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ENERGY INTENSITY OF THE POLISH AGRI-FOOD SECTOR IN THE LIGHT OF INPUT-OUTPUT TABLES[2]

Key words: agribusiness, food production, energy consumption, energy mix, input-output balance

ABSTRACT. The purpose of this paper is to assess the energy intensity of production in the Polish agri-food (agribusiness) sector, split into agriculture, food industry and supply subsectors, in the light of input-output tables. The study relies on input-output tables and physical energy flow accounts. Energy plays a key role in today's society as it affects economic growth and the standards of living, while also being at the core of international conflicts, mainly caused by its limited resources. Compared to other sectors, agribusiness demonstrates particularly high levels of energy consumption. Agriculture, which is part of it, has a large share in the consumption of fuels derived from crude oil. This paper presents the consumption of energy in each of the four aggregates of agribusiness, as well as their GDP (in PPS) and energy consumption mix (split into 6 groups of energy carriers). The authors found that between 2014 and 2019, energy consumption in the agribusiness industry increased by ca. 9% and was accompanied by ca. 8% growth in GDP. The sector's energy intensity was half more than the average level for the economy as a whole, and remained at ca. 5.6 TJ per EUR 1 million of GDP in PPS. Only the food industry was at a level of energy efficiency similar to that of the economy as a whole, whereas the agricultural supply subsector was the only one to demonstrate lower levels. Both the economy as a whole and the agribusiness sector clearly tend to reduce the share of coal and related products in the energy mix.

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INTRODUCTION

In research on the development of the agri-food sector, the concept of sustainable development is the next step of the empirical analysis of the underlying patterns [Zegar 2012, Mrówczyńska-Kamińska 2015]. The agri-food sector and other sectors of the national economy are bound by different types of relationships and links. On the one hand, the production of finished food products involves nearly all sectors of the economy, and it is therefore important to determine their contribution to that process [Schiff and Valdes 1967, Czyżewski and Mrówczyńska-Kamińska 2011, Klepacki 2019]. On the other, however, the sector in charge of food production and distribution is significantly related to the environment. Hence, it is important to show, for instance, how much each industry depends on energy derived from different sources, including fossil fuels which are a major contributor to greenhouse gas emissions [Gołasa et al. 2021]. Energy is used across the food supply chain –from the production and use of agricultural raw materials through to processing, packaging and distribution to consumers. According to research, the agri-food sector is accountable for a large part of total energy consumed in the economy [Pimentel and Pimentel 2007, Li et al. 2014].

In view of today's problems, improving the energy intensity (defined as the ratio between energy consumed and GDP generated in that process) of the sector responsible for food production is of key importance to maintaining food production at a sufficient level to ensure food security. Making an efficient use of energy resources is also of key importance to enhancing the competitiveness of the agri-food sector and ensuring environmental sustainability. Therefore, there is need for reducing the dependency upon the increasingly limited energies derived from fossil fuels through the understanding of patterns of energy consumption and energy balance [Khan et al. 2009]. According to a BP report [BP 2020], the share of petroleum products in energy consumption in the Polish economy was ca. 30% in 2019. Furthermore, the world is largely dependent upon OPEC, an organization which accounts for more than 37% of global oil production while owning over 70% of oil resources.

In the agribusiness as a whole, changes in energy intensity may result not only from technological and technical improvements, but also from indirect consumption patterns (especially including the consumption of fertilizers and pesticides, the use of machinery responsible for direct energy consumption, and the energies used in the processing industry) [Pelletier et al. 2011][3]. Today, the demand for food, the scarcity of energy, and environmental

[3] In the European Union, of which Poland is a member, the first directives on energy efficiency emerged in 1993 [Council Directive 93/76/EEC]. Since then, different sustainable development strategies and programs have been implemented which also relate to energy efficiency. The European Union's most recent environmental goals are laid down in the European Green Deal strategic document. It was designed to create a modern and, above all, resource-efficient and climate-neutral economy which decouples economic growth from the use of natural resources [Commission Staff Working Document 2020].

pollution related to food production have grown to become a major problem [Pagotto and Halog 2016]. The progress in economic development drives changes in food production, and therefore these sectors start to increasingly focus on environmental aspects. Thus, issues related to sustainable development in the food production sector should be subject to different kinds of analysis [Notarnicola et al. 2012]. The relationship between the Polish agri-food sector (agribusiness) and the environment can be examined based on input–output data. The use of input–output methods (IOM) in analyzing the food production sector and environmental flows has been widely addressed in the literature [Goldberg and Davis 1957, Isard 1972, Leontief 1972, 2018, Daly and Farley 2011, Ayres and Kneese 2013]. Extended input–output tables combine data on environmental pressures (e.g. energy consumption) across all sectors with financial transactions between them (intermediate demand) and allow to allocate the pressures to the consumption of product groups (final demand) [Miller and Blair 2009].

