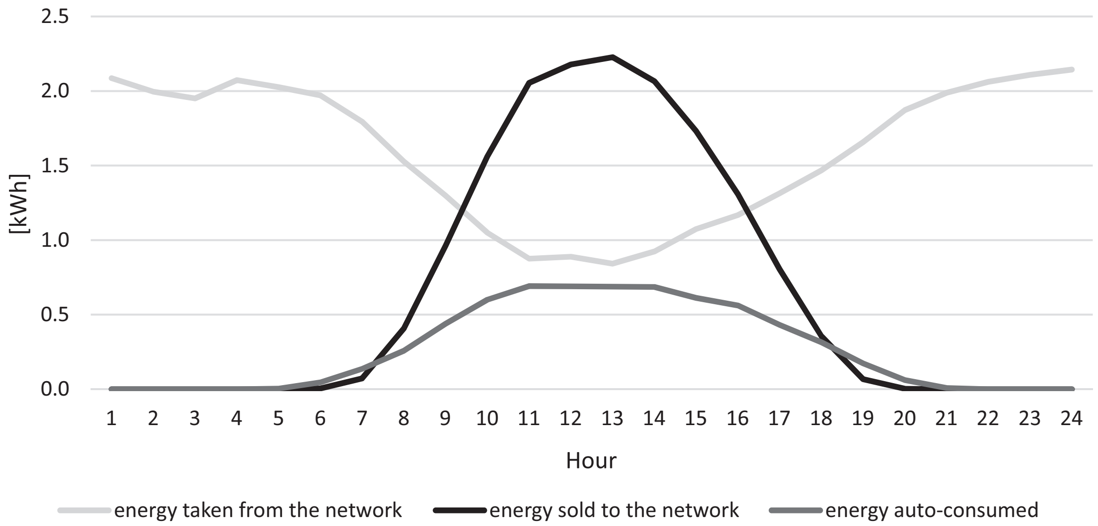

Fig. 6. Average hourly volume of electricity self-consumed, purchased, and supplied to the grid

Source: own calculations.

Scenarios NB and NM

The NB users will pay less per kWh, and the unit cost of electricity rises more slowly during the 15-year period than under the NM system (Fig. 4).

The lower cost per kWh does not imply a lower annual electricity bill (Fig. 8). The prosumer using the NB system will pay more for electricity than the NM user, except in the first three months in 2037, the last year of the 15-year period. As the future calculated electricity prices increase, so do the prices paid to the prosumer for the supplied electricity, but those prices will be lower starting in the second year of the considered period once the system applies the hourly electricity prices.

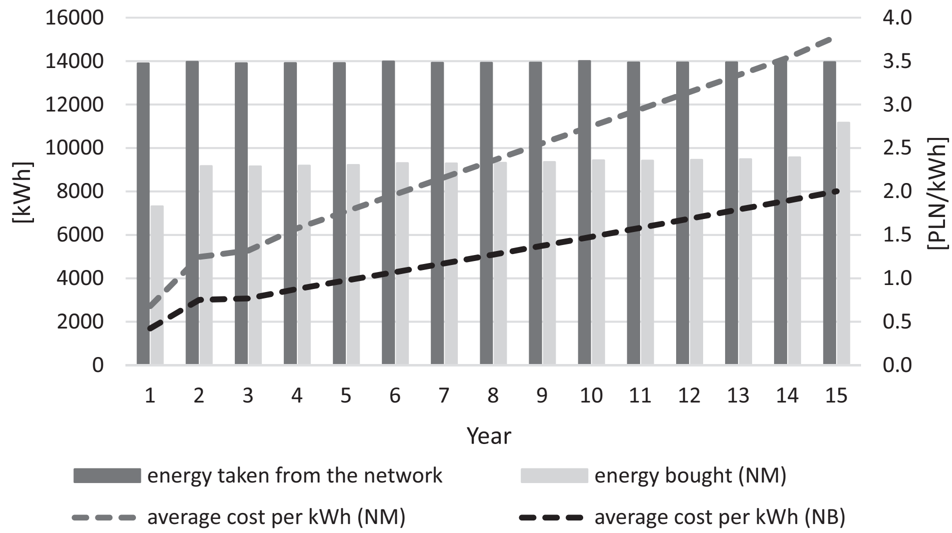

Fig. 7. Expected electricity purchase and the average kWh price in the 15-year period

Source: own calculations.

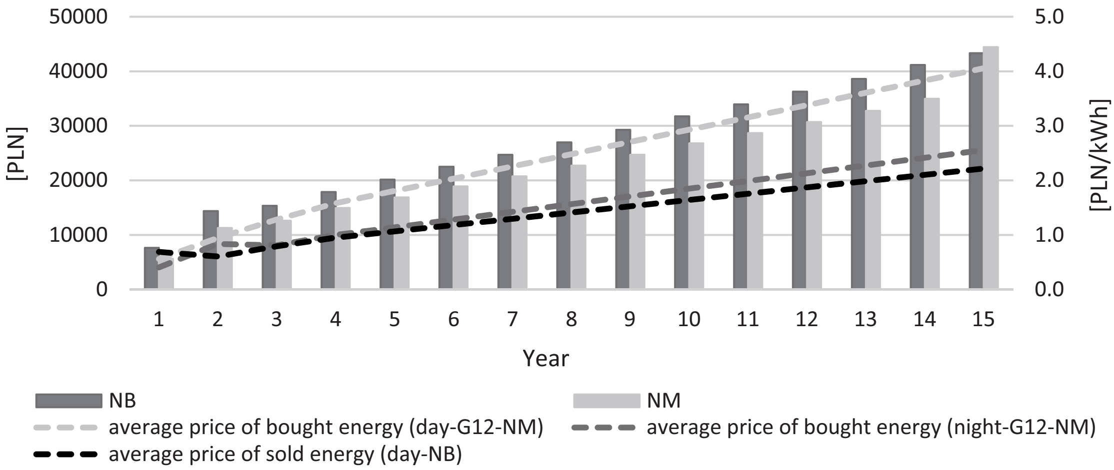

Fig. 8. Annual cost of consumed electricity and average electricity prices for the 15-year period

Source: own calculations.

The LCOE under the NB system is negative because the revenues from sales of surplus electricity average 0.46 PLN/kWh per unit of generated electricity (Table 3). Under the NM system, the LCOE is positive, reflecting the cost of electricity generation of 0.34 PLN/kWh. The LCOEC for scenario NM is lower and in scenario NB, a prosumer will pay about 0.23 PLN/kWh for every unit consumed (Table 3).

Scenarios NB+ and NM+

The flow of electricity changed with the addition of PV panels (Fig. 9). There is a noticeable increase in the volume of electricity sent to the grid after year one (Table 4). The self-consumption share declines from 28% to an average of 25.5% because the volume generated increased, but the self-consumption in hours of the strongest solar radiation remained un-

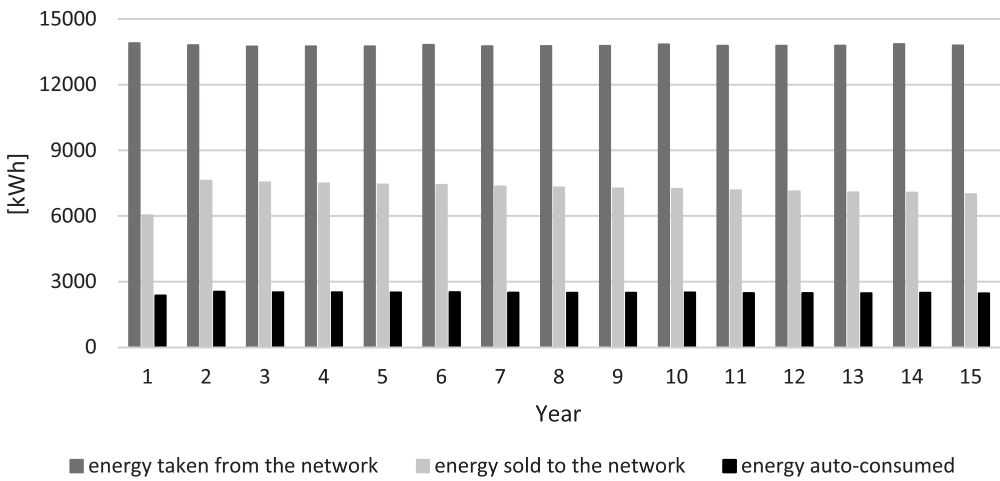

Fig. 9. Volume of the electricity purchased, supplied to the grid, and self-consumed following the addition of PV panels in the 15-year period

Source: own calculations.

Table 3. Calculated LCOE and LCOEC values for NM and NB scenarios for the annual period April 1 – March 31

Year	LCOEC [PLN/kWh]																	
	NB						NM				NB							
	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	K_t [PLN]	Z_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]		
1	39,168	4,000	7,181	39,168	4,000	8,388	2,067	4,443	39,168	4,000	16,255	5,622	39,168	4,000	16,255	7,619		
2			7,188			8,390	1,902	3,410			16,341	11,275			16,341	14,374		
3			7,114			8,304	1,853	4,850			16,255	12,593			16,255	15,332		
4			7,080			8,263	2,030	5,997			16,255	14,949			16,255	17,874		
5			7,046			8,222	2,168	6,695			16,255	16,864			16,255	20,134		
6			7,051			8,224	2,312	7,416			16,341	18,889			16,341	22,514		
7			6,979			8,140	2,436	8,066			16,255	20,744			16,255	24,685		
8			6,946			8,099	2,569	8,737			16,255	22,703			16,255	26,980		
9			6,913			8,058	2,699	9,399			16,255	24,680			16,255	29,285		
10			6,917			8,061	2,839	10,096			16,341	26,806			16,341	31,753		
11			6,847			7,978	2,953	10,699			16,255	28,684			16,255	33,922		
12			6,814			7,938	3,079	11,336			16,255	30,702			16,255	36,260		
13			6,781			7,898	3,202	11,963			16,255	32,739			16,255	38,608		
14			6,786			7,901	3,337	12,636			16,341	34,964			16,341	41,163		
15			6,717			7,820	2,102	13,195			16,255	44,438			16,255	43,329		
	–0.46						1.564				1.798							

Source: authors' calculations.

Table 4. Calculated LCOE and LCOEC values for MNM and MNB scenarios and LCOEC values for BPV scenario for the annual period April 1 – March 31

Year	LCOEC [PLN/kWh]								LCOEC [PLN/kWh]							
	MNB			MNM					MNB				BPV			
	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	K_t [PLN]	Z_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]
1	39,168	4,000	7,181	39,168	4,000	8,388	1,835	4,443	39,168	4,000	16,255	6,258	39,168	4,000	16,255	7,619
2	80,000	19,000	7,599	80,000	19,000	8,295	1,092	1,967	80,000	19,000	16,341	11,093	80,000	19,000	16,341	12,962
3			7,518			8,210	1,035	4,043			16,255	12,891			16,255	13,183
4			7,481			8,169	1,133	5,882			16,255	15,221			16,255	14,428
5			7,443			8,128	1,210	6,568			16,255	17,155			16,255	16,274
6			7,449			8,131	1,288	7,260			16,341	19,179			16,341	18,209
7			7,369			8,048	1,360	7,915			16,255	21,073			16,255	20,016
8			7,333			8,008	1,436	8,574			16,255	23,046			16,255	21,921
9			7,296			7,969	1,510	9,225			16,255	25,042			16,255	23,842
10			7,300			7,971	1,585	9,888			16,341	27,160			16,341	25,887
11			7,223			7,890	1,654	10,503			16,255	29,084			16,255	27,736
12			7,187			7,851	1,728	11,129			16,255	31,115			16,255	29,717
13			7,151			7,813	1,800	11,746			16,255	33,170			16,255	31,718
14			7,155			7,815	1,875	12,381			16,341	35,387			16,341	33,885
15			7,078			7,736	1,032	12,958			16,255	42,707			16,255	35,777
	–0.06			1.826					1.758				2.590			

Source: authors' calculations.

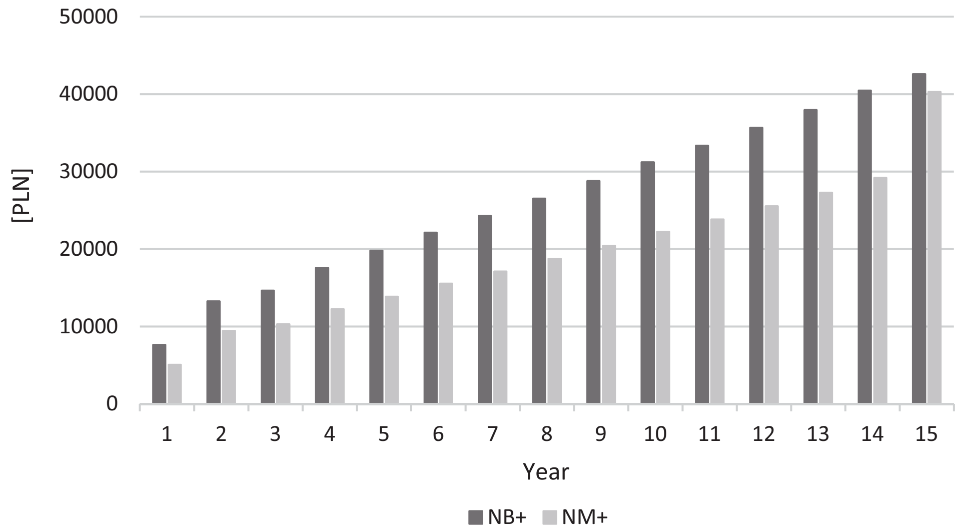

Fig. 10. Annual expenses for the purchased electricity under scenarios NB+ and NM+ following the addition of PV panels

Source: own calculations.

changed. The added capacity of 1.7 kW did not cause a significant decrease in the electricity purchased because the purchase takes place during the 24-hour period when the in the PV installation does not generate electricity.

Fig. 10 shows the costs associated with scenarios NB+ and NM+, which involve the expansion of capacity to 9.86 kW beyond one year after the PV installation. There is a clear advantage of the scenario NM+ over the NB+ regarding lower costs for the electricity consumed. Fig. 10 shows the expenses associated with scenarios NB+ and NM+ one year after the capacity expansion. The NM+ scenario features lower expenses than the NB+.

The LCOE calculations for scenarios increasing the generation of PV electricity involve the added investment of 8,500 PLN. The LCOE for the NB+ scenario is negative because a prosumer earns on average 0.27 PLN/kWh from selling electricity to the grid (Table 5). The LCOE in the NM+ system is positive, reflecting the cost of 0.35 PLN/kWh for the generated electricity. The LCOEC in the NB+ scenario is larger than in the NM+ scenario and the prosumer will pay about 0.43 PLN for every purchased kWh (Table 5).

Scenarios with the storage battery

The LCOEC is used to compare returns from the PV installation with or without storage and for two systems of settlements. The formula for the LCOE calculation varies across the scenarios because of the differences in the total cost of installation (I_t), amount of subsidy (D_t), and the volume of electricity from the prosumer's perspective (E_u'). The formula for scenarios NB, NB+ and MNB include earnings from sending electricity to the grid (Zt), but also additional costs due to higher (than in scenarios NM, NM+ and NMB) distribution fees (K_t).

Scenarios MNB and MNM

Adding a storage battery implies charging it with the prosumer-generated electricity and only once fully charged, sending any excess power to the grid. Electricity is purchased if the battery is empty. The increase in consumption from 28% to 57%, which includes electricity discharged from the battery, lowers the volume purchased and sent to the grid. The largest volume supplied to the grid is around 2 p.m. (Fig. 11), a time of the highest solar radiation and low prosumer electricity needs.

Table 5. Calculated LCOE and LCOEC values for NM+ and NB+ scenarios for the annual period April 1 – March 31

Year	NM+			NB+												
	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	K_t [PLN]	Z_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]
1	39,168	4,000	7,181	39,168	4,000	8,388	2,257	4,443	39,168	4,000	16,255	5,056	39,168	4,000	16,255	7,619
2	8,500	–	8,625	8,500	–	10,147	2,372	4,320	8,500	–	16,341	9,433	8,500	–	16,341	13,239
3			8,537			10,043	2,350	5,295			16,255	10,297			16,255	14,620
4			8,496			9,993	2,575	5,997			16,255	12,250			16,255	17,558
5			8,455			9,943	2,750	6,695			16,255	13,846			16,255	19,780
6			8,461			9,946	2,934	7,416			16,341	15,538			16,341	22,118
7			8,374			9,844	3,091	8,066			16,255	17,095			16,255	24,253
8			8,334			9,795	3,260	8,737			16,255	18,745			16,255	26,510
9			8,294			9,746	3,426	9,399			16,255	20,416			16,255	28,777
10			8,300			9,748	3,604	10,096			16,341	22,214			16,341	31,199
11			8,215			9,648	3,750	10,699			16,255	23,814			16,255	33,337
12			8,175			9,600	3,911	11,336			16,255	25,535			16,255	35,637
13			8,136			9,552	4,068	11,963			16,255	27,278			16,255	37,946
14			8,141			9,555	4,239	12,636			16,341	29,181			16,341	40,454
15			8,058			9,457	2,700	13,195			16,255	40,271			16,255	42,591
		1.370				1.799										

Source: Authors' calculations.

