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Food Production Security in Times of a Long-Term Energy Shortage Crisis: The Example of Poland

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Abstract: In countries with industrialized agriculture, the contribution of fossil energy equals or exceeds the energy provided to society in food. Poland is one of the countries which, in the absence of its own sufficient oil and gas resources, is forced to import these fossil fuels in order to benefit from modern solutions in the field of food production and distribution. This situation poses a serious threat to food security if there is a prolonged shortage of energy from such sources. Using the example of Poland, the following were identified: the causes and level of agricultural dependence on fossil fuels, energy threats to agriculture and energy source alternative to fossil fuels. The results of these considerations indicate that Poland is not a country that has irretrievably lost its ability to restore its food self-sufficiency in the event of loss of access to external sources of fossil fuels.

Keywords: food security; agriculture; fossil fuels; energy security threats

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1. Introduction

Ensuring food security should be considered one of the main tasks of any modern country. Shortages in this area have, for humanitarian reasons, more serious effects than shortages in other spheres of human activity, with the exception of water supply. The aim of this study is an attempt to identify methods to secure agricultural production in Poland in times of a long-term energy shortage crisis. The rationale for addressing this issue is that agriculture in many developed countries, including Poland, has reached a stage where it may be considered to be engaged in transforming energy input into food. In Poland, almost 80% of this energy is produced from fossil fuels, of which more than half is from liquid fuels [1].

The near-complete dependence of agricultural production in developed countries on supplied energy inputs is demonstrated directly and indirectly by a number of comparative studies [2–7]. The studies indicate that the contribution of fuel energy to agriculture in the said countries is at least twice as high as the value of energy provided to society in food [6,8–10]. The utilisation of this energy allows developed countries to achieve much higher crop yields with significantly less human labour input than in other countries [11,12]. This effect is compounded by specialization of agricultural units and urbanization. On the one hand, such solutions have so far served well for the economic development of countries with relatively easy access to these energy sources, allowing them to shift large labour resources from agriculture to other sectors. On the other hand, modern agriculture has become fully dependent on a constant supply of cheap energy.

The prerequisite for maintaining the current method of management is that the availability of fossil fuels is not threatened and that fuel prices remain low, thus preventing food prices from rising to socially unacceptable levels. This assumption can and should be questioned. Political decisions, armed conflicts, terrorist activity and natural causes can lead to catastrophic disruptions in the supply of fossil fuels and the production of energy carriers.

Furthermore, to sustain food production for the population, modern agriculture additionally needs constant support from:

- industries producing fertilisers and plant protection chemicals, as well as agricultural machinery and vehicles;
- distribution system for fertilisers and plant protection chemicals, animal feed, fuel and agricultural products;
- service infrastructure for agricultural machinery and vehicles for transporting agricultural and food products;
- the availability of artificial fertilisers.

The above issues, although important, are not the subject of this article. The article focuses on securing agricultural production during a long-term energy shortage leading to the largest energy demand in the food system [13].

As the source literature lacks publications that directly address the issue of securing food production in times of a long-term energy shortage crisis, it was decided to explore this topic. The studies with the most similar subject matter focus on quantifying energy consumption in agriculture, indicating changes in the consumption, the types of energy consumed, and proposed actions aimed at reducing the level of energy consumption in food production [3,14–17]. Studies examining categories of energy consumption for agriculture and food security in the context of: climate change [18,19] greenhouse gas emissions [20], and prices of energy resources and carriers [21] and social feelings [22] are represented as well. During the twentieth century, the world's population tripled, and growing agricultural productivity allowed not only meeting the increased demand for food of the larger population, but also increasing per capita consumption [23]. Therefore, the analysis of the dependence of food production on fossil energy has become an important subject of research, including broad historical and technological contexts [10,15,24,25].

2. Evolution of Polish Agriculture as an Example of the Consequences of Using Fossil Fuel Energy

Providing an appropriate analytical perspective, the past decades demonstrate that the realities of Polish agriculture have been changing systematically and at a rapid pace. The year 1950 may be taken as a reference point. After World War II, the resource-rich Silesian lands and the former eastern districts of Germany, which were their agricultural base, were incorporated into the Polish economic system.