The purpose of this paper is to assess the energy intensity of production in the Polish agri-food (agribusiness) sector in the light of input–output tables. The study covered all of the sector's aggregates: supply of goods and services to the agriculture and the food industry; agriculture itself; and the food industry. The specific objectives of this study boil down to:

- calculating the levels of energy consumption based on input–output volumes,
- calculating the energy intensity of energy consumption (energy consumed/GDP),
- presenting the energy mix.

Analyzing the input–output tables, their structure and evolution over time is important in determining whether the Polish agri-food sector follows a sustainable development path in both the economic and social context. Increased inputs (intermediate consumption) to agriculture and to the food industry from different sectors of the national economy indicate that the production of raw materials and finished food products becomes increasingly dependent upon certain materials (including energy) and services. From the perspective of the purpose of this paper, the supply of goods and services to agriculture is of key importance because the factors that provide momentum for the production of agricultural raw materials and finished foods mostly originate from the outside: they are products of the industry and of all kinds of services. Examining the inputs from the supply industry is a way to assess progress in sustainable development at sector level. On the one hand, the agri-food sector produces an increasingly greater volume of agricultural raw materials and finished foods whereas on the other, it demands increasingly more productive industrial inputs and all kinds of services.

This paper analyzes the issues related to energy consumption in different spheres of the Polish agribusiness because what matters for the environment is not only the level of energy intensity but also the mix of energy carriers used in the sector concerned. Improvements in energy intensity will be the key measure taken to reduce net greenhouse gas emissions by no less than 55% by 2030, a goal set by the European Union (EU) [Brożyna et al. 2023].

RESEARCH MATERIALS AND METHODOLOGY

The basic statistical resources used in this paper are input–output tables which provide information on material and service (input) flows, expressed in pecuniary units, between 64 economic sectors [Remond-Tiedrez et al. 2019]. In turn, energy consumption data comes from physical energy flow accounts [Eurostat 2023] which show the amount of final energy consumption (split into 29 energy carriers) for the same 64 economic sectors covered by input–output tables, are consistent with NACE Rev. 2, and are expressed in terajoules (TJ). The time scope of this study is 2014–2019, and results from the availability of statistical data on energy consumption.

This paper assumes that the food production system (agribusiness) is composed of four stages: agriculture, the food industry, and the supply of goods and services to both of them. The properties of input–output tables that allow to determine the input coefficients for selected activities were used in order to calculate energy consumption levels at each step of the agribusiness flow. The coefficients are the result of multiplying the inverse Leontief matrix (which presents the cost structure of the economy and takes the multiplier effect into account) by the matrix of direct input coefficients which indicates the scale of the phenomenon (i.e. GDP or energy consumption in this case) involved in delivering one global production unit. The equation may take the following form:

$$FIC = (I - A)^{-1} \times DIC$$

where: FIC – coefficients matrix for total inputs, I – identity matrix, A – cost structure matrix, DIC – coefficients matrix for direct inputs.

A step-by-step description of the procedure used in this paper was presented by Bartłomiej Bajan and his team [2022] as a method for evaluating the emission intensity of the food production system. This study adapts it for an analysis of energy intensity in a way to ensure consistency with input–output tables which allow for determining the coefficients of total inputs for a series of activities [Miller and Blair 2009].

RESULTS OF THE STUDY

Between 2014 and 2019, total energy consumption in the Polish agribusiness sector increased by more than 36,000 TJ, which means ca. 9% growth over 6 years (Figure 1). However, despite this, the share of agribusiness in total energy consumption of the economy declined by 1.4 percentage points, from 17.9% in 2014 to 16.5% in 2019. The above is consistent with a study carried out by Fabio Monfortiefo and his research team [2015] who demonstrated that the EU's whole food chain accounts for ca. 17% of energy consumption. This is because energy consumption in the economy as a whole grew at an even faster rate of 18.1% over the study period (Figure 1), which is consistent with the global trend of increased energy use [Wysokiński et al. 2017].