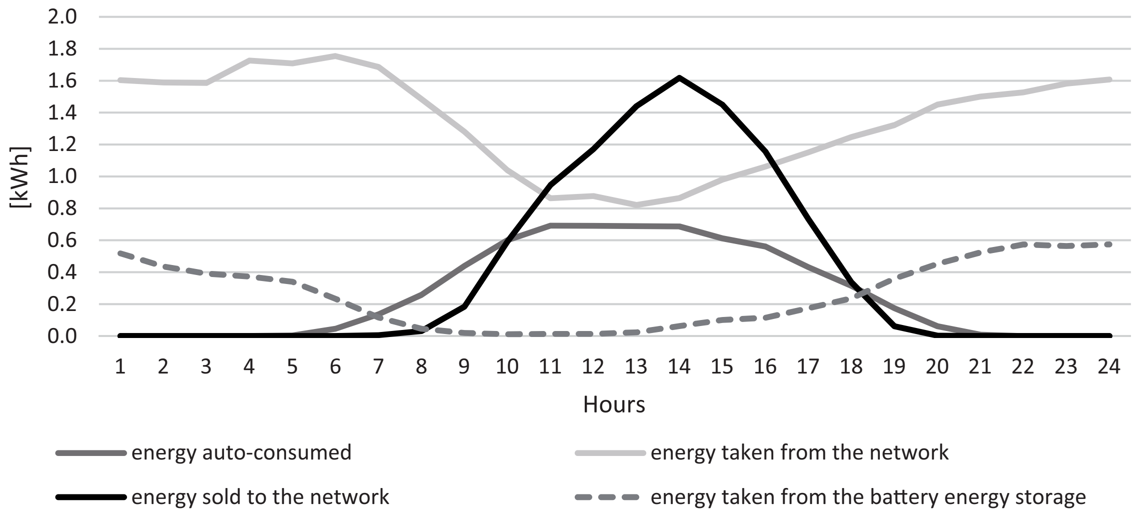

Fig. 11. Average hourly volume of the purchased, supplied, and self-consumed electricity and electricity discharged from the storage battery

Source: own calculations.

Electricity stored in the battery by 7 p.m. is consumed by the household later that evening, when the generation ceases.

The prosumer expenses under scenarios MNB and MNM with a battery added to the existing PV installation are shown in Fig. 12. Under the NB system, the prosumer will pay more in the first two years of using the battery than when using the NM system. Starting in year four, the bill in the MNB scenario is lower than in the MNM scenario.

The advantage of the MNB system over the MNM results from the pricing of the electricity supplied to the grid and the reduced purchases because of the self-consumption. Under the MNB system, the prosumer compensates for a portion of the cost of the electricity obtained from the grid by the revenues from selling their surplus (Fig. 13). Under the MNM system, the prosumer offsets a part of the purchased electricity cost by reducing the volume sent to the grid, as he can only recover up to 80% of the electricity sent. Moreover, in the scenarios involving a storage battery, 4% of generated electricity is used to charge/discharge the battery, which implies a "loss" of 24% of the generated electricity under the MNM scenario.

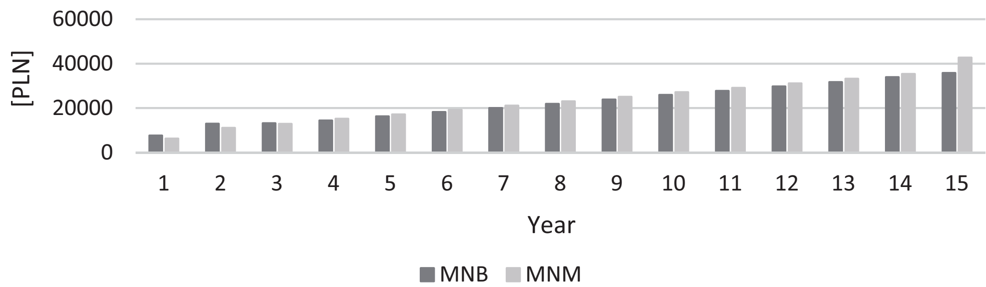

Fig. 12. Annual expenses of purchased, consumed electricity for scenarios MNB and MNM with the addition of a storage battery during the 15-year period.

Source: own calculations.

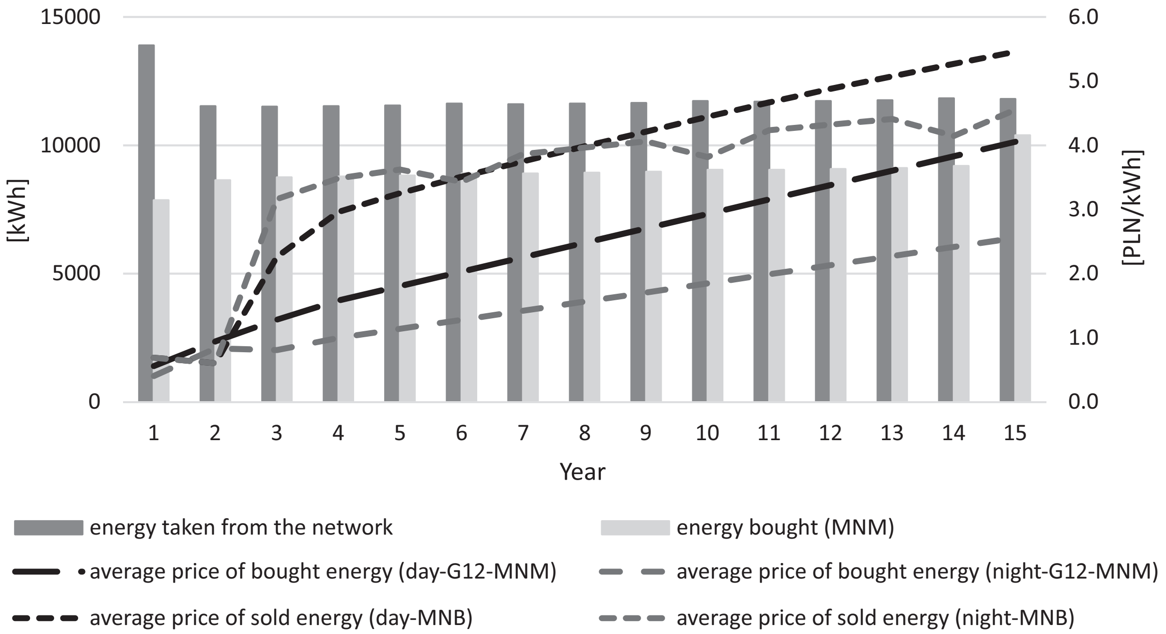

Fig. 13. Annual cost of consumed electricity and the average electricity prices at day- and night-time rates for the 15-year period

Source: own calculations.

The LCOE in the MNB scenario is negative because of the earnings from electricity sales, which implies earnings of an average 0.06 PLN/kWh per unit of electricity generated by the PV installation (Table 6). The LCOEC values under scenario MNM are positive, reflecting the electricity unit costs from the PV installation at 0.88 PLN/kWh. The assumption of additional investment costs is identical for both types of calculated LCOE and LCOEC values. The LCOEC for scenario MNB are lower than for the MNM system and the prosumer pays about 0.07 PLN less for each consumed kWh than under the NM system (Table 6).

BPV scenario

Scenario BPV is for a household that does not operate a micro-PV installation and involves the calculation of consumed electricity for a period of 15 years that a prosumer would have to pay if he did not own PV equipment. The LCOEC in scenario BPV is 2.59 PLN/kWh, assuming constant electricity consumption, and the calculations account for leap years (29 days, not 28 days in February), (Table 6).

Table 6. Calculated LCOEC values for scenario BPV

Year	E_z [kWh]	R_t [PLN]
1	16,255	14,120
2	16,341	21,016
3	16,255	23,954
4	16,255	28,376
5	16,255	31,892
6	16,341	35,602
7	16,255	38,921
8	16,255	42,438
9	16,255	45,954
10	16,341	49,738
11	16,255	52,983
12	16,255	56,501
13	16,255	60,017
14	16,341	63,875
15	16,255	67,045

Note: Each period is from April 1 to March 31.

Source: own calculations.

CONCLUSIONS

The study considered a case of a rural prosumer operating micro-PV installation to supply electricity to the grid and draw it from the grid to operate a heat pump and other uses. With the most recent revisions in the energy sector regulations, the policy to decarbonize the economy, and promotion programs offering new grants for RES utilizations, the prosumer faces the choice between the continued use of the NM settlement system or expanding the micro-PV installation and adding a storage battery under the condition of switching to the NB system. Under the NM settlement system, the prosumer could supply an unlimited volume to the grid, free of access or distribution fees. The fee cost was shifted to non-prosumer households, that is, those whose applications for the grant program were denied or who never considered applying because they could not afford the required matching contribution. An earlier study of Danish prosumers indicated the unfairness of waving the fees.

The NB system is complex because, since the current formula (until June 30, 2024), the price the prosumer receives for the electricity supplied in month N is established in month N+1. Starting July 1, 2024, the prices will be the hourly market prices, which will increase the uncertainty about the value of the household-generated electricity. A potential prosumer will have to manage their own and national electricity consumption patterns and understand the pattern of daily electricity price fluctuations and how electricity demand changes with the seasons.

The calculation of electricity prices through 2037 made it possible to estimate prosumer gains under the NB system. The calculation applied historical data of the electricity hourly market prices. The forecast indicates a steady growth of electricity prices reaching 2.33 PLN/kWh (almost 300% more) in 2037, as compared to 0.79 PLN/kWh in 2022. As the RCE values grow, so do the retail prices established by electricity distributors supplying households. Electricity prices according to the G12 tariff for 2023 for customers of the PGE company equaled 1.2 PLN/kWh during the day and 0.76 PLN/kWh at night and are expected to reach 3.43 PLN/kWh and 2.17 PLN/kWh in 2037, respectively.

Figure 14 shows the summary of the annual electricity costs for the seven scenarios and a 15-year period of operating a PV installation. The results show a prosumer using the NB system for the 15-year period will pay 0.23 PLN/kWh more for every kWh used than under the NM system. Expanding the micro-PV installation capacity when using the NB system will not improve gains from the investment, but for a prosumer using the NM system, the decrease would amount to 0.19 PLN/kWh. It appears that the purpose of the NM system

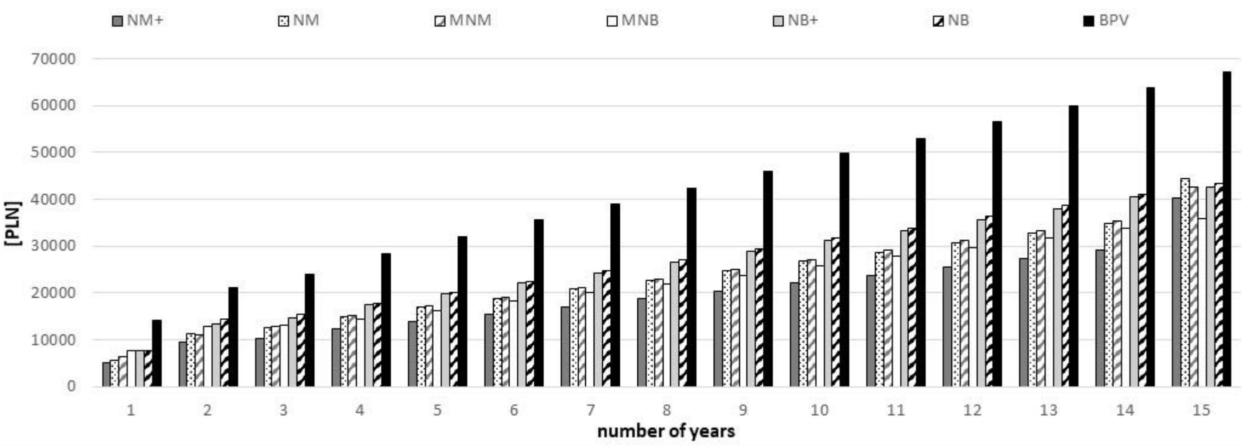

Fig. 14. Annual costs of consumed energy for each scenario for a 15-year period

Source: own calculations.

was to take a portion of the electricity generated by the household to the grid without compensation, discouraging investment in the household storage. However, the storage battery in the NB system increases the gains from the investment by a small amount, lowering the cost of consumed electricity by 0.004 PLN/kWh.

Gains due to electricity storage are linked to the household's pattern of electricity use, and the size of the subsidy because without those factors, the LCOEC in scenario MNB would not have been lower than in scenario NB. Although the settlement conditions have worsened following the introduction of the NB system, it is still worthwhile to invest in RE because the investment in a micro-PV installation can still lower the household electricity bill. A broader question remains how low-income households could benefit from the program. A step in the right direction was the elimination of family per capita income requirements, but the matching funds condition is still at issue. Additionally, since some low-income persons may be cognitively challenged, there is a need to assist low-income households in applying to a program and, later, reporting any grant funding in the mandatory annual tax filing.

Electricity price increases are highly likely in the coming years due to the zero- and low-emission requirements of commercial power generation plants. Any additional shocks like the Russian invasion of Ukraine and the subsequent energy market volatility could further contribute to electricity price increases. Electricity generation is still to a large extent based on fossil fuels in Poland and many power plants are costly to operate because of the high prices of CO_2 emission permits and prices of imported feedstock, which is highly dependent on the geopolitical conditions.

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REFERENCES

Adamska, B. (2021). Rzeczywisty początek magazynowania energii w Polsce? Wszędzie o nich głośno, ale efektów brak (The real beginning of energy storage in Poland? There is talk about them everywhere, but there are no results). Globenergia. Retrieved from https://globenergia.pl/comments/rzeczywisty-poczatek-magazynowania-energii-w-polsce-wszedzie-o-nichglosno-ale-efektow-brak [accessed: 01.02.2024].

Antosiewicz, M., Lewandowski, P., Sokołowski, J. (2022). The economic effects of stopping Russian energy imports in Poland. Instytut Badań Strukturalnych, Research Report 01/2022.

Breeze Energies 2022. Fotowoltaika z magazynem energii – jak przyłączyć magazyn energii do istniejącej instalacji PV? (Photovoltaics with energy storage – how to connect an energy storage facility to an existing PV installation?) Retrieved from https://www.youtube.com/watch?v=8PPcCRzmPnI [accessed: 19.10.2023].

Centrum Informacji Rynku Energii (2023). Trwa budowa Centralnego Systemu Informacji Rynku Energii (The construction of the Central Energy Market Information System is underway). Retrieved from https://www.cire.pl/artykuly/serwis-informacyjny-cire-24/trwa-budowa-centralnego-systemu-informacji-rynku-energii-csire [accessed: 19.10.2023].

Chatzigeorgiou, N.G., Yerasimou, Y.P., Florides, M.A., Georghiou, G.E. (2021). Grid Export Reduction Based on Time-Scheduled Charging of Residential Battery Energy Storage Systems – A Case Study in Cyprus. [In:] Littlewood, J., Howlett, R.J., Jain, L.C. (eds) Sustainability in Energy and Buildings 2020. Smart Innovation, Systems and Technologies, 203. Springer, Singapore, 231–241. https://doi.org/10.1007/978-981-15-8783-2_19

Chatzigeorgiu, N.G., Theocharides, S., Makrides, G., Georghiou, G.E. (2023). Evaluating the techno-economic effect of pricing and consumption parameters on the power-to-energy ration for sizing photovoltaic-batter-systems: an assessment of prosumer in the Mediterranean area. Energies, 16, 4073. https://doi.org/10.3390/en16104073

Chinowski, N. (2023). PKB Polski. Ponad połowę wypracowuje pięć województw (Poland's GDP. More than half is generated by five voivodeships). Retrieved from https://forsal.pl/gospodarka/pkb/artykuly/9389449,pkb-polski-ponad-polowe-wypracowuje-piec-wojewodztw.html [accessed: 05.02.2024]

Chomać-Pierzecka, E., Kokiel, A., Rogozińska-Mitrut, J., Sobczak, A., Soboń, D., Stasiak, J. (2022). Analysis and Evaluation of the Photovoltaic Market in Poland and the Baltic States. Energies, 15, 669. https://doi.org/10.3390/en15020669

Chomać-Pierzecka, E., Sobczak, A., Soboń, D. (2022). Wind Energy Market in Poland in the Background of the Baltic Sea Bordering Countries in the Era of the COVID-19 Pandemic. Energies, 15, 2470. https://doi.org/10.3390/en15072470

Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank Clean Energy For All Europeans. COM/2016/0860 final.

Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality. COM/2021/550 final.

Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions EU Solar Energy Strategy {SWD(2022) 148 final}. COM/2022/221 final.

Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions REPowerEU Plan. COM/2022/230 final.

Derski B. (2021). Źródła energii w Polsce w 2020: mniej węgla, więcej gazu i OZE (Energy sources in Poland in 2020: less coal, more gas and renewable energy). Retrieved from https://wysokienapiecie.pl/35619-zrodla-energii-w-polsce-w-2020-mniej-wegla-wiecej-gazu-oze/ [accessed: 19.10.2023].

Derski, B. (2023). Pomimo „zamrożenia" ceny prądu wzrosły najmocniej od 30 lat (Despite the "freeze", electricity prices increased the most in 30 years). Retrieved from https://wysokienapiecie.pl/93289-pomimo-zamrozenia-ceny-pradu-wzrosly-najmocniej-od-30-lat/ [accessed: 19.01.2024].

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast)

Djaków P. (2023). Zima 2022/2023: rekordy ciepła w Polsce, wielkie śniegi w Ameryce, Nauka o klimacie dla sceptycznych (Winter 2022/2023: heat records in Poland, big snows in America, Climate science for the skeptical). Retrieved from https://naukaoklimacie.pl/aktualnosci/zima-2022-203-rekordy-ciepla-w-polsce-wielkie-sniegi-w-ameryce/ [accessed: 19.10.2023].

Dz.U. 1997 Nr 54 poz. 348 (1997). Ustawa z dnia 10 kwietnia 1997 r. Prawo energetyczne (Act of April 10, 1997 Energy Law). Retrieved from https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU19970540348/U/D19970348Lj.pdf [accessed: 19.10.2023].

Dz.U. 2015 poz. 478 (2015). Ustawa z dnia 20 lutego 2015 r. o odnawialnych źródłach energii (Act of February 20, 2015 on renewable energy sources). Retrieved from https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20150000478/U/D20150478Lj.pdf [accessed: 19.10.2023].

Dz.U. 2021 poz. 1093 (2021). Ustawa z dnia 20 maja 2021 r. o zmianie ustawy – Prawo energetyczne oraz niektórych innych ustaw (Act of May 20, 2021 amending the Energy Law and certain other acts). Retrieved from https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20210001093/U/D20211093Lj.pdf [accessed: 19.10.2023].

Dz.U. 2022 poz. 2127 (2022). Ustawa z dnia 7 października 2022 r. o szczególnych rozwiązaniach służących ochronie odbiorców energii elektrycznej w 2023 roku w wiązku z sytuacją na rynku energii elektrycznej (Act of October 7, 2022 on special solutions to protect electricity consumers in 2023 in connection with the situation on the electricity market). Retrieved from https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20220002127/U/D20222127Lj.pdf [accessed: 19.10.2023].