The turn of the 1940s and 1950s saw the completion of the initial reconstruction of the country after war damage, the deceleration of settlement and migration processes resulting from border shifts, and the formulation of new objectives for the state's economic policy. The agrarian reforms carried out in the first years after World War II led to a significant fragmentation of Polish agriculture. In 1950, the average farm covered 5 hectares, and over the next 70 years its size changed only to a certain extent. In 2019, the average size of a Polish farm increased to 10.4 ha, one of the lowest rates in Europe. The average size of farms in the EU is 15.2 ha, and among countries with more than 1 million ha of acreage, only Romania and Greece have a lower sizes due to their mountainous topography [26].

The Six-Year Plan [27], which was launched on 1 January 1950, and then all subsequent economic plans until the end of the 1980s, were based primarily on the intention to use the enormous coal reserves as a foundation for the power industry and to establish central economic control, which would be also imposed on agriculture. The distribution of means of production, including energy and capital for farmers, the organisation of crop trading, partly also the ownership structure in the countryside, and even building the labour supply, depended on the orders of political decision-makers.

One of the effects of these assumptions was the complete dependence of agriculture on the only source of energy, which was coal, initially hard coal and later lignite. From the 1960s, the Konin and Turoszów coalfields, and from the 1980s the Bełchatów coalfields were exploited. Attempts made since the middle of the 20th century to obtain energy for agriculture from other sources, such as peat [28–30], had little success.

An additional factor preserving the dependence of the Polish countryside on energy obtained from coal was the consequences of Poland's participation in international trade, which was limited primarily to the countries in the Soviet sphere of influence. Due to the economic specialisation imposed on Poland by the Comecon, the exploitation and increasing the availability of coal resources solidified the orientation towards this mineral as an almost exclusive source of energy not only for industry and transport, but also for agriculture [31]. This was reflected in the guidelines for the preparation of a prospective economic development plan for 1961–1980 adopted by the Comecon in July 1960, supervised by the Soviet Gosplan, and finally approved by the 22nd Congress of the CPSU in October 1961 [32]. The status of a coal potentate in Europe with a relatively low price of this resource (determined by political decision-makers) implied domination of coal as the key energy source, without seeking other solutions.

As a result, food production has become dependent on mineral resources management, and the belief that there is no alternative to this state of affairs has become entrenched in the mentality of Polish society. To this day, this is one of the main constraints on the use of technologies based on other energy sources.

Considering the above, the changes that took place in food production in Poland in the past seventy years were based on the assumption, indicated at the beginning, of permanent and easy access to cheap energy based on fossil fuels. Under these conditions, technical production methods changed radically and, as a result the productivity and labour efficiency, increased several times. Crops were given mineral fertilisers and chemical protection, and machinery has almost completely replaced draught animal power (Table 1) [33].

Table 1. Comparison of main technical indicators of Polish agriculture in 1950 and 2019.

Details	1950	2019
wheat yields q/ha	12.3	43.9
number of horses per 100 ha	12.2	0.13
number of tractors per 100 ha	0.14	10.3
nitrogen fertiliser consumption kg/ha	6.2	67.7

Source: Own study based on [34–38].

In spite of the fact that the cost of mechanisation in the total outlays on crop production, depending on the kind of crop, ranges from 39.0 to 57.6% [39], the prices of fossil fuel energy in the last 70 years made such a solution significantly cheaper than any other available to Polish producers. The most demanding energy activities in the entire food production and distribution system include:

- production of mineral fertilisers, plant protection chemicals and machinery used for food production;
- mechanical field work;
- transport of agricultural and food products;
- industrial food processing (mills, slaughterhouses, food preservation and packaging).