The study period witnessed growth in energy consumption in the food industry itself and in its supply sector (at a rate of 24% and 18.1%, respectively). On the other hand, the agricultural sector reported a slight decline in energy consumption (whereas the energy consumed by the supply of goods and services to the agriculture went down by ca. 6%).

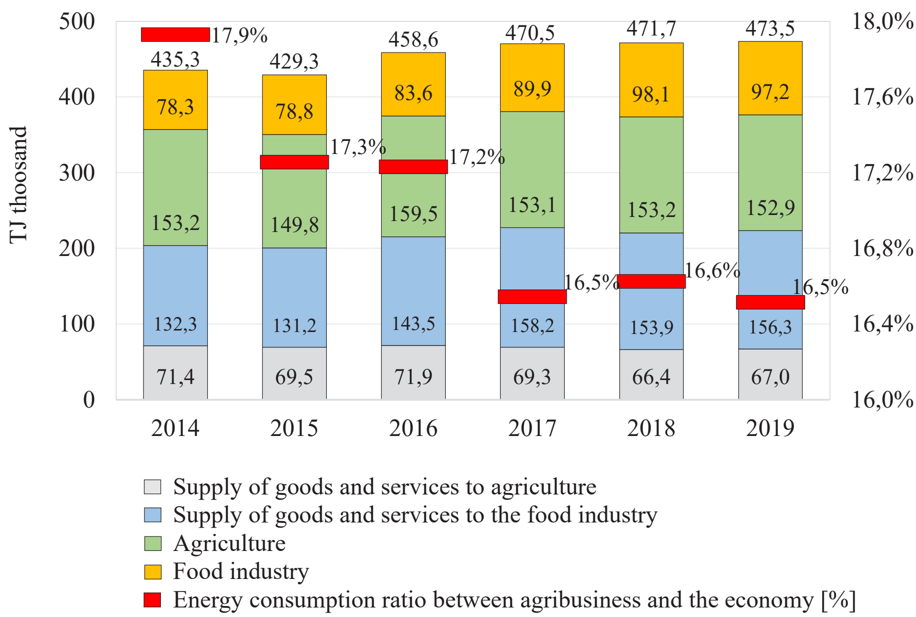

Figure 1. Energy consumption in the agribusiness sector grouped by aggregates. Share of agribusiness in energy consumption of the economy as a whole (%)

Source: own calculations based on Eurostat data [2014-2019]

In the years covered by this study, the share of sectors accountable for direct energy use (i.e. agriculture and the food sector) was higher than that of intermediate (supply) sectors. In 2014, it was 53.2%, and decreased by 0.4 percentage points by 2019. Meanwhile, the share of the food industry and of its supply sector increased by over 5% as a consequence of its growing demand for energy which, in turn, was driven by its development and by growth in material intensity. Additionally, according to Marcin Wysokiński and his team [2017], the energy consumption ratio between agriculture and the economy as a whole was 5.3% in 2015. In this study, it was 6% (and dropped between one year and the next).

This reflects the complex relationships between agribusiness, food industry, and total energy consumption in Poland [Kasztelan et al. 2021]. These studies provide an opportunity for analyzing the trends and the way the development of each sector impacts the country's energy structure. This is a matter of importance for decision-making regarding these sectors' energy efficiency, and for planning development activities designed to enable sustainable economic development.

The analysis of data shown in Figure 2 provides grounds for concluding that the GDP of agribusiness in the years covered by this study grew by 8.4%, and reached EUR 84.6 billion (compared to the initial level of EUR 78 billion). The above shows that GDP grew at a slower rate than energy consumption. In this context, note that growth in GDP for the economy as a whole was ca. 20% over that period. Moreover, the GDP of agribusiness remained at a similar level from 2016 to 2019. Between 2017 and 2019, the contribution of the agribusiness sector to total GDP of the economy declined by 1 percentage point, from 11.9% to 10.9%. It follows from the analysis of GDP and energy consumption that the agribusiness demonstrates relatively high levels of energy use and generates a small level of GDP which has not been on the rise since 2016 (Figure 2).