Dz.U. 2022 poz. 2243 (2022). Ustawa z dnia 27 października 2022 r. o środkach nadzwyczajnych mających na celu ograniczenie wysokości cen energii elektrycznej oraz wsparciu niektórych odbiorców w 2023 roku (Act of October 27, 2022 on emergency measures aimed at limiting electricity prices and supporting certain customers in 2023). Retrieved from https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20220002243/U/D20222243Lj.pdf [accessed: 19.10.2023].

European Council and Council of the European Union (2023). Timeline – EU sanctions against Russia. Retrieved from https://www.consilium.europa.eu/en/policies/sanctions-against-russia/timeline-sanctions-against-russia/ [accessed: 19.10.2023].

Fotowoltaikaonline.pl. (2023). Net billing – jak działa? Pokazujemy faktury! (Net billing – how does it work? We show invoices!). Retrieved from https://fotowoltaikaonline.pl/net-billing [accessed: 19.10.2023].

GUS (2023). Zużycie energii w gospodarstwach domowych w 2021 r. (Energy consumption in households in 2021). Urząd Statystyczny w Rzeszowie.

Instytut Energetyki Odnawialnej. (2021). Rynek Fotowoltaiki w Polsce 2021 (Photovoltaics market in Poland 2021). Retrieved from https://ieo.pl/raport-rynek-fotowoltaiki-w-polsce-2021 [accessed: 19.10.2023].

Instytut Energetyki Odnawialnej. (2022). Rynek Fotowoltaiki w Polsce 2022 (Photovoltaics market in Poland 2022). Retrieved from https://ieo.pl/raport-rynek-fotowoltaiki-w-polsce-2022 [accessed: 19.10.2023].

Instytut Energetyki Odnawialnej. (2023). Rynek Fotowoltaiki w Polsce 2023 (Photovoltaics market in Poland 2023). Retrieved from https://ieo.pl/raport-rynek-fotowoltaiki-w-polsce-2023 [accessed: 19.10.2023].

International Renewable Energy Agency. Innovation Landscape Brief: Net Billing Schemes. (2019). Retrieved from https://irena.org//media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Net_billing_2019.pdf?la=en&hash=DD239111CB0649A9A9018BAE77B9AC06B9EA0D25 [accessed 01.02.2024].

International Renewable Energy Agency. (2022). Renewable power generation costs in 2021. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Power_Generation_Costs_2021.pdf?rev=34c22a4b244d434da0accde7de7c73d8 [accessed: 19.10.2023].

Jarosiński, M., Godlewski, W., Sierakowski, M. (2021). Opłacalność instalacji PV z bateryjnymi magazynami energii a proponowane zmiany w rozliczaniu prosumentów (Profitability of prosumer photovoltaic installations with battery energy storage in the context of the proposed changes in the settlement of prosumers in Poland). Rynek Instalacyjny, 9, 38–44.

Kancelaria Prezesa Rady Ministrów. (2022). Założenia do aktualizacji Polityki Energetycznej Polski do 2040 r. (PEP2040) – wzmocnienie bezpieczeństwa i niezależności energetycznej (Assumptions for updating the Polish Energy Policy until 2040 (PEP2040) – strengthening energy security and independence). Retrieved from https://www.gov.pl/web/premier/zalozenia-do-aktualizacji-polityki-energetycznej-polski-do-2040-r-pep2040--wzmocnienie-bezpieczenstwa-i-niezaleznosci-energetycznej [accessed: 19.10.2023].

Kaya, O., Klepacka, A.M., Florkowski, W.J. (2019). Achieving renewable energy, climate, and air quality policy goals: Rural residential investment in solar panels. Journal of Environmental Management 248, 109309. https://doi.org/10.1016/j.jenvman.2019.10930

Klepacka A.M., Florkowski, W.J. (2019). The wood pellet sector, barriers to growth, and opinions of manufacturers in Poland. Problems of World Agriculture, 19(4), 9–18. https://doi.org/10.22630/PRS.2019.19.4.52

Klepacka A.M., Florkowski W.J. (2021). An Opportunity for Renewable Energy: Wood Pellet Use by Rural Households. [In:] Lackner M., Sajjadi B., Chen WY. (eds) Handbook of Climate Change Mitigation and Adaptation. Springer, New York, https://doi.org/10.1007/978-1-4614-6431-0_110-1

Klepacka, A.M., Florkowski, W.J., Meng, T. (2018). Clean, accessible, and cost-saving: Reasons for rural household investment in solar panels in Poland. Resources, Conservation, & Recycling, 139: 338–350, https//doi.org/10.1016/j.resconrec.2018.09.004.

Klepacka, A.M., Pawlik, K. (2018). Return on investment in PV power plants under changing support regimes (schemes). Zagadnienia Ekonomiki Rolnej, 356, 168–191.

Kurz, D., Nowak, A. (2023). Analysis of the impact of the level of self-consumption of electricity from a prosumer photovoltaic installation on its profitability under different energy billing scenarios in Poland. Energies 16, 946. https://doi.org/10.3390/en16020946

Leiren, M.M., Reimer, I. (2018). Historical institutionalist perspective on the shift from feed-in tariffs towards auctioning in German renewable energy policy. Energy Research & Social Science, 41, 33–40.

Lorenc, H. (2005). Atlas Klimatyczny Polski (Climatic Atlas of Poland). Instytut Meteorologii i Gospodarki Wodnej, Warszawa, Poland.

Mahoney, J., Thelen, K. 2010. A theory of gradual institutional change. [In:] Mahoney, J., Thelen, K. (eds.), Explaining Institutional Change. Ambiguity, Agency, and Power. Cambridge University Press, New York, 1–37.

Ministerstwo Funduszy i Polityki Regionalnej, (2023). Szczegółowy opis osi priorytetowych Programu Operacyjnego Infrastruktura i Środowisko 2014–2020 (Detailed description of the priority axes of the Operational Program Infrastructure and Environment 2014–2020). Retrieved from https://www.pois.gov.pl/media/115095/SzOOP_POIiS_v_24_4.pdf [accessed: 19.10.2023].

Ministerstwo Klimatu i Środowiska (2021a). Nowy system rozliczania, tzw. net-billing – od 1 kwietnia 2022 r. dla nowych prosumentów (A new settlement system, the so-called net-billing – from April 1, 2022 for new prosumers). Retrieved from https://www.gov.pl/web/klimat/nowy-system-rozliczania-tzw-net-billing---od-1-kwietnia-2022-r-dla-nowych-prosumentow [accessed: 19.10.2023].

Ministerstwo Klimatu i Środowiska (2021b). Silniejszy i aktywniejszy odbiorca na rynku energii (A stronger and more active consumer on the energy market). Retrieved from https://www.gov.pl/web/klimat/silniejszy-i-aktywniejszy-odbiorca-na-rynku-energii [accessed: 19.10.2023].

Ministerstwo Klimatu i Środowiska (2022a). Program Mój Prąd część 1 (My Electricity program part 1). Retrieved from https://mojprad.gov.pl/images/program-moj-prad-czesc-1_20221202_mp4-2.pdf [accessed: 19.10.2023].

Ministerstwo Klimatu i Środowiska (2022b). Net-billing i net-metering a progi mrożące stawki za prąd. Jak w 2023 r. będą rozliczać się prosumenci? (Net-billing and net-metering and thresholds freezing electricity rates. How will prosumers settle their accounts in 2023?). Retrieved from https://www.gov.pl/web/klimat/net-billing-i-net-metering-a-progi-mrozace-stawki-za-prad-jak-w-2023-r-beda-rozliczac-sie-prosumenci [accessed: 19.10.2023].

Ministerstwo Klimatu i Środowiska (2023). Dotacje z programu Mój Prąd (Grants from the My Electricity program). Retrieved from https://mojprad.gov.pl/ [accessed: 19.10.2023].

Ministerstwo Klimatu i Środowiska (2024). Polska przekazała do KE wstępną wersję aktualizacji „Krajowego planu w dziedzinie energii i klimatu do 2030 r." (Poland has submitted to the EC a preliminary version of the update of the "National Energy and Climate Plan until 2030"). https://www.gov.pl/web/klimat/polska-przekazala-do-ke-wstepna-wersje-aktualizacji-krajowego-planu-w-dziedzinie-energii-i-klimatu-do-2030-r [accessed: 28.05.2024].

Monitor Polski poz. 264. (2021). Obwieszczenie Ministra Klimatu i Środowiska z dnia 2 marca 2021 r. w sprawie polityki energetycznej państwa do 2040 r. (Announcement of the Minister of Climate and Environment of March 2, 2021 on the state energy policy until 2040). Retrieved from https://isap.sejm.gov.pl/isap.nsf/download.xsp/WMP20210000264/O/M20210264.pdf [accessed: 19.10.2023].

Nyga-Łukaszewska, H., Aruga, K. (2020). Energy Prices and COVID-Immunity: The Case of Crude Oil and Natural Gas Prices in the US and Japan. Energies, 13, 6300. https://doi.org/10.3390/en13236300

Official Journal of the European Union (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (Text with EEA relevance) Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=ES [accessed: 19.10.2023]. 37

Official Journal of the European Union (2019). Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0943&from=HR [accessed: 19.10.2023]. 25

Polska Grupa Energetyczna (2023). Podstawowe zasady rozliczania prosumentów (Basic rules for settling prosumers). Retrieved from https://www.gkpge.pl/content/download/45094cd18a7469aa1a24a218deee2c8e/file/podstawowe-zasady-rozliczania-prosumentow.pdf?contentId=98298 [accessed: 19.10.2023].

Polskie Sieci Elektroenergetyczne (2022). Zestawienie danych ilościowych dotyczących funkcjonowania KSE w 2022 roku (Summary of quantitative data on the operation of the National Power System in 2022). Retrieved from https://www.pse.pl/dane-systemowe/funkcjonowanie-kse/raporty-roczne-z-funkcjonowania-kse-za-rok/raporty-za-rok-2022#r6_2 [accessed: 19.10.2023].

Polskie Sieci Elektroenergetyczne (2023a). Plan wdrożenia CSIRE (CSIRE implementation plan). Retrieved from https://www.pse.pl/documents/20182/976314471/Plan_wdrozenia_CSIRE_publikacja_13022023.pdf [accessed: 19.10.2023].

Polskie Sieci Elektroenergetyczne (2023b). Rynkowa cena energii elektrycznej (RCE) (Market price of electricity (RCE)). Retrieved from https://www.pse.pl/dane-systemowe/funkcjonowanie-rb/raporty-dobowe-z-funkcjonowania-rb/podstawowe-wskazniki-cenowe-i-kosztowe/rynkowa-cena-energii-elektrycznej-rce [accessed: 19.10.2023].

Polskie Sieci Elektroenergetyczne (2023c). RCEm – Rynkowa miesięczna cena energii elektrycznej – PSE (RCEm – Market monthly price of electricity – PSE). Retrieved from https://www.pse.pl/oire/rcem-rynkowa-miesieczna-cena-energii-elektrycznej [accessed: 19.10.2023].

Polskie Sieci Elektroenergetyczne (2023d). Rynek Dnia Następnego (Day Ahead Market). Retrieved from https://www.pse.pl/obszary-dzialalnosci/wymiana-miedzysystemowa/rynek-dnia-nastepnego [accessed: 19.10.2023].

Pomorski M., Nemś A., Kolasiński P., Malecha Z., Chorowski M. (2022). Analiza wpływu magazynowania energii elektrycznej na opłacalność prosumenckiej mikroinstalacji fotowoltaicznej (Analysis of the impact of electricity storage on the profitability of a prosumer photovoltaic micro-installation), INSTAL, 9, 26–32.

Redakcja PIT.pl. (2022). 1 stycznia 2023 r. wraca wyższy VAT na energię i paliwa. Żywność do czerwca z zerową stawką (On January 1, 2023, higher VAT on energy and fuel returns. Food until June at zero rate). Retrieved from https://www.pit.pl/aktualnosci/1-stycznia-2023-r-wraca-wyzszy-vat-na-energie-i-paliwa-zywnosc-do-czerwca-z-zerowa-stawka-1007752 [accessed: 19.10.2023].

Serwis Samorządowy PAP (2022). Rząd przyjął projekt ustawy blokujący w 2023 r. ceny prądu (The government has adopted a bill blocking electricity prices in 2023). Retrieved from https://samorzad.pap.pl/kateoria/aktualnosci/rzad-przyjal-projekt-ustawy-blokujacy-w-2023-r-ceny-pradu [accessed: 19.10.2023].

Serwis Rzeczpospolitej Polskiej (2023). Rządowa Tarcza Solidarnościowa – Chronimy rodziny (Government Solidarity Shield – We protect families). Retrieved from https://www.gov.pl/web/chronimyrodziny/rzadowa-tarcza-solidarnosciowa [accessed: 19.10.2023].

Siudek, A., Klepacka, A.M., Florkowski, W.J., Gradziuk, P. (2020). Renewable energy utilization in rural residential housing: economic and environmental facets. Energies, 13, 6637, https://doi.org/10.3390/en13246637

Sulewski, P., Majewski, E., Wąs, A., Szymańska, M., Malak-Rawlikowska, A., Fraj, A., Trząski, A., Wiszniewski, A., Amrozy, M. (2016). Uwarunkowania ekonomiczno-prawne i opłacalność inwestycji w biogazownie rolnicze w Polsce (Economic and legal conditions and profitability of investments in agricultural biogas plants in Poland). Zagadnienia Ekonomiki Rolnej, 1(346), 119–143.

Szczygieł L. (2005). Urząd Regulacji Energetyki, Model rynku energii elektrycznej (Energy Regulatory Office, Electricity market model). Retrieved from https://www.ure.gov.pl/pl/urzad/informacje-ogolne/edukacja-i-komunikacja/publikacje/seria-wydawnicza-bibli/jaki-model-rynku-energ/1183,1-Model-rynku-energii-elektrycznej.html [accessed: 19.10.2023].

Towarowa Giełda Energii. (2023). TGE – Market Coupling. Retrieved from https://tge.pl/market-coupling [accessed: 19.10.2023].

Trela, M., Dubel, A. (2022). Net-Metering vs. Net-Billing from the investors perspective – impacts of changes in RES financing in Poland on the profitability of a joint photovoltaic panels and heat pump system. Energies, 15, 227. https://doi.org/10.3390/en15010227

Yagi, M., Managi, S. (2023). The spillover effects of rising energy prices following 2022 Russian invasion of Ukraine. Economic Analysis and Policy, 77, 680–695.

Zasuń R., Derski, B. (2022). Żegnamy rynek energii. Jeszcze zatęsknimy (We say goodbye to the energy market. We will miss you again). Retrieved from https://wysokienapiecie.pl/77866-zegnamy-rynek-energii-jeszcze-zatesknimy [accessed: 19.10.2023].

Ziras, C., Calearo, L., Marinelli, M. (2021). The effect of net metering methods on prosumer energy settlements. Sustainable Energy, Grids and Networks, 27, 46–57.

Urząd Regulacji Energetyki (2020). Co oznaczają różne rodzaje opłat na moim rachunku? (What do the different types of charges mean on my bill?). Retrieved from https://www.ure.gov.pl/pl/konsumenci/faq-czesto-zadawane-py/energia-elektryczna/3921,Co-oznaczaja-rozne-rodzaje-oplat-na-moim-rachunku.html [accessed: 19.10.2023].

Urząd Regulacji Energetyki (2022). Biuletyn Urzędu Regulacji Energetyki (Bulletin of the Energy Regulatory Office), 3(115).

Urząd Regulacji Energetyki (2023a). Taryfy opublikowane w 2023 r. (Tariffs published in 2023). Retrieved from https://bip.ure.gov.pl/bip/taryfy-i-inne-decyzje-b/energia-elektryczna/4367,Taryfy-opublikowane-w-2023-r.html [accessed: 19.10.2023].

Urząd Regulacji Energetyki (2023b). Ile zapłacimy za energię elektryczną od stycznia 2023 roku? (How much will we pay for electricity from January 2023?). Retrieved from https://www.ure.gov.pl/pl/urzad/informacje-ogolne/aktualnosci/10718,Ile-zaplacimy-za-energie-elektryczna-od-stycznia-2023-roku.html [accessed: 19.10.2023].

OPŁACALNOŚĆ MIKROINSTALACJI PV W NOWEJ WERSJI PROSUMENCKIEJ – STUDIUM PRZYPADKU

STRESZCZENIE

Cel: Artykuł generuje informację o oczekiwanych kosztach elektryczności przy uwzględnieniu kilku scenariuszy dotyczących instalacji PV i dodania baterii magazynującej energię elektryczną, a dotyczących przypadku prosumenta wiejskiego posiadającego mikro-instalcję PV w obliczu wyboru decyzji przejścia na nowy system billingu (NB) lub kontynuację umowy w systemie net-metering (NM) (w nowych warunkach subsydiowania baterii magazynującej). **Metody:** Na podstawie danych wyjściowych sporządzono prognozę cen energii elektrycznej na okres 15. lat i obliczono przyszłe zmiany w kosztach energii elektrycznej dla alterantywnych wariantów, w tym dla gospodarstw domowych nie posiadających instalacji PV. Koszt energii elektrycznej zużytej przez prosumenta obliczono przy użyciu wartości Levelized Cost of Electricity (LCOE) oraz wskaźnika LCOE poszerzonego o konsumpcję (LCOEC) według własnego opracowania. **Wyniki:** W 2037 roku przewiduje się średnią cenę energii elektrycznej na poziomie 2,33 zł/kWh (prawie trzykrotnie wyższą niż w 2022 roku). Podobny wzrost wskazują prognozy w przypadku cen energii elektrycznej wynikającej z taryfy G12 dla gospodarstw domowych. Elastyczność prosumenta w samo-konsumpcji wygenerowanej energii elektrycznej determinuje korzyści wynikające z magazynowania energii elektrycznej, jednakże decydująca jest wysokość dofinansowania do inwestycji PV. Bez wsparcia finansowego wariant rozliczania mikroinstalacji PV z magazynem w systemie net-billingu (NB) nie miałby niższego wskaźnika LCOEC w porównaniu z wariantem net-billlingu (NB) bez magazynu. **Wnioski:** System rozliczeń w formule net-billingu (NB) jest droższy niż wcześniejszy systemu net-meteringu (NM) chociaż posiadanie mikroinstalacji PV wciąż skutkuje mniejszymi rachunkami za energię elektryczną w porównaniu do gospodarstw domowych nie posiadających takiego wyposażenia. Inwestowanie w mikro-instalcje PV będzie kontynuowane przez gospodarstwa domowe, lecz w tempie wolniejszym niż w ostatnich latach.