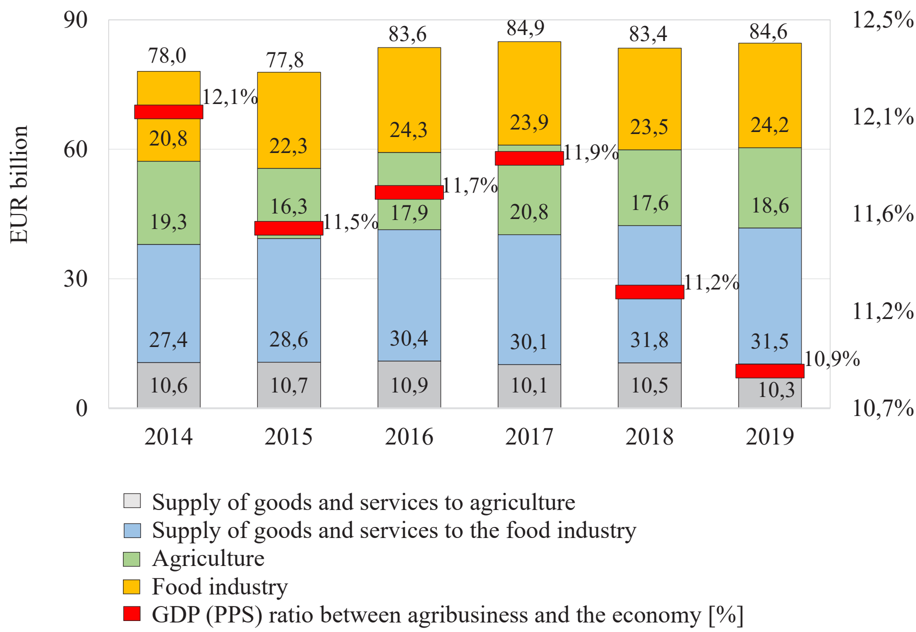

Figure 2. GDP (at constant prices and in the Purchasing Power Standard, PPS) in the agribusiness sector grouped by aggregates (EUR billion). Share of agribusiness in GDP of the economy as a whole (%)

Source: own calculations based on Eurostat data [2014-2019]

Just like it was the case for energy consumption, the food industry and its supply sector experienced growth in GDP over the study period (by 16.5% and 15.0%, respectively). Conversely, there was a 3.5% decline in GDP of agriculture and a 2.8% drop in GDP of its supply sector. However, what also matters are the considerable fluctuations in these values between the years, mostly caused by agriculture being vulnerable to changing weather conditions which may affect agricultural productivity [Battisti and Naylor 2009, Gornall et al. 2010].

The study found that a positive correlation existed between energy consumption and GDP levels over the years covered. It means that an increase in energy consumption led to growth in GDP and, similarly, a drop in energy consumption entailed a decline in GDP [Belke et al. 2011, Caraiani et al. 2015]. Another finding is that each unit of energy consumed in the economy contributed EUR 0.3 million to growth in GDP. In the whole agribusiness and in the food industry together with its supply sector, that contribution was ca. EUR 0.17 million. Note however that as regards agriculture (which experienced a drop in energy consumption), the relation between those variables had adverse consequences. Namely, a 1 TJ decline in energy consumption resulted in reducing GDP by EUR 2.3 million. On the other hand, the sector in charge of supplying goods and services to agriculture also witnessed a decline in energy consumption but had a relatively positive contribution (of EUR 0.07 million) to growth in GDP. Ultimately, it allowed to strongly reduce energy consumption while driving only a slight decline in GDP (Figure 2).

What also needs to be mentioned is the decoupling of economic growth from energy consumption. While the study found that a reduction in energy consumption was not accompanied by economic growth, the case of the supply sector shows there is potential for that to happen. Making this a reality would require deploying innovative technologies, using energy-efficient machinery and equipment, providing better insulation for buildings, optimizing production processes, and promoting an informed use of energy [Stern 2011, 2019, Chowdhury et al. 2018].

The analysis of energy intensity data for the agribusiness sector allows for drawing some important conclusions. First of all, the agribusiness clearly differs in energy intensity from the economy as a whole. The energy intensity ratio, which reflects the amount of energy consumed in order to create EUR 1 million worth of GDP (PPS), remains at a constant level, fluctuating between 5.49 and 5.65 TJ per EUR 1 million (Figure 3). Note that the agribusiness demonstrates greater energy intensity than the economy as a whole (the difference is ca. 50%). However, some progress was witnessed in 2017, as the gap narrowed to 40%. Nevertheless, it was mostly related to a general increase in energy intensity in the economy as a whole; the energy intensity ratio for agribusiness itself did not change much (Figure 3).

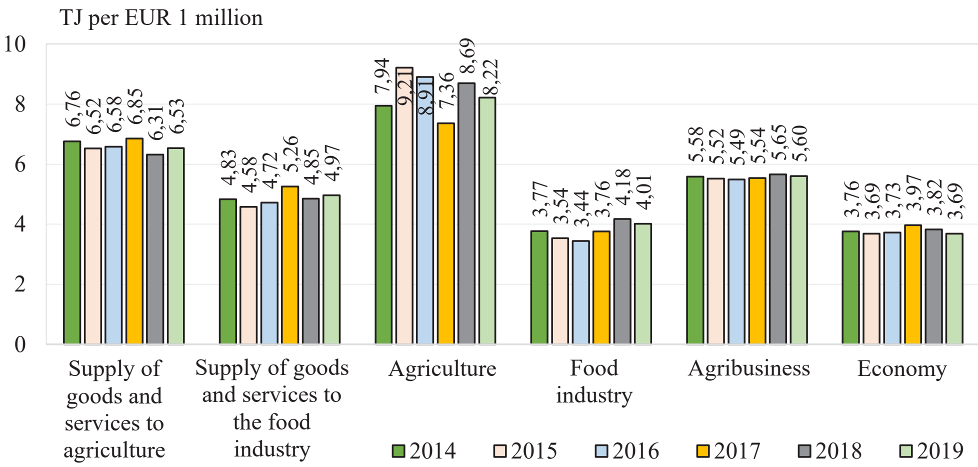

Figure 3. Energy intensity in the economy and in the agribusiness, grouped by aggregate
Source: own calculations based on Eurostat data [2014-2019]

At whole economy level, energy intensity followed a downward trend over the next years, reaching 3.69 TJ per EUR 1 million in 2019, i.e. a ca. 2% reduction against 2014. Such a drop in energy intensity indicates that the economy has the potential to make production processes more energy-efficient. However, as emphasized in an IEA report [2019], there are increasingly smaller improvements in energy intensity between one year and the other, which is also the case for Poland. According to IEA data, the amounts of investments in energy efficiency remained at a level of over USD 70 billion between 2014 and 2018.

In the agricultural sector, energy intensity is extremely high and subject to strong fluctuations, mostly caused by variation in GDP (PPS) amounts. In fact, it is more than twice the average level recorded in the economy as a whole. In 2015 and 2017, the gap was 150% and 85%, respectively. Furthermore, energy intensity in agriculture was on an upward trend in the years covered by this study despite the decline in the number of Polish farms (most of which reported low levels of efficiency). While the above contradicts the findings by Marcin Wysokiński and co-authors [2017], it may result from the fact that this study uses GDP in purchasing power parities. Also, the strong changes in that sector's energy intensity were mostly caused by variation in GDP levels.

While the sector in charge of supplying goods and services to agriculture also reports high levels of energy intensity, it follows a downward trend. Indeed, its ratio dropped by 3.4% over the study period, moving from 6.76 to 6.53 TJ per EUR 1 million (Figure 3).

In turn, energy intensity of the sector in charge of supplying goods and services to the food industry was below the average level for the agribusiness, and was only ca. 30% higher than that recorded in the economy as a whole. Also, the sector experienced a 2.8% increase in energy intensity, caused by greater energy inputs. The energy intensity of the food industry is at the lowest level of the whole agribusiness (and is similar to average figures for the whole economy). Between 2014 and 2016, it dropped by 0.33 TJ per EUR 1 million, from 3.77 TJ per EUR 1 million. However, it went up in the next years, and was 6.5% higher in 2019 than in 2014 (Figure 3).

As mentioned earlier, economic growth needs to be decoupled from adverse environmental impacts. In order for that to happen, it is necessary not only to improve energy efficiency, but also to restructure the whole energy mix so as to focus it on smaller emissions [UNEP 2011, Ozturk et al. 2021]. The analysis of energy consumption structures in the sectors in charge of supplying goods and services to agriculture and to the food industry revealed similarities between them (Figures 4 and 5). Both sectors predominantly relied on natural gas, fossil fuels and electricity derived from non-renewable sources. These three energies accounted for more than 87% of total energy consumption in those sectors. Note that coal and related products gradually lose their importance over time, and represent an increasingly smaller share in total energy consumption. Note also that although the share of renewable energies grows in those sectors, it remains relatively small. In the sector in charge of supplying goods and services to the food industry, the share of petroleum products increased by ca. 6 percentage points, from 23.5% to 29.3% (Figure 5).