Słowa kluczowe: prosument, mikroinstalacja PV, system net-billing i net-metering, opłacalność produkcji energii elektrycznej

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ANALYSIS OF THE CHALLENGES OF CASHEW REHABILITATION TECHNIQUES (CRTS) IN OSUN STATE, NIGERIA

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ABSTRACT

Aim: This study sought to analyze the challenges faced by cashew farmers in the adoption of cashew rehabilitation techniques (CRTs) in Osun State, Nigeria. **Methods:** Data was collected from primary sources using structured questionnaires. A total of eighty (80) respondents were considered, forty (40) from each of the selected local government areas. The study adopted descriptive analysis to examine the socio-economic characteristics of the farmers, multinomial logistic (MNL) regression was used to evaluate the factors affecting the level of adoption of the CRTs while a Likert scale was adopted to measure the level of severity of identified constraints to CRTs adoption in the state. **Results:** The adoption level of coppicing is significantly affected by farm size, age of farmers and access to extension services. The adoption level of side-grafting is affected by farm size and level of education, and the level of adoption of total replanting is significantly influenced by age of farmers, age of farms and level of education. High labor costs, the high cost of agrochemicals and a labor shortage are highly severe constraints to the adoption of CRTs, while a lack of adequate knowledge and the existence of fire incidences are considered to be mildly severe constraints. **Conclusions:** Adoption of techniques is affected by factors such as age, education, farm size, and access to extension. Constraints to adoption include a lack of knowledge, high labor and chemical costs, labor shortage, and fire risk. Farmer education is highly encouraged to improve the technology adoption among cashew farmers in the study area.

Key words: cashew, rehabilitation, techniques, constraints, CRT adoption

JEL codes: D91, O39, Q16

INTRODUCTION

The cashew (*Anacardium Occidentale* L.) is a tropical economic crop that originates from the Amazon basin in Brazil [Subbarao et al. 2011]. The crop was introduced to Africa and Nigeria in particular by Portuguese explorers around the 15th and 16th centuries [Asogwa et al. 2009]. Individuals were initially obscured to the economic and commercial potentials of the crop, as the tree was only planted for erosion control at the time. However, the commercial value of the crop was later discovered as demand for the crop keeps rising in the global market [Tola and Mazengia 2019]. The cashew has since become a global economic crop and remains a major source of revenue for many economies around the world.

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The cashew is one of the most valued crops in the Nigeria agricultural sector. According to the Food and Agriculture Organization (FAO) of the United Nations [2020], the value of the crop was just below that of cocoa and sesame seed in the year 2020. The cashew, along with cocoa, oil palm and the peanut, was among the top export commodities in Nigeria before the discovery of oil in the 70s. The crop, along with other agricultural commodities, was affected by the discovery of oil and the shift of the Nigerian economy away from agriculture [Clinton-Etim and Manishimwe 2021]. Despite the discovery of oil in the 70s, the cashew still experienced a gradual increase in production over the years; although the growth in yield was not encouraging. Cashew nut was 800,000 tons in 2009. However, according to the FAO [2020], in the year 2011, the production of cashews in Nigeria started to plummet and by 2014, the production value had dropped to 126,490 tons. There have been some concerns about the low yield of cashews in Nigeria. However, when the actual production quantity fell, there was genuine panic among cashew producers and other stakeholders. Many causes have been attributed to the fall in cashew production and yield. Oluyole et al. [2015] cited a lack of adequate labor as one of the reasons. Asogwa et al. [2008] opined that the increased infestation of pests and diseases is a cause of the low cashew yield.

Furthermore, there has been an institutional effort geared at addressing the problem of the low yield in Nigeria, which has resulted in the development of various rehabilitation techniques in a bid to rehabilitate and regenerate the cashew farms to improve the cashew production yield and quality. According to Oluyole et al. [2015], some of the benefits of farm rehabilitation include an increase in yield, weed control as well as control of pests and diseases. However, despite the introduction of technologies in cashew rehabilitation techniques (CRTs) that are available, cashew productivity is still to recover to a satisfactory level, which leads to the question of what factors are militating against cashew rehabilitation practices in Nigeria?

To answer the above question, there is a need to take a cogent look into the challenges of cashew rehabilitation techniques in Nigeria since with such rehabilitation practices, the cashew output is expected to increase, hence the need for this study.

With respect to the above, the study seeks to achieve the following objectives:

- to examine the socio-economic characteristics of cashew farmers in Osun State
- to identify the challenges faced by farmers in cashew rehabilitation
- to analyze the impact of these challenges on the adoption of the CRTs

THEORETICAL REVIEW

Adoption of new technology in agriculture is a complex process that involves various factors. Here are some theoretical backgrounds for the adoption of new technology in agriculture.

Diffusion of Innovations Theory: Developed by Rogers [2003], this theory explains how innovations (including agricultural technologies) spread through a population over time. It classifies individuals into categories, such as innovators, early adopters, early majority, late majority, and laggards, based on their willingness to adopt new technologies. Factors influencing adoption include the innovation's relative advantage, compatibility, complexity, trialability, and observability.

Technology Acceptance Model (TAM): TAM focuses on the user's perceived ease of use and perceived usefulness of a technology. It posits that users are more likely to adopt a technology when they believe it is easy to use and will enhance their work or life [Marangunić and Granić 2015]. TAM has been applied to the context of agricultural technology adoption, emphasizing farmers' perceptions of how technology can improve their farming practices.

Theory of Planned Behavior (TPB): People's desire to embrace a technology is determined by their attitude toward the technology, subjective norms (influence of peers and society), and perceived behavioral control (self-efficacy), according to the TPB. Farmers' ideas and attitudes toward agricultural technology can have a substantial impact on their willingness to adopt it [Senger et al. 2015].

Innovation-Decision Process: This framework divides the technology adoption process into five stages: knowledge, persuasion, decision, implementation, and confirmation. It acknowledges that not all potential adopters will go through all of these stages, and that the process is influenced by factors such as the perceived features of the innovation, communication routes, and the social structure [Meena and Singh 2012].

Economic Theory: Economic reasons frequently impact agricultural technology adoption. Farmers analyze the costs and benefits of adopting a technology, taking into account factors such as predicted production gains, lower labor or material costs, and potential dangers. Understanding these decisions relies on a cost-benefit analysis and economic modeling [Gallardo and Sauer 2018].

MATERIALS AND METHODS

Study Area

The study was carried out in Osun State, Nigeria. The capital of Osun State is Osogbo, the state covers an area of about 14, 875 sq. kilometers and it is bounded by Ogun State to the south, Oyo State in the West, Ondo and Ekiti States in the East and Kwara State in the north. The state lies between longitude 6°51'N and 8°N and latitude 4°05'E and 5°02'E [Fakayode et al. 2012]. Osun State has a population of over three million people and is divided into six administrative zones, namely Ife, Ila, Ikirun, Iwo, Ilesa and Osogbo [Nigerian Population Census 2006].

Sampling Technique

A multistage sampling procedure was adopted in the course of this study. The first stage involved the purposive selection of the Iwo administrative zone out of the six zones due to the prominence of cashew production in this zone. The next stage involved the random selection of two Local Government Areas (LGAs), which were the Ejigbo and Iwo LGAs. The third stage involved the random selection of 40 cashew farmers from each of the LGAs previously selected. This was done from a list of cashew farmers provided by the Agricultural Development Projects (ADPs) (180 from Ejigbo and 200 from Iwo).

Likert Scale

Likert scales can be used to measure a variety of variations, including agreement, likelihood, frequency, importance, and quality [Matell et al. 1972]. Responses to several Likert questions can be summed and treated as interval data measuring a latent variable, to which parametric statistical tests, such as the analysis of variance, can be applied. While some researchers argue that three-point scales contain less information and can introduce rounding errors, others suggest that they can be sufficient in some cases and do not necessarily diminish the reliability or validity of the resulting scores [Jacoby et al. 1971, Taherdoost 2019]. A three-point Likert scale is a type of rating scale used to measure attitudes or opinions. Respondents are asked to indicate their level of agreement or disagreement with a statement using three possible responses, such as "agree," "undecided," or "disagree." A three-point Likert scale was used to analyze the severity of the constraints affecting the adoption of cashew rehabilitation techniques in Osun State, where the possible responses were: Not Severe = 1, Severe = 2 and Very Severe = 3.

Multinomial Logistic Regression

The multinomial logistic model is an extension of the Logit model. The multinomial logistic regression (MLR) model is used to estimate models where the dependent variable can assume more than two categorical values. The model is specified thus:

$$Zij = \beta_0 + \beta_1 AGE + \beta_2 FAGE + \beta_3 LOE + \beta_4 FS + \\ + \beta_5 EXTC + \beta_6 KCRT + e \quad (1)$$

Zij = Adoption levels for each of the CRTs

The CRTs considered included: Coppicing, Side Grafting, and Total Replanting, for which the adoption levels for each were: Not Adopted, Low Adoption and High Adoption.

AGE – age of farmers measured in years
FAGE – farm age in years
LOE – level of education in years of schooling
FS – farm size in hectares
EXTC – contact with extension agent
KCRT – knowledge of CRTs.

RESULTS AND DISCUSSION

Descriptive statistics of the socio-economic characteristics of cashew farmers in the study area are shown in Table 1. The table shows that the mean age of the cashew farmers is about 53 years. This implies that the majority of the farmers are aging but still in their productive years. This agrees with the findings of Akinpelu et al. [2021], who reported an average age of 53 years for cashew farmers in Oyo State. Furthermore, the table also reveals that the mean age of cashew farms is about 18 years, showing that the majority of the cashew farms in Osun State are relatively young, at less than 20 years old, which may dissuade the farmers from adopting any of the rehabilitation techniques because there may be no need for rehabilitation since the farms are likely to be in their productive stage. This result contrasts with the findings of Ogunwolu et al. [2020], who asserted that the majority of cashew farms in Nigeria are aging. The maximum level of education attained by the cashew farmers in Osun State is tertiary education. The table shows that the majority of the farmers have at least secondary education. This implies that the farmers may be more informed about new technologies. According to Amaegberi and Oyintonbra [2023], education is crucial for promoting the adoption of new technology and techniques, increasing production and profitability, and boosting the competitiveness of the cashew farming industry as a whole. This contrasts with the findings of Akinpelu et al. [2021], who stated that most of the cashew farmers in Oyo State are unlearned. The average household size (number of persons in the household) of the cashew farmers in Osun State is about 8 persons per household, as shown in the table; the implication of this is that the farmers are likely to have more hands to assist them on the farm. Furthermore, the table shows that the average farm size of cashew farmers is about 3 hectares of cashew farmland per farmer; this shows that majority of the cashew farmers are smallholders. This is in line with the findings of Kakwagh et al. [2023]. The average cashew crop harvested by the farmers is about 2.3 tons per year in Osun State.

The factors affecting the adoption level of CRTs among cashew farmers in Osun State are presented in Table 2. The results show that a unit increase in the age of farmers will result in about a 61% decrease in the adoption level of coppicing at a 10% probability level. This implies that the farmers are unwilling to adopt coppicing as a method of rehabilitation as they get older. This contradicts the findings of Adeogun et al. [2010], who stated that the age of farmers is positively correlated with the rehabilitation information sources, leading to greater adoption as a farmer gets older. However, farmers are willing to adopt total replanting as they get older. A unit increase in the age of farmers will result in about a 10% increase in the adoption level of farmers at a 5% probability level. This is contrary to the expected, as older farmers are usually unwilling to replant trees, especially when the current trees are old. In contrast, it is revealed that a unit increase in the age of cashew farms will result in about 64% decrease in the adoption level for total replanting. This shows that farmers with old farms are generally unwilling to adopt total replanting, as they may feel it is too risky and they would rather stick with the old trees. Furthermore, an increase in the level of education of farmers will result in a greater level of adoption of side-grafting at a 5% level of probability. Educated farmers are more exposed to and have learned about the benefits of side-grafting,

Table 1. Summary statistics of socio-economic characteristics of cashew farmers in Osun State, Nigeria

Variables	Mean	Standard Deviation	Minimum	Maximum
Age of Farmers	53.23	16.81	20.0	85
Age of Cashew Farms	18.30	10.27	2.0	50
Level of Education	2.71	0.97	1.0	4
Household Size	8.16	4.29	4.0	25
Farm Size (Hectares)	3.05	2.55	0.4	12
Quantity Harvested (Tons)	2.31	0.92	0.5	4
Number of observations: 80				

Source: Author's field survey, 2021.

Table 2. Factors Affecting the Adoption of CRTs in Osun State

Variables	Coppicing	Side Grafting	Total Replanting
Age of Farmers	–0.61(–1.68)*	–0.26(–0.56)	0.10(2.48)**
Age of Cashew Farms	0.50(0.90)	–1.48(–1.56)	–0.64(–2.49)**
Level of Education	–0.86(–1.38)	2.03(1.97)**	–0.81(–1.82)*
Farm Size	0.43(1.77)*	0.64(1.83)*	–0.18(–0.10)
Contact with Extensionist	1.93(1.67)*	–2.02(–1.26)	–0.29(–0.33)
Number of observations: 80			

Note: *, ** and *** imply significance at 1%, 5% and 10%, respectively, while values in parentheses indicates the *t*-values.

Source: Author's Field Survey, 2021.

hence they are expected to adopt it more than their less educated counterparts. This, however, contradicts the findings of Oluyole et al. [2015], who discovered that most farmers are unwilling to adopt side-grafting in Nigeria despite their education level. In contrast, an increase in the level of education of farmers results in a decrease in the adoption level for total replanting at a 5% level of significance. This may be due to the fact that educated farmers are equipped with information on the risk and uncertainty involved with the adoption of total replanting. Furthermore, an increase in the farm size by one hectare will result in about a 43% increase in the adoption level for coppicing at a 10% level of probability. This corroborates the findings of Taiwo et al. [2015], who stated that coppicing is the second most widely adopted rehabilitation technique, especially among large-scale farmers. The same can be said for the adoption of side grafting; an increase in the farm size by one hectare will result in an increase in the adoption level of side-grafting by 64% at a 10% probability level. This is in line with the a-priori; farmers with bigger farms should be more willing to adopt rehabilitation techniques due to the number of trees on their farm. The table also shows that farmers who have regular contact with extension agents are more willing to adopt coppicing as a method of rehabilitation.

Severity of the constraints affecting the adoption of cashew rehabilitation techniques

The range for the three-point Likert scale technique adopted to investigate the severity of constraints affecting the adoption of CRTs in Osun State is depicted in Table 3. Based on the assigned values for each of the responses, the mean score for each respondent was derived by summing the numerical values of their responses and dividing by the total number of questions. The mean value that falls within a range implies the state of the constraint considered.

Table 3. Scoring range of Likert scale of the survey

Scale	Range	Response
1	1–1.67	Not Severe
2	1.68–2.33	Severe
3	2.34–3.00	Very Severe

Source: Author's calculation.

Presented in Table 4 is the mean value for each of the considered constraints to the adoption of CRTs in Osun State. From the table, it can be deduced that a lack of awareness of cashew farm rehabilitation (LACF) is not considered a severe constraint to the adoption of CRTs. This implies that increasing the farmers' awareness about CRTs is not enough; farmers need to be encouraged to adopt these techniques. Lack of knowledge of the techniques (LAKNT) is considered by the majority of the farmers to be a severe constraint to the adoption of CRTs. This implies that farmers' inadequate knowledge about CRTs may be one of the major reasons why many are reluctant to adopt the techniques. This is in line with the findings of Adebiyi and Okunlola [2013], who stated that a lack of information about rehabilitation techniques is still a major reason behind the non-adoption of rehabilitation techniques. High labor cost (HLBC) is considered by most of the farmers as a very severe constraint to the adoption of CRTs in Osun State. This is expected because most of the CRTs require additional labor hours, which the farmers may find expensive. Adebiyi and Okunlola [2013] cited the high cost of labor as one of the main reasons for non-adoption of rehabilitation technique by farmers. The majority of the farmers find the high cost of agrochemicals and other inputs (HCACH) a very severe constraint to the adoption of CRTs. The implication of this is that if farmers are to be encouraged to adopt CRTs, the input cost and agrochemical costs must be subsidized. Most of the farmers find Labor shortage (LABSH) a very severe constraint to the adoption of CRTs. According to Agbongiarhuoyi et al. [2015], cashew farmers complain of a shortage of labor as the majority of the available labor pool is only in search of white-collar jobs; adopting a CRT will require more labor and this will place a burden on the farmers. Olufemi et al. [2021] opined that youths do not find cashew farming economically attractive enough, hence there is a dearth of youth involvement, resulting in a reduction of available labor for cashew production. Fire incidence (FIRENC) is considered to be a severe constraint to the adoption of CRTs in Osun State; many farms are often faced with the risk of being engulfed by a fire outbreak, so it is logical that farmers are reluctant to adopt any of the CRTs due to the fear of fire. According to Lawal and Uwagboe [2017], cashew farmers in Nigeria constantly face the risk of a fire outbreak, especially in the dry season.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this study, it can be concluded that the majority of the cashew farmers surveyed are educated smallholders who are still in their productive years, and their farms are relatively young, hence there may not be a need to rehabilitate them. The level of adoption of coppicing is affected by factors such as the age of the farmers, farm size and contact with extension agents. The level of adoption of side-grafting is affected by the level of education of the farmers and the farm size, while the level of adoption of total replanting is affected by the age of the farmers, age of their cashew farms and their level of education. The major constraints to the adoption of CRTs identified by this study include a lack of knowledge of the techniques, high labor cost, high cost of agrochemicals, shortage of labor, and fire incidence. This is in line with some of the adoption theories explored. According to the innovation-decision process, knowledge is the first stage in the adoption of technology. If knowledge is a constraint, then there needs to be more efforts geared towards educating the farmers. The economic theory of adoption states that farmers will adopt only technologies that they find economically viable, hence the high cost of labor and agrochemicals are legitimate reasons why farmers may refuse to adopt a rehabilitation technique.