Agriculture heavily relies on high-emission energy carriers, such as coal and fuels derived from crude oil, which represented a share of 26.8% and 55.8%, respectively, in 2014 (Figure 6) [Strzelecki 2018, Rokicki et al. 2021]. Also, "other energy sources" of that sector are largely based on wood and charcoal. Combined together, these energies had a share of more than 95% in 2014. The next years witnessed an increase in the share of fuels derived from crude oil and a decline in the share of coal. However, the share of these three energies continued to exceed 94% in 2019. First, it shows that agriculture exhibits high levels of energy intensity. Second, it relies on high-emission energies. The above proves that the sector needs immediate improvements through increased investment in the development of and support for low-emission energy sources.

Of all the sectors, the food industry has the largest share in coal consumption (it was still around 32% in 2014) (Figure 7). That value was on a consistent decline over the next years, and reached 24.6%, which continues to be high. The food industry also reports high consumption levels of natural gas and electricity, which may be reflective of it being a production sector. In this context, note that in Poland, energy is mostly derived from coal [Drożdż et al. 2021]. Hence, despite the sector's low levels of energy intensity, more than half of energy it consumes originates from sources with a heavy environmental footprint.

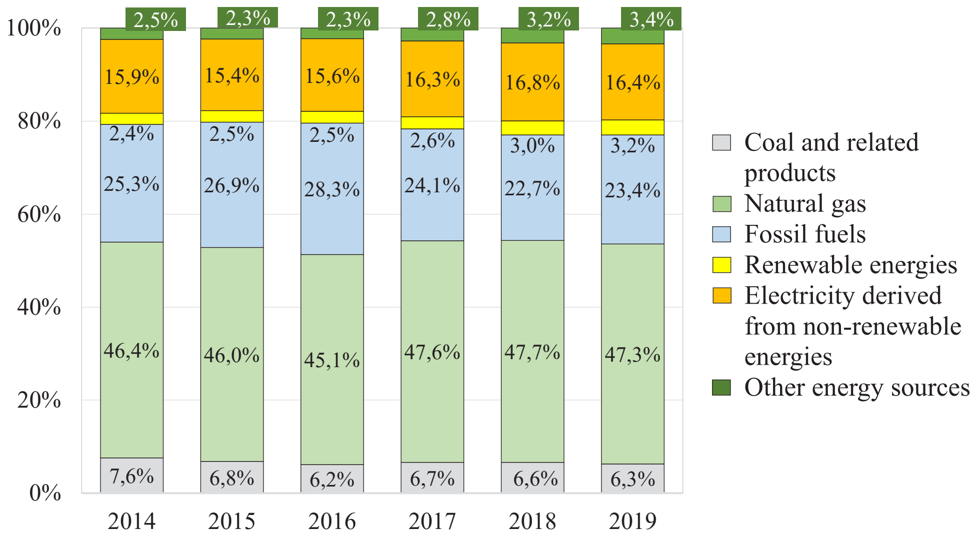

Figure 4. Energy consumption structure in the sector in charge of supplying goods and services to agriculture, grouped by energy source

Source: own calculations based on Eurostat data

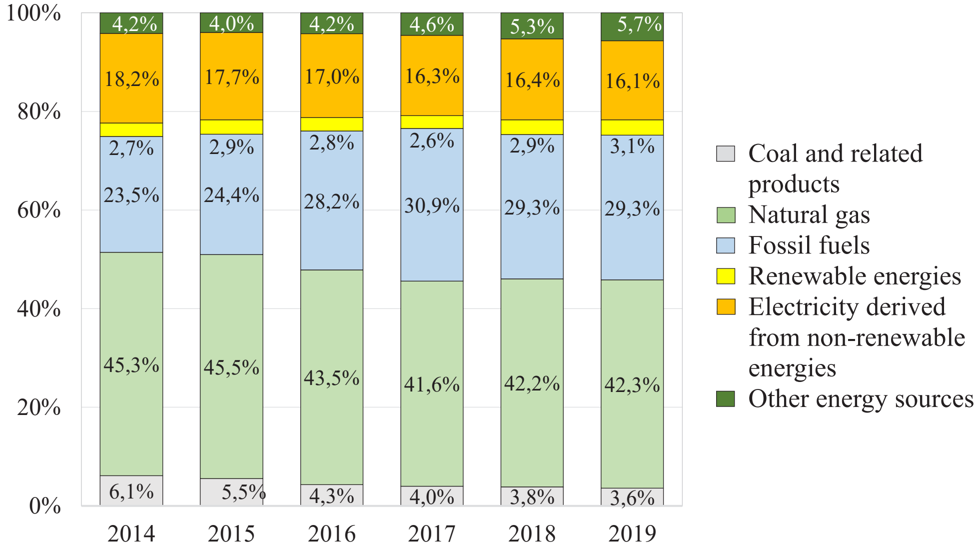

Figure 5. Energy consumption structure in the sector in charge of supplying goods and services to the food industry, grouped by energy source