Based on the findings of this study, it is recommended that farmers should be more exposed to extension agents and training on cashew rehabilitation, as this will enhance the rate of adoption of the CRTs, as portrayed in the case of coppicing. This training and contact with extension agents should be focused on the older farm-

Table 4. Mean values for CRT adoption constraints

Constraints	LACF	LAKNT	HLBC	HCACH	LABSH	FIRENC
Mean	1.64	1.79	2.64	2.77	2.34	1.75

Note: LACF: Lack of awareness of cashew farm rehabilitation; LAKNT: Lack of knowledge of the techniques; HLBC: High labor cost; HCACH: High cost of agrochemicals and other inputs; LABSH: Labor shortage; FIRENC: Fire incidence.

Source: Author's calculation

ers, since they are less receptive to the adoption of coppicing. This will improve the farmers' knowledge of CRTs. There is also a need for a proper land reform act that will enable the farmers to access larger farmlands at affordable prices, since the majority of the farmers are smallholders. Perhaps larger farm sizes will improve the level of adoption of CRTs. The government should endeavor to subsidize the cost of the agrochemicals used by farmers, as this will encourage them to adopt CRTs and ultimately improve their output.

REFERENCES

Adebiyi, S., Okunlola, J.O. (2013). Factors affecting adoption of cocoa farm rehabilitation techniques in Oyo State of Nigeria. World Journal of Agricultural Sciences, 9(3), 258–265.

Adeogun, S.O., Olawoye, J.E., Akinbile, L.A. (2010). Information sources to cocoa farmers on cocoa rehabilitation techniques (CRTs) in selected states of Nigeria. Journal of Media and Communication Studies, 2(1), 9.

Agbongiarhuoyi, A.E., Uwagboe, E.O., Ibiremo, O.S., Olasupo, F.O., Aigbekaen, E.O. (2015). Assessment of factors associated with low yield of cashew among farmers in growing areas of Nigeria. American Journal of Experimental Agriculture, 6(4), 258–266.

Akinpelu, A.O., Oluyole, K.A., Adelusi, A.A., Ogunwolu, Q.A. (2021). Socio Economic Variables of Cashew Farmers in Oyo State, Nigeria. International Journal of Business Marketing and Management, 6(5), 17–19.

Amaegberi, D.H., Oyintonbra, O.P. (2023). Savings and Its Determinants among Cashew Farmers: Evidence from Dekina Local Government Area, Kogi State, Nigeria. IRE Journals, 7(1), 475–483.

Asogwa, E.U., Anikwe, J.C., Ndubuaku, T.C.N., Okelana, F.A. (2009). Distribution and damage characteristics of an emerging insect pest of cashew, Plocaederus ferrugineus L.(Coleoptera: Cerambycidae) in Nigeria: A preliminary report. African Journal of Biotechnology, 8(1), 053–058.

Asogwa, E.U., Hammed, L.A., Ndubuaku, T.C.N. (2008). Integrated production and protection practices of cashew (Anacardium occidentale) in Nigeria. African Journal of Biotechnology, 7(25), 4868–4873.

Clinton-Etim, N., Manishimwe, T. (2021). Vertical integration and financial performance in African emerging economies: Case Study of Olam Nigeria Limited, Nigeria. The Business & Management Review, 12(1), 117–127.

Fakayode, S.B., Rahji, M.A.Y., Adeniyi, S.T. (2012). Economic analysis of risks in fruit and vegetable farming in Osun state, Nigeria. Bangladesh Journal of Agricultural Research, 37(3), 473–491.

FAO (2020). FAOStat, data of Food and Agriculture Organization. Retrieved from https://www.fao.org/faostat/en/#data/QC [accessed: 19.04.2022].

Gallardo, R.K., Sauer, J. (2018). Adoption of labor-saving technologies in agriculture. Annual Review of Resource Economics, 10, 185–206.

Jacoby, J., Matell, M.S. (1971). Three-point Likert scales are good enough. Journal of Marketing Research, 8(4), 495––500. https://doi.org/10.1177/002224377100800414

Kakwagh, V.V., Gomment, T.I., Sombu, A.A., Sani, J.O. (2023). Prospects and challenges of cashew production in Igala Land, Kogi State Nigeria. International Journal of Innovative Science and Research Technology, 8(5), 3380–3385. https://doi.org/10.5281/zenodo.8055400

Marangunić, N., Granić, A. (2015). Technology acceptance model: a literature review from 1986 to 2013. Universal Access in The Information Society, 14, 81–95. https://doi.org/10.1007/s10209-014-0348-1

Matell, M.S., Jacoby, J. (1972). Is there an optimal number of alternatives for Likert-scale items? Effects of testing time and scale properties. Journal of Applied Psychology, 56(6), 506–509. https://doi.org/10.1037/h0033601

Meena, M.S., Singh, K.M., (2012). Decision Process Innovations, Constraints and Strategies for Adoption of Conservation Agriculture, June 21. http://dx.doi.org/10.2139/ssrn.2088710

Nigerian Population Census (NPC) (2006). Official Gazatte (FGP 71/52007/2,500(OL24): Legal notice on publication of the details of the breakdown of the national and state provisional totals 2006 census. Retrieved from http://www.nigerianstate.gov.ng [accessed: 16.07.2023].

Ogunwolu, Q.A., Ugwu, C.A., Alli, M.A., Adesanya, K.A., Agboola-Adedoja, M.O., Adelusi, A.A., Akinpelu, A.O. (2020). Prospects and challenges of cash crop production in Nigeria: The case of cashew (Anacardium occidentale, Linn.). World Journal of Advanced Research and Reviews, 8(3), 439–445. https://doi.org/10.30574/wjarr.2020.8.3.0503

Oluyole, K.A., Famaye, A.O., Agbeniyi, S.O., Ogunlade, M.O., Oloyede, A.A., Aikpokpodion, P.E., Orisajo S.B, Adejobi, K.B. (2015). Evaluation of the practices of cocoa rehabilitation techniques among cocoa farmers in Nigeria. Global Journal of Agricultural Economics, Extension and Rural Development, 3(2), 188–193.

Oluyole, K.A., Yahaya, A.T., Uwagboe, E.O., Mokwunye, I.U., Agbeniyi, S.O., Orisajo, S.B., Otunoye, A.H., Ndagi, I., Shittu, T.R. and Aderolu, I.A. (2015). Constraints in Cashew Production among Cashew Farmers in Southwestern Nigeria. International Journal of Science and Nature, 6(3). 329–333.

Rogers, E.M. (2003). Diffusion of innovations. Simon & Schuster, New York, USA.

Senger, I., Borges, J.A.R., Machado, J.A.D. (2017). Using the theory of planned behavior to understand the intention of small farmers in diversifying their agricultural production. Journal of Rural Studies, 49, 32–40. https://doi.org/10.1016/j.jrurstud.2016.10.006

Subbarao, C.N., Krishna Prasad, K.M.M., Prasad, V.S.R.K. (2011). Review on applications, extraction, isolation and analysis of cashew nut shell liquid (CNSL). The Pharma Research Journal, 6(1), 21–41.

Taherdoost, H. (2019). What is the best response scale for survey and questionnaire design; review of different lengths of rating scale/attitude scale/Likert scale. International Journal of Academic Research in Management, 8(1), 1–10.

Taiwo, O., Ogunlade, M.O., Ayegboyin, K.O., Famaye, A.O., Adeniyi, D.O., Oyedokun, V.A., Adeosun, S.A., Adejobi, K.B. (2015). Factors affecting the practice of cocoa rehabilitation techniques in Nigeria: A case of South-west and South-south geoecological zone. International Journal of Advance Agricultural Research, 3, 25–30.

Tola, J., Mazengia, Y. (2019). Cashew production benefits and opportunities in Ethiopia: a review. Journal of Agricultural and Crop Research, 7(2), 18–25.

ANALIZA WYZWAŃ ZWIĄZANYCH Z TECHNIKAMI ODNAWIANIA UPRAWY NERKOWCÓW (CRT) W STANIE OSUN W NIGERII

STRESZCZENIE

Cel: Celem badania było przeanalizowanie wyzwań stojących przed hodowcami nerkowców w związku z przyjęciem technik rehabilitacji nerkowców (CRT) w stanie Osun w Nigerii. **Metody:** Dane zebrano ze źródeł pierwotnych za pomocą ustrukturyzowanych kwestionariuszy. Łącznie wzięto pod uwagę osiemdziesięciu (80) respondentów, po czterdziestu (40) z każdego z wybranych obszarów samorządu terytorialnego. W badaniu zastosowano analizę opisową w celu zbadania charakterystyki społeczno-ekonomicznej rolników, do oceny czynników wpływających na poziom przyjęcia CRT wykorzystano wielomianową regresję logistyczną (MNL), natomiast do pomiaru poziomu dotkliwości zidentyfikowanych ograniczeń przyjęto skalę Likerta. **Wyniki:** Na poziom wykorzystania zagajników istotny wpływ ma wielkość gospodarstwa, wiek rolników i dostęp do usług doradczych. Na poziom zastosowania szczepienia bocznego wpływ ma wielkość gospodarstwa i poziom wykształcenia, na poziom zastosowania całkowitego ponownego nasadzenia istotny wpływ ma wiek rolników, wiek gospodarstw i poziom wykształcenia. Wysokie koszty pracy, wysokie koszty środków agrochemicznych i niedobory siły roboczej stanowią bardzo poważne przeszkody w przyjęciu CRT, podczas gdy brak odpowiedniej wiedzy i występowanie pożarów uważa się za umiarkowanie poważne przeszkody. **Wnioski:** Na przyjęcie technik wpływają takie czynniki, jak wiek, wykształcenie, wielkość gospodarstwa i dostęp do rozbudowy. Ograniczenia w przyjęciu obejmują brak wiedzy, wysokie koszty pracy i środków chemicznych, niedobór siły roboczej i ryzyko pożaru. Zalecane jest podnoszenie poziomu edukacji rolników, aby wdrażanie technologii wśród rolników uprawiających orzechy nerkowca na badanym obszarze przebiegało sprawniej.

Słowa kluczowe: orzechy nerkowca, odnawianie uprawy, techniki, ograniczenia, zastosowanie CRT

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ORIGINAL PAPER

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IMPACT OF THE GREEN TRANSITION ON THE PRODUCTION OF CEREALS IN THE EUROPEAN UNION. NEW INSIGHTS BASED ON THE FGLS PANEL DATA MODEL

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ABSTRACT

Aim: The aim of this study is to econometrically assess the long-term impact of Green Deal-related regulatory areas on cereal crop production in European Union countries. **Methods:** The study is based on an analysis of panel data for 21 European Union countries for the period 1995–2021. The FGLS, PCSE and CCEMG models, which are robust to heteroskedasticity and cross-sectional dependence, were used to determine the impact of agricultural CO2 emissions, agricultural area, food production volumes and fertilizer consumption on cereal production. In addition, a robust test of the Westerlund ECM panel test model was applied to confirm cointegration. All models were bootstrapped to strengthen the results. **Results:** The results show that, in the long run, a 10% increase in CO2 emissions from agriculture leads to an average decrease in cereal production of 0.5%. A 1% increase in cultivated area leads to a 1.1% positive change in the value of cereal production, and a 1% increase in fertilizer use per hectare leads to a 0.38% increase in cereal production. The value of the food production index also shows a positive effect on cereal production. If the index increases by 1 p.p., cereal production increases by 1.13% in the long term. The study also found a positive relationship between an increase in the share of renewable energy and the volume of cereal production. If the share of renewable energy increases by 1%, the volume of cereal production in the EU countries increases by 0.11%. **Conclusions:** Overall, it can be concluded that the green transformation brings both negative and positive aspects of change to agriculture. The decrease in cultivated land and reduced use of artificial fertilizers may negatively impact farm productivity in crop production areas. On the other hand, the improvement of climatic conditions and the development of renewable energies could be beneficial for agriculture in the long term. The study is original in the sense that it fills an empirical and theoretical gap related to the verification of the impact of the Green Deal on the cereal production sector and thus on agriculture in the European Union.

Key words: Cereal production, Agriculture, FGLS, Green transformation, European Union

JEL codes: C23, O47, O13, Q15, Q54

INTRODUCTION

Crop production is a very important sector of the European economy and a pillar of food security. Cereals provide almost 60% of calories for European consumers, forming the basis of nutrition and ensuring food security in the European Union [Laskowski et al. 2019]. Cereals are used both for direct consumption, in the form of raw and processed products, and as an important component of animal feeds and oils, influencing animal production [Iji et al. 2011]. In addition, the evolution of dietary habits in recent years, combined with the change in preferences of a large group of consumers towards vegetarian, vegan and organic food, whose

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production is based on cereals, further increases the importance of cereal production in the European economy [Dorgbetor et al. 2022, Macdiarmid 2022].

Cereal production is one of the most sensitive agricultural activities to climate change [Wang et al. 2018]. Rising global temperatures are influencing the instability of weather conditions and the occurrence of many extreme events, creating uncertainty for producers and markets [Neupane et al. 2022]. Climate variability has significant implications for agriculture, including increased crop damage, low productivity, and high production costs [Malhi et al. 2021]. This can cause a decrease in farmers' income, leading to a shift in production or even the complete abandonment of farming [Karaczun and Kozyra 2020].

Due to global warming, the European Union aims to reduce CO_2 emissions. To achieve this, two strategies have been developed that affect agriculture: the European Green Deal with the Field-to-Fork (F2F) part and REPowerEU. These programs aim to transition European agriculture, including crop production, toward a greener and more sustainable energy model [Grochowska and Staszczak 2021]. As part of the transition to environmentally friendly agriculture, the members of the European Union plan to implement the following measures [Parlińska et al. 2020]:

– 55% reduction in greenhouse gas emissions by 2030 compared to 1990, while considering that agriculture is one of the sectors that needs to reduce emissions significantly,
– 50% reduction in pesticide use and a 20% reduction in fertilizer use by 2030,
– restoring at least 10% of the agricultural area to natural ecosystems by 2030,
– increasing the share of renewable energy in the EU to 45% in 2030,
– reduction in meat consumption and production and an increase in the consumption of plant and organic foods.

The implementation of all regulations, according to European Commission (EC) estimates, could result in a 10% decrease in total European Union (EU) food production by 2030. Meanwhile, the Food and Agriculture Organization (FAO) predicts that the European Green Deal could lead to a 2–4% reduction in total EU food production by 2030 [COM(2019) 640 final].

The European Community has set climate objectives for agriculture, which present both opportunities and challenges. This study aims to assess the impact of regulatory areas related to the broader Green Deal on cereal crop production in the EU. The study establishes the following research hypotheses:

H_1 – Implementation of the European Green Deal strategy, which involves reducing cultivated areas and fertilizer use, is expected to have a negative impact on cereal production in the long term.
H_2 – Increased use of renewable energy can indirectly increase cereal production in the European Union.
H_3 – Food production is a significant factor in determining cereal production in European Union countries.

A panel data model feasible generalized least squares (FGLS) model based on bootstrap estimation was used to achieve the stated objective and to test the research hypotheses. This method was chosen to provide consistent and robust results for long-term data characterized by heteroskedasticity and cross-sectional dependencies (CSD). The FGLS model, along with robust estimation of confidence intervals and standard errors, produces highly reliable results [Bai et al. 2021]. The study uses data for the period 1995–2021 for 21 European Union countries. The article tries to fill both the theoretical and empirical gap in the impact of the European Green Deal on cereal crop production.

The study selected variables based on the work of Kibria et al. [2023], who examined the impact of CO_2 emissions and the food production index (FPI) on cereal food production in South Asia. Fertilizer use and sown area were also added to the variable sets based on a study by Koondhar et al. [2021], which estimated the impact of sown area and fertilizer use on CO_2 emissions and cereal production in China. The choice of renewable energy as a variable was supported by the work of Liu et al. [2017], who estimated the impact of renewable energy on agricultural value added and CO_2 emissions in their model for BRICS countries.

Assessing the impact of the European Green Deal on EU cereal production is a complex task, with limitations. The long-term effects of the strategy are still unknown, and a comprehensive analysis of the impacts requires access to detailed data. Additionally, cereal production is influenced by various factors, including climate change and market trends. Therefore, it is essential to interpret the conclusions and recommendations in this text with these limitations in mind. The provisions of the Green Deal also could change as a result of various factors, including pressure from trade unions, agricultural producers and social tensions.

The article is divided into four sections. The first section is the introduction, followed by a review of the existing literature. The third section provides a detailed description of the variables, the model specification, and the econometric method. The final section presents the empirical results and discussions. Conclusions and practical implications are also presented in this section.

LITERATURE REVIEW

The theories and concepts related to cereal production include the necessity of increasing cereal yield to ensure food security [Oishi 2021]. There is a gap in cereal production between developing and developed countries due to the lack of capital, technology and human resource skills in developing countries [Zhang and Long 2013]. The relationship between population undernourished and cereal production has been analyzed using Grey System Theory, and it has been found that promoting cereal production can help reduce undernourishment [Wood and Lenné 2018]. Factors affecting cereal production are diverse and their relative importance may change in the future [Adviento-Borbe 2020].

The Green Deal proposes the establishment of a green economy with zero emissions, based on renewable energy sources. It also aims to promote sustainable agriculture [Fayet et al. 2022], which meets current food and material needs without compromising the ability of future generations to do the same [Prandecki et al. 2021]. The Green New Deal for agriculture focuses on combating environmental degradation, social inequality, and improving crop efficiency [Selwyn 2022]. These actions aim to enhance the resilience of food systems, ensuring their capacity to provide sufficient, adequate, and accessible food in the face of environmental challenges [Blake 2020].

The implementation of the green transformation in agriculture involves various measures, including the reorientation of state subsidies, attention to the rights of agricultural workers, reform of agricultural relations, decommodification of food, agroecology, and the application of new technologies in agricultural production [Adamowicz 2021]. The European Green Deal strategy aims to achieve ambitious climate and environmental goals. To achieve this, a complex, multi-pronged approach to agricultural policy is required, which includes greater consideration of non-productive aspects such as environmental protection [Wrzaszcz and Prandecki 2020]. The Common Agricultural Policy (CAP) in the European Union is placing an increasing emphasis on developing environmentally friendly forms of agriculture, as reflected in subsequent standards and measures [Rudnicki et al. 2021].

The green transformation in agriculture has both positive and negative aspects. The positive aspects include the drive to transform agricultural practices toward environmentally friendly activities. This transformation will require substantial investment and research, which could increase labor demand, accelerate structural transformation, and offset the adverse effects of climate change [Nico and Christiaensen 2023]. Conversely, increasing the proportion of organic farming could enhance the quality and characteristics of agricultural products and food, thereby positively impacting human health [Li et al. 2022].

There are concerns among consumers and agricultural producers regarding the potential negative consequences of implementing green agriculture as part of the "Farm to Fork" strategy proposed by the European Commission. This strategy, which is part of the European Green Deal, aims to establish sustainable agrifood production and distribution processes [Poczta et al. 2023, Szajner and Szczepaniak 2023]. To implement the strategy's objectives, it is necessary to reduce the use of pesticides and fertilizers, reclaim arable land, increase the share of organic farming, reduce CO_2 emissions from agriculture, and increase the use of renewable energy [Szubska-Włodarczyk 2023].

Wesseler [2022] highlights that the proposed solutions may negatively impact agricultural production, the availability of agricultural products to consumers, and global food prices. Beckman et al. [2020] conducted an economic assessment of the Green Deal assumptions in agriculture and found that there is potential for a decline in EU agricultural production, a net loss of welfare, and transition costs for consumers.

The energy transition targets as well as the CO_2 reduction from agriculture set by EU countries should be regarded as ambitious. To date, however, there have been few econometric studies analyzing the effects of the proposed regulations. Köprücü and Acarođlu [2023] and Xiang and Solaymani [2022] note that there is a scarcity of scientific papers that concentrate on the ecological – environmental impact of climate change on agricultural production, particularly cereals, using advanced econometrics.

Chandio et al. [2022] demonstrated, using the Autoregressive Distributed Lag (ARDL) model, that CO_2 has a significant negative impact on cereal production in both the short and long term in Bangladesh. Similarly, Abbasi [2021] found, using a combination of the ARDL and vector error correction model (VECM) models, that an increase in CO_2 emissions in agriculture leads to a decrease in cereal production productivity in China. Simionescu et al. [2019] used 2000–2016 data for the European Union and applied the FGLS model and the generalized method of moments. They found a positive effect of GHG emissions on cereal production. Kumar et al. [2021] used a combination of the FGLS and Fully Modified Ordinary Least Squares (FMOLS) models for lower- and middle-income countries and indicated a positive impact of increased CO_2 on cereal production. In contrast, Demirhan [2020] analyzed global data and found that rising temperatures lead to a decrease in wheat yields. The study also highlights the negative impact of climatic instability on agriculture as a whole. Furthermore, individual studies have been conducted on the effects of climate change on cereal yields in specific countries such as Pakistan [Ahsan et al. 2020], India [Baig et al. 2020] and Turkey [Chandio et al. 2020], indicating a long-term relationship with varying impacts.

Additionally, several studies have examined the impact of changes in arable land on cereal production. Abbasi et al. [2021] confirmed that an increase in arable land devoted to cereals has a positive effect on crop productivity in China, using the ARDL model. Similarly, Ahsan et al. [2020] found that an increase in arable land in Pakistan has a positive impact on cereal production using the same model. Abdullahi et al. [2023] also reported similar estimates for Nigeria. Research conducted by Köprücü and Acarođlu [2023] showed a positive correlation between fertilizer consumption and yields of wheat, barley, and maize in Turkey. Similarly, Zwane et al. [2022] found similar results for selected African countries using the FMOLS methodology.

There is a scarcity of recent econometric studies on the correlation between food production and cereal production. Kibria et al. [2023] used the FMOLS model to demonstrate that increases in the FPI and land use lead to an increase in cereal production in South Asia. Kibria et al. [2023] and Abbasi et al. [2021] confirmed that the increase in cereal production in China was induced by an increase in the food production index.

Currently, there are no large-scale studies using econometric modeling on the relationship between renewable energy and crop production. However, Koondhar et al. [2021] determined that there is a positive relationship between overall energy use and agricultural production in Pakistan. The study by Rahman et al. [2020] confirmed the same conclusion for Bangladesh.

Despite the problem's relevance, there is a significant research gap in the area under investigation. The literature review clearly indicates that no empirical studies using panel econometric models have been conducted on the impact of green transformation on agriculture and cereal production in the European Union. Therefore, this study fills the identified gap and provides new scientific evidence.

METHODS

Data sources and variables

The model development process utilized panel data, encompassing both time series and cross-sectional data. The empirical study analyzed data from the World Bank's database (World Development Indicators), the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Framework Convention on Climate Change (UNFCCC) for

Table 1. Variables and Sources

Variables	Symbol	Measure	Dataset source
Cereal production	CP	tons	FAO
Carbon dioxide emission from agriculture	ACO_2	kilotons	UNFCC
Land under cereal production	CLS	hectares	WDI
Food production index	FPI	2014–2016 = 100	WDI
Fertilizer consumption	FZ	kilograms per hectare of arable land	WDI
Renewable energy consumption	REW	% of total energy consumption	WDI

Source: Author's own research.

21 European Union countries from 1995 to 2021. Belgium, Cyprus, Luxembourg, Malta, and Slovenia were excluded from the research group due to incomplete data or a lack of data for the studied variables.

The literature review was conducted using the Scopus and Web of Science databases. Based on a thorough literature study and the clearly stated aim of the study, the selection of variables was made. Table 1 presents all variables used in the study and their sources.

Econometric framework

The research procedure involves conducting a preliminary data analysis and selecting the best model based on the data's properties. The first stage of the study was the identification of the presence of a cross-sectional dependence in the panel data under study, which is a common problem in economic aggregates [Wooldridge 2010]. Cross-sectional dependence tests using the Breusch-Pagan Lagrange Multiplier (LM) are recommended when $T > N$ and N is not asymptotic [Baltagi et al. 2012]. Serial correlation and group heteroskedasticity were analyzed in the panel data under study. Heteroskedasticity was tested using White's [1980] test, while autocorrelation was tested using the Wooldridge [2001] approach. Robust estimators must be used if these properties are present, making testing for them crucial.

The study utilized the Dumitrescu-Hurlin [2012] panel causality test to establish causality between the variables. This test is appropriate for time series where $T > N$ and accounts for panel data heterogeneity. The results confirm the existence of a causal relationship between the variables. A bootstrap is employed to enhance test outcomes when dealing with CSD.

To test for stationarity, this study uses two second-generation unit root tests that are robust to the presence of CSD: the Dickey-Fuller extended cross--section (CADF) test and the Cross-sectionally augmented Im-Pesaran-Shin (CIPS) test [Im et al. 2003]. The lags were determined according to the Akaike Information Criterion (AIC). Variables were tested at both levels and transformations to first differences.

To identify long-run dependencies, the study uses robust cointegration tests suitable for cross-sectional dependencies, as proposed by Westerlund [2007]. The test confirms the presence of cointegration by detecting error correction for individual panel members and for the panel as a whole. The bootstrapping method can be used to obtain reliable results when cross-sectional units are suspected to be dependent.

In this study, the long-term impact of the climate strategy of the European Union on the agricultural sector was determined using the FGLS model. This model was chosen due to its suitability for large data sets (where $T > N$) that exhibit problems with heteroskedasticity, serial correlation, and cross-sectional dependence [Bai et al. 2021]. The following formula represents the precise form of the FGLS model [Fomby et al. 1984]:

$$\hat{\beta}_{FGLS} = \left(X' \hat{\Omega}^{-1} X \right)^{-1} X' \hat{\Omega}^{-1} y$$

$$Var\left(\hat{\beta}\right) = \left(X' \hat{\Omega}^{-1} X \right)^{-1}$$

The model under study is presented in the following initial form:

$$CP = f\left(ACO_2, CLS, FPI, FZ, REW \right) \quad (1)$$

The following equation can be derived from the above:

$$CP_{2,it} = \alpha + \beta_1 ACO_{2it} + \beta_2 CLS_{it} + \beta_3 FPI_{it} + \\ + \beta_4 FZ_{it} + \beta_5 REW_{it} + \varepsilon_{it} \quad (2)$$

where α is the intercept, *i* and *t* represent countries and time individually, $\beta_1 \ldots \beta_5$ are the coefficients of the independent variables, and ε is the error term. After logarithmic transformation, the analytical form of the model was determined as follows:

$$\ln CP_{2,it} = \alpha + \beta_1 \ln ACO_{2it} + \beta_2 \ln CLS_{it} + \\ + \beta_3 \ln FZ_{it} + \beta_4 \ln FZ_{it} + \beta_5 \ln REW_{it} + \varepsilon_{it} \quad (3)$$

A robustness check was carried out using alternative methods to ensure a stable and consistent model. A regression model with Panel-Corrected Standard Errors (PCSE) was estimated. PCSE is similar to linear regression but is more robust to heteroskedasticity, CSD and autocorrelation [Beck and Katz 2011]. Furthermore, the model's robustness was tested using a second-generation panel model based on the Common Correlated Effects Mean Group (CCEMG) estimator. This estimator is known to be robust to cross-sectional dependence and heteroskedasticity [Pesaran 2006].

RESULTS

Descriptive analysis

During the initial phase of the study, a preliminary analysis of the data was carried out. Descriptive statistics and correlations were examined. Table 2 presents the descriptive statistics, which clearly demonstrate the mean, median, maximum, minimum, and standard deviation.

Table 3 presents the results of the correlation analysis. The study variables demonstrate moderate to low correlation. Notably, ln*CP* exhibits a moderate and positive correlation with $\ln ACO_2$ (0.624), ln*CLS* (0.651), and ln*FPI* (0.354). Additionally, $\ln ACO_2$ has a moderate positive correlation with lnCLS (0.710). However, lnFPI only shows a weak positive correlation with lnFZ (0.166). The Variance Inflation Factor (VIF) value of 1.860 confirms the absence of any multicollinearity issue.

Table 2. Descriptive statistics

Variable	Obs	Mean	Min	Max	*SD*
ln*CP*	567	15.705	12.903	18.107	1.170
$\ln ACO_2$	567	9.754	7.882	11.810	1.021
ln*CLS*	567	14.230	12.251	16.089	1.073
ln*FPI*	567	4.556	4.113	4.906	0.119
ln*FZ*	567	4.885	3.089	7.542	0.686
ln*REW*	567	2.679	0.647	4.067	0.735

Source: Author's own research.

Table 3. Pairwise correlations

Variable	lnCP	$\ln ACO_2$	lnCLS	lnFPI	lnFZ	lnREW
ln*CP*	1.000					
$\ln ACO_2$	0.624	1.000				
ln*CLS*	0.651	0.710	1.000			
ln*FPI*	0.354	0.231	0.221	1.000		
ln*FZ*	0.088	0.217	–0.118	0.166	1.000	
ln*REW*	–0.329	–0.270	–0.310	–0.163	–0.338	1.000

Source: Author's own research.

Table 4. Pairwise Dumitrescu Hurlin Panel Causality Tests

Causality	Zbar-Stat.		Causality	Zbar-Stat.	
$ACO_2 \rightarrow CP$	12.429	***	$ACO_2 \rightarrow$ FZ	4.856	*
$CP \rightarrow ACO_2$	0.8587		FPI $\rightarrow ACO_2$	2.173	
$CLS \rightarrow CP$	7.3440	***	$ACO_2 \rightarrow$ FPI	10.714	***
$CP \rightarrow CLS$	6.3832	***	REW → CLS	12.398	***
$REW \rightarrow CP$	3.2634	**	CLS → REW	2.534	
$CP \rightarrow REW$	2.3898	*	FZ → CLS	5.308	**
$FZ \rightarrow CP$	8.9655	***	CLS → FZ	2.476	
$CP \rightarrow FZ$	1.352		FPI → CLS	4.257	**
$FPI \rightarrow CP$	2.713	**	CLS → FPI	9.052	***
$CP \rightarrow FPI$	7.772	***	FZ → REW	5.392	*
$CLS \rightarrow ACO_2$	3.568		REW → FZ	4.882	
$ACO_2 \rightarrow CLS$	8.363	***	FPI → REW	6.695	***
$REW \rightarrow ACO_2$	8.906	**	REW → FPI	7.121	**
$ACO_2 \rightarrow REW$	13.599	***	FPI → FZ	1.922	
$FZ \rightarrow ACO_2$	6.883	**	FZ → FPI	5.441	**

Note: Significance of the coefficients is indicated by an asterisk in the tables, where *, **, *** denote a 10%, 5%, and 1% significance level, respectively.

Source: Author's own research.

Table 4 presents the results of the Pairwise Dumitrescu-Hurlin Panel Causality Tests, which are suitable for panel data when $T > N$. To strengthen the findings regarding the presence of CSD, a bootstrap with 800 replications was also used. The results demonstrate bidirectional and unidirectional causality between the variables. The results identify predictive relationships based on statistical patterns in the data. The time-series studied can be used in the econometric modeling process.

Preliminary analysis included performing the Wooldridge autocorrelation (AR1) test using the F statistic, which confirmed the absence of first-order autocorrelation. To test for homoskedasticity of the study variables, the White test based on the chi-square test statistic was used, which confirmed the presence of heteroskedasticity.

Prior to estimation, cross-sectional dependence tests were also conducted between variables. Table 5 presents the results of these tests. The variables in the panel have $T > N$, and tests based on the Breusch-Pagan Lagrange Multiplier were applied to determine their characteristics. The results of the test indicate that the variables used exhibit cross-sectional dependence for all countries. Therefore, the models must be estimated using estimators that are robust to cross-sectional dependence.

Table 5. Results of cross-sectional dependence test

Variable	Statistic (χ^2)	*p*-value
ln*CP*	780.080	0.000
$\ln ACO_2$	1140.726	0.000
ln*CLS*	1189.964	0.000
ln*FPI*	997.287	0.000
ln*FZ*	1079.128	0.000
ln*REW*	1540.556	0.000

Source: Author's own research.

The study tested the stationarity of the variables using the IPS and CADF tests, which are robust to cross-sectional dependence. Lag determination was based on the AIC. Table 6 shows the results of the

Table 6. Results of the unit ring test

Variable	CIPS		CADF	
	level	1st difference	level	1st difference
ln*CP*	–4.390 ***	–6.096 ***	–2.531 ***	–4.662 ***
lnACO_2	–1.708 **	–4.655 ***	–1.944	–3.529 ***
ln*CLS*	–2.295 **	–5.542 ***	–1.835	–3.921 ***
ln*FPI*	–3.002 ***	–5.987 ***	–1.967	–4.475 ***
ln*FZ*	–1.802	–5.575 ***	1.400	–3.297 ***
ln*REW*	–2.726 ***	–5.247 ***	–2.293 ***	–3.694 ***

Note: CIPS and CADF critical values: –2.07 for 10%, –2.15 for 5% and –2.3 for 1%.

Source: Author's own research.

two-unit root tests applied, indicating that all variables are stationary at I (1) and none are stationary at I (2). The results of the CIPS test confirm that the variables lnCP, lnACO_2, ln*FPI*, ln*CLS*, and ln*REW* are stationary at both I(0) and I(1). Additionally, the CADF test confirms that ln*CP* and ln*REW* are stationary at both the level and first difference.

Table 7 presents the results of the Westerlund cointegration test based on the Error correction model (ECM). For data with cross-sectional dependence, these tests are appropriate. To ensure robust results under CSD conditions, testing with a bootstrap with 800 replications was performed. The probability results for all G and P parameters reject the H_0 hypothesis of no cointegration and confirm strong cointegration between the selected variables. Therefore, estimation methods such as FGLS, CCE, and PCSE can be applied.

Table 7. Westerlund ECM panel cointegration tests

Statistic	Value	*z*-value	*p*-value	Robust *p*-value
Gt	–4.091	–8.523	0.000	0.000
Ga	–12.819	–0.654	0.257	0.000
Pt	–18.427	–8.023	0.000	0.000
Ba	–13.563	–3.188	0.001	0.000

Source: Author's own research.

Model estimation and discussion

The FGLS model, which is robust to cross-sectional dependence and heteroskedasticity, was used to achieve the study's objectives and to account for the characteristics of the variables [Fomby et al. 1984]. In addition, a bootstrap-based method of standard error estimation with 800 replications was used to further strengthen the results. Additionally, a control estimation was performed using the PCSE and CCEMG models to verify the robustness of the results. Both control estimations utilized a bootstrap. The results of the long-run estimation of the FGLS model are presented in Table 8.

Table 8. Result of FGLS estimation

Variable	Coefficient	Standard errors	*z*-statistic	*p*-value
lnACO_2	–0.048	0.016	–2.980	0.003
ln*CLS*	1.102	0.018	61.630	0.000
ln*FPI*	1.135	0.081	13.960	0.000
ln*FZ*	0.375	0.014	25.920	0.000
ln*REW*	0.109	0.017	6.510	0.000
Constant	–6.796	0.329	–20.650	0.000

Note: Significance of the coefficients is indicated by an asterisk in the tables, where *, **, *** denote a 10%, 5%, and 1% significance level, respectively. Wald χ^2 21137.18, prob. 0.000.

Source: Author's own research.

The results obtained for CO_2 emissions from agriculture indicate that they have a statistically significant and negative impact on the volume of cereal production in the European Union. A 10% increase in CO_2 emissions from agriculture leads to a 0.5% decrease in cereal production on average over the long term. These results therefore suggest that it is in the interest of both Member States and farmers themselves to limit the growth of CO_2 emissions from agriculture. Indeed, excessive carbon dioxide emissions can cause adverse weather events and unstable climatic conditions, which will contribute to lower crop yields.

These results are not in line with the study by Simionescu et al. [2019], which shows a positive impact of CO_2 on cereal production in the European Union, using data for the period 2000–2016. This difference may be due to the fact that this study uses a longer time series, allowing more robust conclusions to be drawn for a longer time horizon. However, the results of this study confirm the observations of Ben Mariem et al. [2021] and Wang and Liu [2021] that while CO_2 may provide some short-term benefits for cereal production under controlled conditions, these benefits are not sustainable in the long term. Addressing the broader challenge of climate change and its impact on agriculture is critical to ensuring long-term food security.