Source: own calculations based on Eurostat data

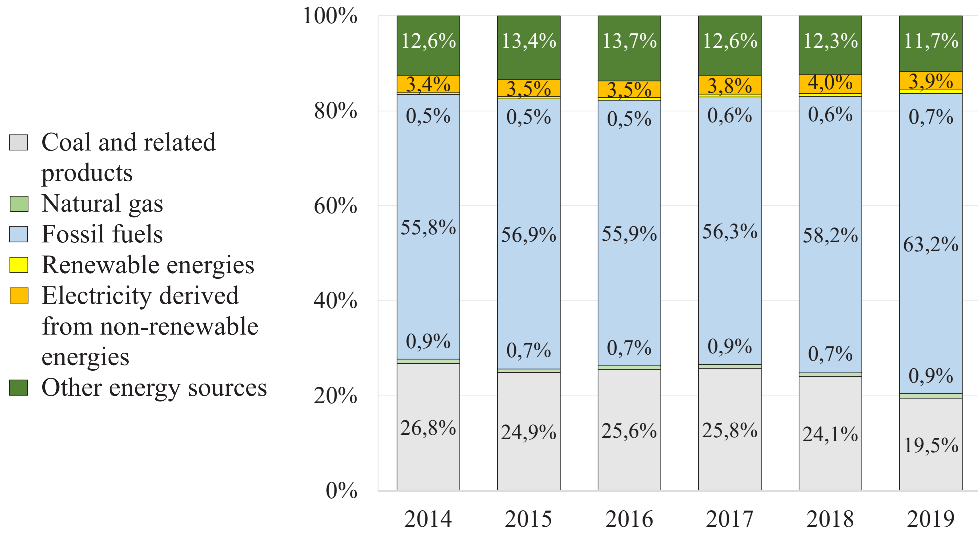

Figure 6. Energy consumption structure in agriculture, grouped by energy source
Source: own calculations based on Eurostat data

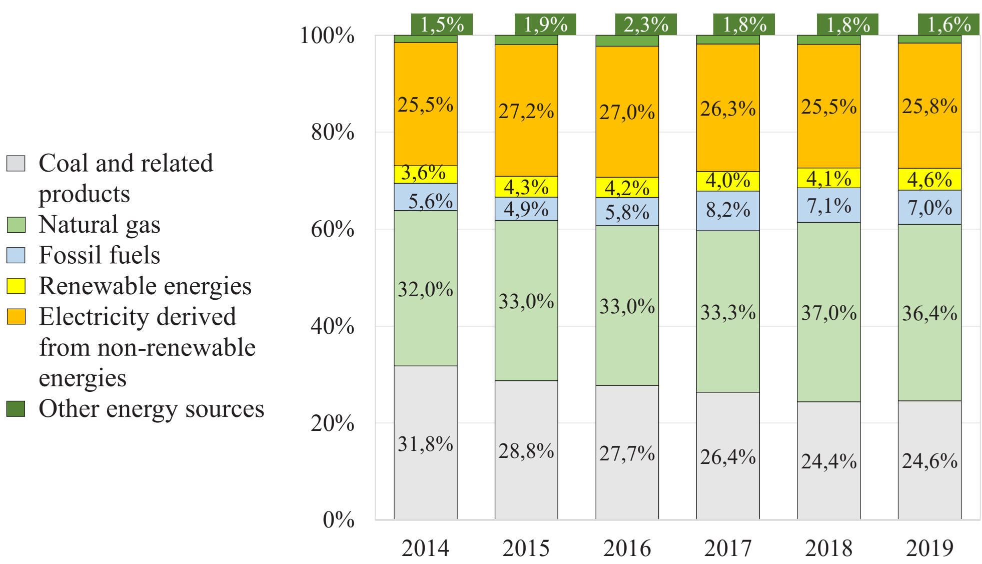

Figure 7. Energy consumption structure in the food industry, grouped by energy source
Source: own calculations based on Eurostat data

CONCLUSIONS

Based on the analyses carried out above, it may be concluded that in the years covered by this study, agriculture and the food sector had a greater share in energy consumption involved in food production than intermediate (supply) sectors. Also, the share of agribusiness in energy consumed in the economy as a whole kept decreasing. These findings reflect the complex relationships between agribusiness, food industry, and total energy consumption in Poland. Analyzing these trends is important for decision-making regarding energy efficiency, and for planning the development of these sectors in a context of sustainable economic development.