The estimation results suggest that there is a positive relationship between the size of the area sown and the yield. Specifically, the data indicate that a 1% increase in the area sown leads to a 1.1% increase in the volume of cereal production. These results are consistent with Abbasi et al. [2021] and Abdullahi et al. [2023]. According to Yu et al. [2019], the multiplicity of cultivated areas is a significant factor in promoting production growth and influencing food security. The authors suggest that optimizing productivity, including the better utilization of cultivated land, is imperative within the context of sustainable development. The results indicate that the implementation of the European Green Deal in agriculture, which aims to reduce arable land by 10%, may have a significant impact on cereal production across the EU. To ensure food security and maintain current cereal production levels, it may be necessary to explore options to increase crop productivity. One potential solution that could be considered is organic farming. However, as suggested by Röös et al. [2018], for organic farming to make a greater contribution to sustainability in the food system, it may be necessary to explore and accept new sources of plant nutrients. This could involve greater nutrient recycling within society, the use of mineral nitrogen fertilizers from renewable sources in certain circumstances, and the adoption of alternative livestock production systems.

The EU's climate targets do not explicitly address the matter of food production volumes. Nevertheless, they do have an impact on agricultural practices and policies, which in turn affect food security. According to the study's findings, an increase in the food production index results in a corresponding increase in cereal production. Specifically, if the index increases by 1 percentage point, cereal production will increase by 1.13% in the long run.

These findings are consistent with Abbasi et al.'s [2021] study, which showed that an increase in FPI affects CO_2 emissions, with a greater impact observed in the European Union than in China. Likewise, Kibria et al. [2023] verified that an increase in FPI can result in increased cereal production in Southeast Asian countries. According to Bernabéu et al. [2023], the implementation of the European Green Deal may result in an increase in agricultural and food prices due to the rise in production and supply costs. As per Green et al.'s [2013] research, a 1% increase in cereal prices can lead to a 0.61% decrease in consumption, which could have a direct and negative impact on the volume of cereals produced in EU countries.

The model suggests that a 1% increase in fertilizer use per hectare of crop leads to a 0.38% increase in cereal production. These findings are in line with Simionescu et al.'s [2019] study, albeit indicating a slightly smaller impact of fertilizers on cereal crops. The parameters obtained in this study are comparable to the results of the model estimated by Köprücü and Acarođlu [2023] for Turkey.

Taking into account the climate policy objective of reducing mineral fertilizer use by 20% by 2030 and the evidence from models and literature, it is possible that cereal yields in EU countries may experience a decrease. Considering the presented results and references to other studies, hypotheses H_1 and H_3 are confirmed.

The final variable analyzed in relation to agricultural transformation in the surveyed European Union countries was the rise in the proportion of renewable energy. It is recommended by the REPowerEU programme that member states should aim for 45% renewable energy usage by 2030. According to the model, a 1% increase in renewable energy usage results in a 0.11% increase in cereal production volume.

The positivistic relationship between renewable energy and cereal production corresponds with the study of Monforti et al. [2013], who indicate that cereal crop residues can generate significant bioenergy resources in the European Union. Thus, an increase in the share of renewable energy may represent an opportunity for cereal producers, by providing a raw material for biomass gasification [Centi et al. 2019].

This approach not only offers a source of renewable energy but also aids in the management of waste from cereal production. The increase in the share of renewable energy sources can contribute to the reduction of environmental degradation, as suggested by Dogana and Sekera [2016] and Jebli and Youssef [2017]. According to Kumar et al. [2021], enhancing the quality of the environment can stabilize weather patterns and rainfall, leading to increased crop production. Therefore, the results confirm hypothesis H2.

The Figures 1–5 presents average marginal effects plots, which graphically represent the obtained results. These plots show how the dependent variable is affected by a marginal increase in the independent variable, assuming the ceteris paribus principle. To test the robustness of the results, estimations were made using the PCSE and CCEMG methods, which are known for their robustness to heteroskedasticity and cross-sectional dependence. Table 9 presents the results of the control models.

Table 9. Robust check

Variable	PCSE	CCEMG
$\ln ACO_2$	–0.050*	–0.082***
	[0.014]	[0.026]
lnCLS	1.090*	0.630*
	[0.015]	[0.140]
lnFPI	1.148*	1.640*
	[0.077]	[0.210]
lnFZ	0.369*	0.212***
	[0.014]	[0.042]
lnREW	0.099*	0.100***
	[0.014]	[0.06]
Constant	–6.628*	2.49*
	[0.342]	[0.126]
R^2	0.959	0.910
F-statistic		4.41*
χ^2	12455.96*	

Note: Significance of the coefficients is indicated by an asterisk in the tables, where *, **, *** denote a 10%, 5%, and 1% significance level, respectively. [] are standard errors.

Source: Author's own research.

The results confirm the robustness of the estimation carried out with the FGLS model, as both the PCSE and CCEMG models have significant coefficients with values similar to the FGLS model. However, it should be noted that the coefficients for the CCEMG model exhibit more variability due to the different estimation technique used. Both models confirm the robustness of the model used and its ability to make inferences about the studied phenomena. It is important to acknowledge the validity of these findings and consider them in future research.

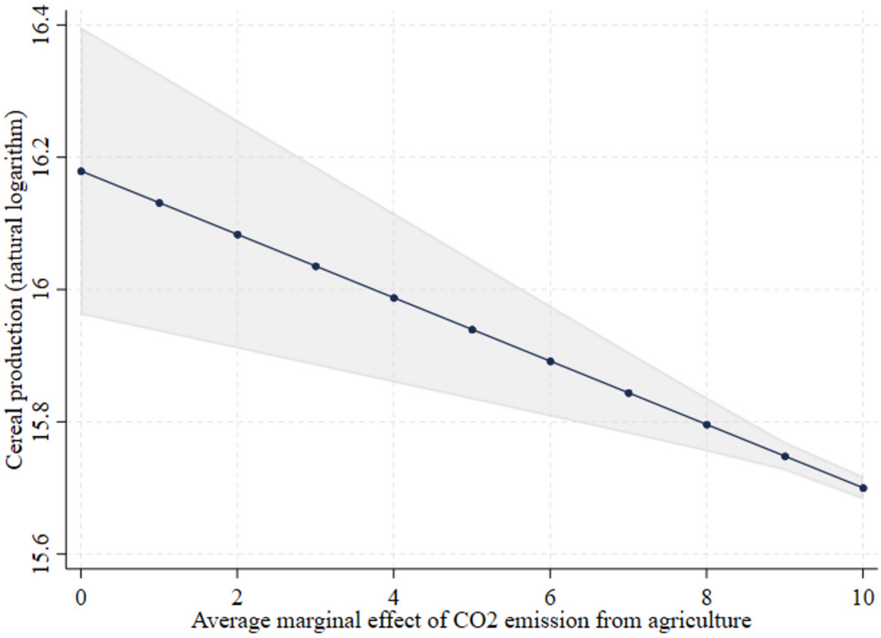

Fig. 1. Average marginal effect of CO_2 emissions from agriculture on cereals production

Source: Author's own research.

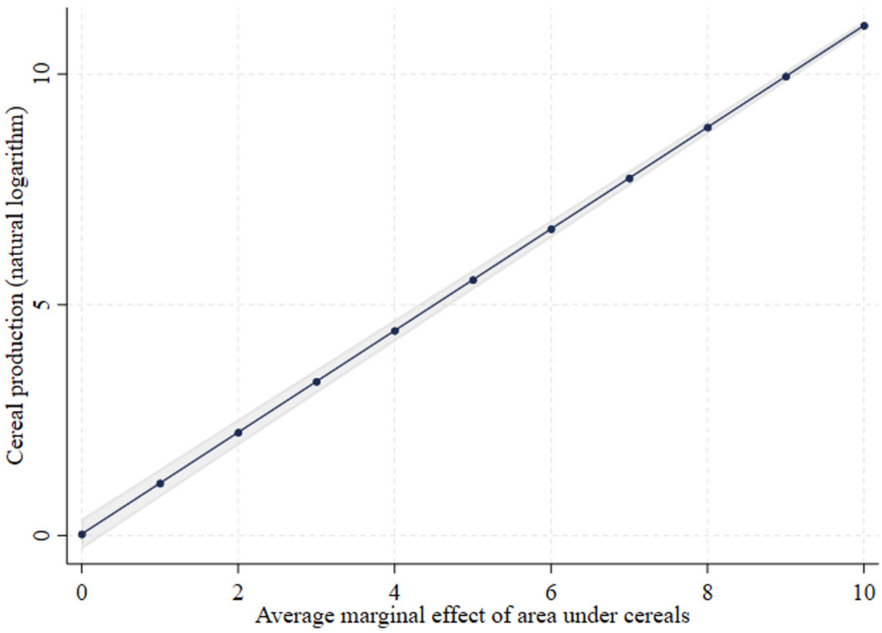

Fig. 2. Average marginal effect of land under cereal production on cereal production

Source: Author's own research.

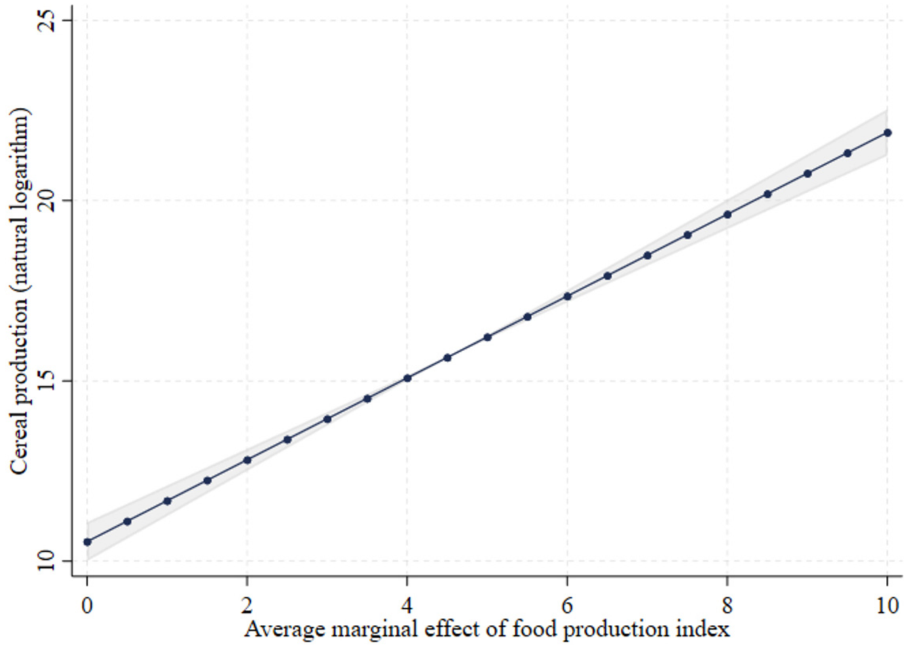

Fig. 3. Average marginal effect of food production index on cereals production

Source: Author's own research.

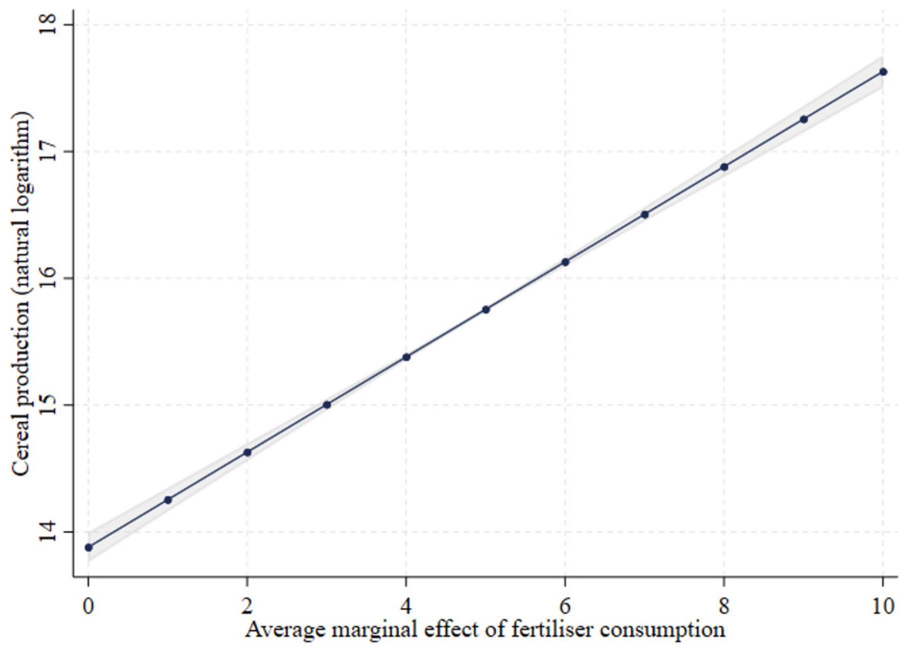

Fig. 4. Average marginal effect of fertilizer consumption on cereals production

Source: Author's own research.

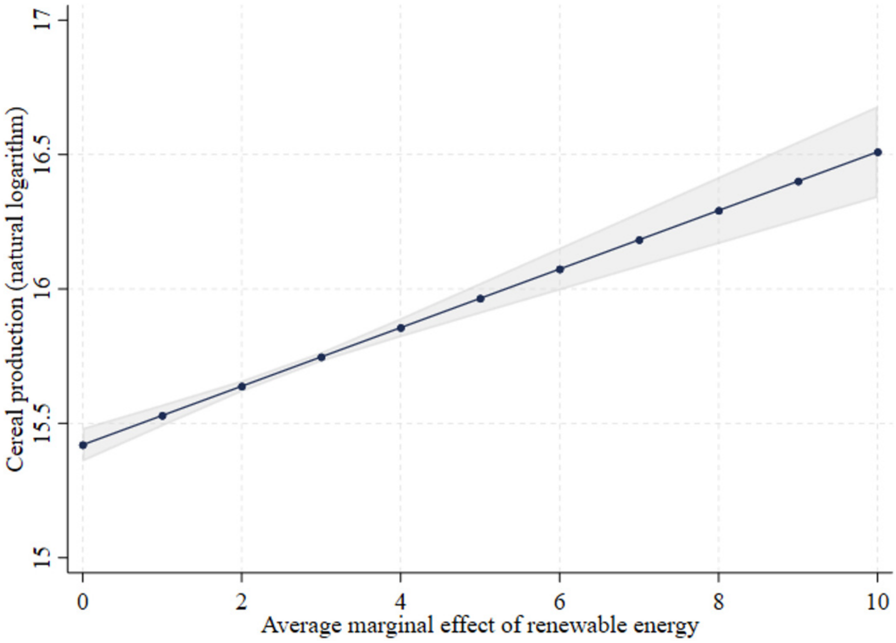

Fig. 5. Average marginal effect of renewable energy share on cereals production

Source: Author's own research.

CONCLUSIONS

This article explores the effects of the European Union's climate policy and strategy on cereal production in 21 member countries from 1995 to 2021. The study employed various models, including FGLS to account for heteroscedasticity and cross-sectional dependence, and PCSE and CCEMG as controls to validate the findings. The study suggests that the impact of the green transition on agriculture in EU countries is intricate and diverse. Nevertheless, the study provides significant new insights that can guide policy decisions and future Green Deal implementation efforts.

The results of the study show that the areas that are regulated by the European Union's climate policy have a significant impact on cereal production in the countries studied. Changes in the size of cultivated areas and in the number of fertilizers used can have a significant impact on reducing the volume of cereal crop production. Changes in food production volumes also have a significant impact on the yields of European agriculture. These areas require the creation of appropriate regulations that will provide protective measures for farmers in European Union countries, and which will not lead to a decrease in food availability.

The energy transition presents opportunities for agricultural producers. One such opportunity is the use of waste from cereal and crop production to produce biogas. This not only improves climatic conditions, but also provides green energy for agriculture to increase production efficiency. In the long term, it is believed that reducing CO_2 emissions from agriculture and economic activities could potentially improve climatic stability, increase crop production volume, and reduce the risk of climate anomalies.

With regard to the policy implications of the results obtained, it is worth noting that supporting farms during the green transition in agriculture can help to minimize negative effects. Furthermore, it is crucial to educate and inform the public about the positive aspects of these activities. It is recommended that policy makers provide tax and legal incentives for investments in organic crop production and energy production in biogas plants.

This study has some limitations, such as the relatively short time period for which the data was collected. It is possible that more precise results could be obtained with a longer time series. Furthermore, the study focuses on the European Union countries as a whole, and it may be beneficial for future analyses to consider a regional or income-based breakdown of these countries. This will facilitate a more precise examination of the issue, considering regional disparities and enabling the proposal of customized solutions at a more localized level.

REFERENCES

Abbasi, K. (2021). Green growth of cereal food production under the constraints of agricultural carbon emissions: A new insights from ARDL and VECM models. Sustainable Energy Technologies and Assessments, 47, 101452. https://doi.org/10.1016/j.seta.2021.101452

Abdullahi, N.M., Ibrahim, A., Ahmad, A., Huo, X. (2023). Cereal production amidst fertilizer usage, cereal cropland area, and farm labor in Nigeria: A novel dynamic ARDL stimulations approach. Research Square. https://doi.org/10.21203/rs.3.rs-3666789/v1

Adamowicz, M. (2021). Zielona gospodarka, zielony wzrost i zazielenienie jako formy realizacji koncepcji zrównoważonego rozwoju (Green economy, green growth and greening as the forms of sustainable development concept). Wieś i Rolnictwo, 2(191), 13–33. https://doi.org/10.53098/wir022021/01

Adviento-Borbe, M.A.A. (2020). 3 – An agronomic overview of US cereal cropping systems. [In:] A. A. Perdon, S.L. Schonauer, K. S. Poutanen (eds), Breakfast Cereals and How They Are Made (Third Edition). AACC International Press, 39–71. https://doi.org/10.1016/B978-0-12-812043-9.00003-5

Ahsan, F., Chandio, A.A., Fang, W. (2020). Climate change impacts on cereal crops production in Pakistan: Evidence from cointegration analysis. International Journal of Climate Change Strategies and Management, 12(2), 257–269. https://doi.org/10.1108/IJCCSM-04-2019-0020

Bai, J., Choi, S.H., Liao, Y. (2021). Feasible generalized least squares for panel data with cross-sectional and serial correlations. Empirical Economics, 60(1), 309–326. https://doi.org/10.1007/s00181-020-01977-2

Baig, I., Ahmed, F., Salam, Md. A., Khan, S. (2020). An assessment of Climate change and Crop Productivity in India: A a Multivariate Cointegration Framework. Test Engineering and Management, 83, 3438–3452.