Agribusiness consumes large amounts of energy and generates a small GDP which has not been on the rise since 2016. Growth in GDP was witnessed in the food industry and its supply sector (by 16.5% and 15.0%, respectively). In turn, agriculture and its supply sector reported a decline by 3.5% and 2.8%, respectively. Fluctuations is these values mostly result from agriculture being vulnerable to changing weather conditions.

The study found a positive correlation between energy consumption and GDP levels. An increase in energy consumption led to growth in GDP, whereas a drop in consumption entailed a decline in GDP. One unit of energy was found to contribute EUR 0.3 million to growth in GDP of the economy as a whole; ca. EUR 0.17 million to growth in GDP of the agribusiness; and EUR 2.3 million to growth in GDP of the agricultural sector. However, the sector in charge of supplying goods and services to agriculture also witnessed a decline in energy consumption but had a positive contribution (of EUR 0.07 million) to growth in GDP. Note that the case of the sector in charge of supplying goods and services to agriculture shows there is potential for growing the economy while reducing energy consumption. To do that, it is necessary to deploy innovative technologies and energy-efficient machinery and equipment, optimize production processes, and make an informed use of energy.

Changing the economic model is also an important aspect of decoupling economic growth from energy consumption. Using circular economy as a basis – which promotes an efficient use, recovery and recycling of resources – is a way to reduce energy consumption and pollutant atmospheric emissions.

However, the implementation of these measures requires collaboration between the government, industries, scientists and the society. The government may provide incentives for investing in renewable energies and low-energy technologies, and regulate the use of energy-intensive ones. The industry should focus on innovations and on the development of efficient technologies. The scientists must continue researching on energy efficiency and renewable energies. The society may contribute to these efforts by making an informed use of energy, promoting renewable energies, and support environmentally-friendly policies.

Decoupling economic growth from energy consumption is not only necessary due to environmental aspects but also provides a future-proof solution for the Polish economy. Implementing these measures is a way to embark on a sustainable growth path which minimizes adverse environmental impacts while contributing to improvements in the quality of living.

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ENERGOCHŁONNOŚĆ SEKTORA ROLNO-ŻYWNOŚCIOWEGO W POLSCE W ŚWIETLE TABEL PRZEPŁYWÓW MIĘDZYGAŁĘZIOWYCH

Słowa kluczowe: agrobiznes, produkcja żywności, zużycie energii, mix energetyczny, bilans przepływów międzygałęziowych

ABSTRAKT. Celem artykułu jest ocena zużycia energii w sektorze agrobiznesu w Polsce z podziałem na sektory rolnictwa, przemysłu spożywczego i ich zaopatrzenia. Do badań użyto metodę input-output, z wykorzystaniem tablic przepływów międzygałęziowych i fizycznych rachunków przepływu energii. Energia odgrywa kluczową rolę we współczesnym społeczeństwie, wpływając na wzrost gospodarczy, standard życia, a także jest źródłem konfliktów na arenie międzynarodowej, które wynikają głównie z jej ograniczonych źródeł. Agrobiznes jest sektorem charakteryzującym się szczególnie wysokim zużyciem energii w porównaniu do innych sektorów gospodarki. Rolnictwo, będące częścią agrobiznesu, wykazuje duży udział w zużyciu energii pochodzącej z paliw ropopochodnych. Przedstawiono zużycie energii w każdym z czterech agregatów agrobiznesu, ich wartość PKB PPS i energochłonność oraz strukturę zużycia energii z podziałem na 6 grup nośników energii. Stwierdzono, że w latach 2014-2019 zużycie energii w agrobiznesie wzrosło o około 9%, przy jednoczesnym wzroście PKB o około 8%. Energochłonność sektora była o połowę wyższa niż średnia energochłonność gospodarki, utrzymując się na poziomie około 5,6 TJ/mln euro PKB PPS. Jedynie przemysł spożywczy wykazywał zbliżoną energetyczną wydajność do gospodarki, a zmniejszenie energochłonności występowało tylko na etapie zaopatrzenia rolnictwa. Zarówno w gospodarce, jak i w sektorze agrobiznesu można zauważyć tendencję do zmniejszenia udziału węgla i jego produktów w miksie energetycznym.

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