Baltagi, B.H., Feng, Q., Kao, C. (2012). A Lagrange Multiplier test for cross-sectional dependence in a fixed effects panel data model. Journal of Econometrics, 170(1), 164–177. https://doi.org/10.1016/j.jeconom.2012.04.004

Beck, N., Katz, J.N. (2011). Modeling Dynamics in Time-Series – Cross-Section Political Economy Data. Annual Review of Political Science, 14(1), 331–352. https://doi.org/10.1146/annurev-polisci-071510-103222

Beckman, J., Ivanic, M., Jelliffe, J.L., Baquedano, F.G., Scott, S. G. (2020). Economic and Food Security Impacts of Agricultural Input Reduction Under the European Union Green Deal's Farm to Fork and Biodiversity Strategies. https://doi.org/10.22004/ag.econ.307277

Ben Jebli, M., Ben Youssef, S. (2017). The role of renewable energy and agriculture in reducing CO_2 emissions: Evidence for North Africa countries. Ecological Indicators, 74, 295–301. https://doi.org/10.1016/j.ecolind.2016.11.032

Ben Mariem, S., Soba, D., Zhou, B., Loladze, I., Morales, F., Aranjuelo, I. (2021). Climate Change, Crop Yields, and Grain Quality of C3 Cereals: A Meta-Analysis of [CO_2], Temperature, and Drought Effects. Plants, 10(6), 1052. https://doi.org/10.3390/plants10061052

Blake, R. (2020). Will the European Green Deal Make Agriculture More Sustainable? Outlooks on Pest Management, 31(5), 198–200. https://doi.org/10.1564/v31_oct_01

Centi, G., Iaquaniello, G., Perathoner, S. (2019). Chemical engineering role in the use of renewable energy and alternative carbon sources in chemical production. BMC Chemical Engineering, 1(1), 5. https://doi.org/10.1186/s42480-019-0006-8

Chandio, A.A., Jiang, Y., Fatima, T., Ahmad, F., Ahmad, M., Li, J. (2022). Assessing the impacts of climate change on cereal production in Bangladesh: Evidence from ARDL modeling approach. International Journal of Climate Change Strategies and Management, 14(2), 125–147. https://doi.org/10.1108/IJCCSM-10-2020-0111

Chandio, A.A., Ozturk, I., Akram, W., Ahmad, F., Mirani, A.. A. (2020). Empirical analysis of climate change factors affecting cereal yield: Evidence from Turkey. Environmental Science and Pollution Research, 27(11), 11944––11957. https://doi.org/10.1007/s11356-020-07739-y

The European Green Deal (2019). European Commission. Communication from the Commission to the European Parliament, the European Council, the Council, the European

Economic and Social Committee and the Committee of the Regions. The European Green Deal, [COM(2019) 640 final]. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX%3A52019DC0640

Demirhan, H. (2020). Impact of increasing temperature anomalies and carbon dioxide emissions on wheat production. Science of The Total Environment, 741, 139616. https://doi.org/10.1016/j.scitotenv.2020.139616

Dogan, E., Seker, F. (2016). Determinants of CO_2 emissions in the European Union: The role of renewable and non-renewable energy. Renewable Energy, 94, 429–439. https://doi.org/10.1016/j.renene.2016.03.078

Dorgbetor, I.K., Ondrasek, G., Kutnjak, H., Mikuš, O. (2022). What If the World Went Vegan? A Review of the Impact on Natural Resources, Climate Change, and Economies. Agriculture, 12(10), 10. https://doi.org/10.3390/agriculture12101518

Dumitrescu, E.-I., Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. Economic Modelling, 29(4), 1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Fayet, C.M.J., Reilly, K.H., Van Ham, C., Verburg, P.H. (2022). The potential of European abandoned agricultural lands to contribute to the Green Deal objectives: Policy perspectives. Environmental Science & Policy, 133, 44–53. https://doi.org/10.1016/j.envsci.2022.03.007

Fomby, T.B., Johnson, S.R., Hill, R.C. (1984). Feasible Generalized Least Squares Estimation. [In:] T.B. Fomby, S.R. Johnson, R.C. Hill (Edseds.), Advanced Econometric Methods., Springer, New York, 147–169. https://doi.org/10.1007/978-1-4419-8746-4_8

Green, R., Cornelsen, L., Dangour, A.D., Turner, R., Shankar, B., Mazzocchi, M., Smith, R.D. (2013). The effect of rising food prices on food consumption: Systematic review with meta-regression. BMJ, 346, f3703. https://doi.org/10.1136/bmj.f3703

Grochowska, R., Staszczak, A. (2021). Możliwości implementacji założeń unijnej strategii „Od pola do stołu" w sektorze rolno-spożywczym (Possibilities of implementing the assumptions of the EU " Farm to Fork" strategy in the agri-food sector). Przemysł Spożywczy, 75(7). https://doi.org/10.15199/65.2021.7.1

Iji, P.A., Barekatain, M.R., Iji, P.A., Barekatain, M.R. (2011). Implications for the Feed Industry. [In:] M.A. Dos Santos Bernardes (Eded.), Economic Effects of Biofuel Production. IntechOpen. https://doi.org/10.5772/16434

Im, K. S., Pesaran, M. H., Shin, Y. (2003). Testing for unit roots in heterogeneous panels. Journal of Econometrics, 115(1), 53–74. https://doi.org/10.1016/S0304-4076(03)00092-7

Karaczun, Z., Kozyra, J. (2020). Wpływ zmiany klimatu na bezpieczeństwo żywnościowe Polski (The impact of climate change on Poland's food security). Wydawnictwo SGGW, Warszawa.

Kibria, Md.G., Aspy, N.N., Ullah, E., Dewan, Md.F., Hasan, Md.A., Hossain, Md.A., Haseeb, M., Hossain, Md.E. (2023). Quantifying the effect of agricultural greenhouse gas emissions, food production index, and land use on cereal production in South Asia. Journal of Cleaner Production, 432, 139764. https://doi.org/10.1016/j.jclepro.2023.139764

Koondhar, M.A., Aziz, N., Tan, Z., Yang, S., Raza Abbasi, K., Kong, R. (2021). Green growth of cereal food production under the constraints of agricultural carbon emissions: A new insights from ARDL and VECM models. Sustainable Energy Technologies and Assessments, 47, 101452. https://doi.org/10.1016/j.seta.2021.101452

Koondhar, M.A., Udemba, E.N., Cheng, Y., Khan, Z.A., Koondhar, M.A., Batool, M., Kong, R. (2021). Asymmetric causality among carbon emission from agriculture, energy consumption, fertilizer, and cereal food production – A nonlinear analysis for Pakistan. Sustainable Energy Technologies and Assessments, 45, 101099. https://doi.org/10.1016/j.seta.2021.101099

Köprücü, Y., Acarodlu, H. (2023). How cereal yield is influenced by eco-environmental factors? ARDL and spectral causality analysis for Turkey. Cleaner Environmental Systems, 10, 100128. https://doi.org/10.1016/j.cesys.2023.100128

Kumar, P., Sahu, N. C., Kumar, S., Ansari, M. A. (2021). Impact of climate change on cereal production: Evidence from lower-middle-income countries. Environmental Science and Pollution Research, 28(37), 51597–51611. https://doi.org/10.1007/s11356-021-14373-9

Laskowski, W., Górska-Warsewicz, H., Rejman, K., Czeczotko, M., Zwolińska, J. (2019). How Important are Cereals and Cereal Products in the Average Polish Diet? Nutrients, 11(3), 3. https://doi.org/10.3390/nu11030679

Li, X., Xia, X., Ren, J. (2022). Can the Participation in Quality Certification of Agricultural Products Drive the Green Production Transition? International Journal of Environmental Research and Public Health, 19, 17. https://doi.org/10.3390/ijerph191710910

Liu, X., Zhang, S., Bae, J. (2017). The nexus of renewable energy-agriculture-environment in BRICS. Applied Energy, 204, 489–496. https://doi.org/10.1016/j.apenergy.2017.07.077

Macdiarmid, I. (2022). The food system and climate change: Are plant-based diets becoming unhealthy and less environmentally sustainable? Proceedings of the Nutrition Society, 81(2), 162–167. https://doi.org/10.1017/S0029665121003712

Malhi, G.S., Kaur, M., Kaushik, P. (2021). Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. Sustainability, 13, 3. https://doi.org/10.3390/su13031318

Monforti, F., Bódis, K., Scarlat, N., Dallemand, J.-F. (2013). The possible contribution of agricultural crop residues to renewable energy targets in Europe: A spatially explicit study. Renewable and Sustainable Energy Reviews, 19, 666–677. https://doi.org/10.1016/j.rser.2012.11.060

Neupane, D., Adhikari, P., Bhattarai, D., Rana, B., Ahmed, Z., Sharma, U., Adhikari, D. (2022). Does Climate Change Affect the Yield of the Top Three Cereals and Food Security in the World? Earth, 3, 1. https://doi.org/10.3390/earth3010004

Nico, G., Christiaensen, L. (2023). Jobs, Food and Greening: Exploring Implications of the Green Transition for Jobs in the Agri-food System. World Bank. https://doi.org/10.1596/39819

Oishi, R. (2021). Economic Perspectives on Analysis of Ensuring Cereal Production and Consumption Security. In Cereal Grains – Volume 2. IntechOpen. https://doi.org/10.5772/intechopen.96377

Parlinska, M., Jaskiewicz, J., Rackiewicz, I. (2020). Wyzwania dla rolnictwa związane za strategią Europejski Zielony Ład w okresie pandemii (Challenges for agriculture related to the European Green Deal strategy during the pandemic). Zeszyty Naukowe Szkoły Głównej Gospodarstwa Wiejskiego w Warszawie. Problemy Rolnictwa Światowego, 20(2), 22–36. https://doi.org/10.22630/PRS.2020.20.2.10

Pesaran, M.H. (2006). Estimation and Inference in Large Heterogeneous Panels with a Multifactor Error Structure. Econometrica, 74(4), 967–1012. https://doi.org/10.1111/j.1468-0262.2006.00692.x

Poczta, W., Gradziuk, P., Matyka, M., Sadowski, A. (2023). Potential Changes in Land Use and Plant Production in Poland in the Context of Implementing the European Green Deal. Regional Barometer. Analyses & Prognoses, 19, 2. https://doi.org/10.56583/br.2303

Prandecki, K., Wrzaszcz, W., Zieliński, M. (2021). Environmental and Climate Challenges to Agriculture in Poland in the Context of Objectives Adopted in the European Green Deal Strategy. Sustainability, 13, 18. https://doi.org/10.3390/su131810318

Rahman, M.H., Majumder, S.C., Debbarman, S. (2020). Examine the Role of Agriculture to Mitigate the CO_2 Emission in Bangladesh. Asian Journal of Agriculture and Rural Development, 10, 1. https://doi.org/10.18488/journal.1005/2020.10.1/1005.1.392.405

Röös, E., Mie, A., Wivstad, M., Salomon, E., Johansson, B., Gunnarsson, S., Wallenbeck, A., Hoffmann, R., Nilsson, U., Sundberg, C., Watson, C.A. (2018). Risks and opportunities of increasing yields in organic farming. A review. Agronomy for Sustainable Development, 38(2), 14. https://doi.org/10.1007/s13593-018-0489-3

Rudnicki, R., Wiśniewski, Ł., Biczkowski, M. (2021). A Spatial Typography of Environmentally Friendly Common Agricultural Policy Support Relevant to European Green Deal Objectives. Land, 10, 10. https://doi.org/10.3390/land10101092

Selwyn, B. (2022). A green new deal for agriculture: for, within, or against capitalism? Journal of Peasant Studies, 48 (4), 778–806. https://doi.org/10.1080/03066150.2020.1854740

Simionescu, M., Bilan, Y., Gędek, S., Streimikiene, D. (2019). The Effects of Greenhouse Gas Emissions on Cereal Production in the European Union. Sustainability, 11, 12. https://doi.org/10.3390/su11123433

Szajner, P., Szczepaniak, I. (2023). Gospodarowanie energią w polskim przemyśle spożywczym (Energy management in the Polish food industry). Przemysł Spożywczy, 77(8). https://doi.org/10.15199/65.2023.8.1

Szubska-Włodarczyk, N. (2023). Organic Farming in the European Union in the Face of the Challenges of Sustainable Consumption. Zagadnienia Ekonomiki Rolnej, 376(3), 47–65.

Wang, J., Vanga, S.K., Saxena, R., Orsat, V., Raghavan, V. (2018). Effect of Climate Change on the Yield of Cereal Crops: A Review. Climate, 6, 2. https://doi.org/10.3390/cli6020041

Wang, X., Liu, F. (2021). Effects of Elevated CO_2 and Heat on Wheat Grain Quality. Plants, 10(5), 1027. https://doi.org/10.3390/plants10051027

Wesseler, J. (2022). The EU's farm-to-fork strategy: An assessment from the perspective of agricultural economics. Applied Economic Perspectives and Policy, 44(4), 1826–1843. https://doi.org/10.1002/aepp.13239

Westerlund, J. (2007). Testing for Error Correction in Panel Data. Oxford Bulletin of Economics and Statistics, 69(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

White, H. (1980). A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. Econometrica, 48(4), 817–838. https://doi.org/10.2307/1912934

Wood, D., Lenné, J. M. (2018). A natural adaptive syndrome as a model for the origins of cereal agriculture.

Proceedings of the Royal Society B: Biological Sciences, 285(1875), 20180277. https://doi.org/10.1098/rspb.2018.0277

Wooldridge, J.M. (2001). Applications of Generalized Method of Moments Estimation. Journal of Economic Perspectives, 15(4), 87–100. https://doi.org/10.1257/jep.15.4.87

Wooldridge, J.M. (2010). Econometric Analysis of Cross Section and Panel Data. The MIT Press, Cambridge.. https://www.jstor.org/stable/j.ctt5hhcfr

Wrzaszcz, W., Prandecki, K. (2020). Agriculture and the European Green Deal. Zagadnienia Ekonomiki Rolnej, 365(Special Issue 4), 156–179. https://doi.org/10.30858/zer/131841

Xiang, X., Solaymani, S. (2022). Change in cereal production caused by climate change in Malaysia. Ecological Informatics, 70, 101741. https://doi.org/10.1016/j.ecoinf.2022.101741

Yu, Q., Xiang, M., Wu, W., Tang, H. (2019). Changes in global cropland area and cereal production: An inter-country comparison. Agriculture, Ecosystems & Environment, 269, 140–147. https://doi.org/10.1016/j.agee.2018.09.031

Zhang, X., Long, H. (2013). MDG Hunger Target: Analysis of Cereal Production System and the Evaluation of Cereal Production Potential in Africa. Journal of Sustainable Development, 6, 11. https://doi.org/10.5539/jsd.v6n11p82

Zwane, T., Udimal, T.B., Pakmoni, L. (2022). The Impact of Renewable Energy Consumption, Fertiliser Consumption and Agricultural Economic Growth on Agricultural Carbon Emissions: An Application of FMOLS and DOLS Approaches. Research Square. https://doi.org/10.21203/rs.3.rs-1841173/v1

WPŁYW ZIELONEJ TRANSFORMACJI NA PRODUKCJĘ ZBÓŻ W UNII EUROPEJSKIEJ. NOWE SPOSTRZEŻENIA OPARTE NA MODELU PANELOWYM FGLS

STRESZCZENIE

Cel: Celem badania była ekonometryczna ocena długookresowego wpływu obszarów regulacji związanych z Zielonym Ładem na produkcję roślinną zbóż w krajach Unii Europejskie. **Metody:** Badanie opiera się na analizie danych panelowych dla 21 krajów Unii Europejskiej za lata 1995–2021. Do określenia wpływu emisji CO_2 z rolnictwa, powierzchni użytków rolnych, wielkości produkcji żywności oraz konsumpcji nawozów na produkcję zbóż wykorzystano modele FGLS, PCSE oraz CCEMG, które są odporne na heteroskedastyczność i zależności przekroju poprzecznego. Dodatkowo w celu potwierdzenia kointegracji został zastosowany silny test oparty na modelu ECM Westerlunda. Wszystkie modele w celu wzmocnienia uzyskanych wyników zostały estymowane na podstawie *bootstrap*. **Wyniki**: Uzyskane wyniki wskazują, że w długiej perspektywie wzrost emisji CO_2 z rolnictwa o 10% powoduje średni spadek produkcji zbóż o 0,5%. Wzrost powierzchni upraw o 1% powoduje pozytywną zmianę wartości produkcji zbóż o 1,1%, a wzrost zużycia nawozów na 1 ha upraw o 1% powoduje, przyrost produkcji zbóż o 0,38%. Również wartość wskaźnika produkcji żywności wykazuje pozytywny wpływ na produkcję zbóż. Jeżeli indeks wzrośnie o 1 p.p. to produkcja zbóż rośnie o 1,13% w długim okresie. Badanie wykryło również pozytywną relację pomiędzy wzrostem udziału energii odnawialnej a wielkości produkcji zbóż. Jeżeli udział energii odnawialnej rośnie o 1%, to wielkość produkcji zbóż w krajach Unii Europejskiej wzrasta o 0,11%.

Wnioski: Generalnie można stwierdzić, że „zielona transformacja" niesie dla rolnictwa zarówno negatywne, jak i pozytywne aspekty zmian. Zmniejszenie powierzchni gruntów uprawnych i redukcja wykorzystania nawozów sztucznych może negatywnie wpłynąć na wydajność gospodarstw rolnych. Z kolei poprawa warunków klimatycznych oraz rozwój energii odnawialnej mogą być korzystny dla rolnictwa w długiej perspektywie. Badanie jest oryginalne w tym sensie, że wypełnia lukę empiryczną i teoretyczną związaną z weryfikowaniem wpływu zielonego ładu na sektor produkcji zbóż, a tym samym rolnictwo w Unii Europejskiej.

Słowa kluczowe: produkcja zbóż, rolnictwo, FGLS, zielona transformacja, Unia Europejska, dane panelowe

CONTENTS
SPIS TREŚCI

FOR AUTHORS

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