A comparative reference to 1950s is also justified because 1950 was the first year in the post-war history of Poland with a surplus of exports of agricultural and food products over imports [40], which in view of the abandonment of food rationing on the domestic market and the suspension in 1948 of significant food aid obtained by Poland from abroad, [41] can be seen in simplified terms, in the authors view, as the time the country achieved complete food self-sufficiency. The reintroduction of obligatory crop supplies in 1952 [42–44] resulted from an improper agricultural policy rather than from objective limitations to the productivity of Polish agriculture. These obligations were not abolished until 1971 [45].

Between 1950 and 2019, the agricultural population, aggregated by main means of livelihood, decreased eightfold in Poland [24,34,46], and agricultural productivity, measured in tons, both for crops and livestock production, increased threefold during this period (Table 2). In 1950, 11.3 million tons of cereals and 36.5 million tons of potatoes were produced, which were mainly used as fodder. Nowadays in Poland about 30 million tons of cereals are produced annually, out of which 27 million tons are used for internal needs, including approx. 16 million tons for fodder, 1.3 million for seeds and approx. 4.5 million tons for food consumption. In the past decade, the average annual potato production in Poland averaged 8 million tons with a downward trend [24].

Table 2. Comparison of main production indicators of Polish agriculture in 1950 and 2019.

Details	1950	2019
population earning their living off agriculture (in percent)	47.1	14.8
agricultural crop production cereals (in thousands of tons)	11.3	29
agricultural crop production potatoes (in thousands of tons)	36.5	6.5
agricultural production animals (in millions of tons in post slaughter warm weight)	1.63	5.48
agricultural area (in millions of ha)	20.4	14.69

Source: Own study based on [34–38].

As of 2019, the total agricultural area, i.e., sown land, fallow land, orchards, kitchen gardens, meadows and pastures, was 14.689 million ha in Poland. The increase in the productivity of arable crops resulted in a 27.5% reduction in sown land compared to 1950 (Table 3), which, in turn, allowed the forest area to increase from 6.8 to 9.2 million ha [34].

Table 3. Area of the main sown land in Poland in the years 1950 and 2019.

Years	Total	Main Cereals	Grain Maize	Potatoes	Other, Including Fodder Crops, Industrial Crops and Vegetables
Sown areas in thousand ha					
1950	15,010.00	9092.70	4	2615.90	3297.40
2019	10,897.70	6200.79	665	291	3820.80
Percentage share of sown area					
1950	100	60.6	0	17.4	22
2019	100	56.9	6.1	2.8	34.2

Source: Own study based on [34,35,46,47].

3. Energy Crisis as a Fundamental Threat to National Food Security

An energy crisis leads to severe reduction in energy access for end-users, threatening human life, health, property and the environment. This crisis can occur suddenly or build up gradually and be caused by human or natural factors or by disruptions to both the generation, processing and supply of energy.

Sudden events that can lead to an energy crisis include interruption of energy supplies from domestic and foreign producers as a result of blocked transport routes or failure of transport systems, including damage to or destruction of transport systems. Disruptive intentional acts that could cause physical damage to energy infrastructure include cyber and physical attacks of a military or terrorist nature. Cyberattacks may be carried out using information systems and may affect information systems and occur in cyberspace. Software and data transmission vulnerabilities and computer sabotage are used to carry out attacks. It should be noted that until 2007–2010, the risk of a successful cyberattack on key industrial and energy infrastructure was only considered in theory due to the best available commercial security measures in place. The perception of this threat changed for the first time with the attack on Estonia's state security infrastructure in 2007, and then with the attack on Iran's nuclear programme by US forces. The algorithms used at the time broke through the enhanced security of the uranium enrichment facility, setting a precedent that raised awareness of the reality of threats from professional cyber warfare teams. Experts believe that the IT weapons used by the secret services and armies of countries such as the US, Russia and China surpass commercial security measures by several levels [48].

Natural causes of energy crises include catastrophic large-scale floods and fires, tornadoes, earthquakes and weather phenomena on a global scale such as geomagnetic storms caused by coronal mass ejections [49]. The processes that may result in an energy crisis include depletion of energy carrier sources and power plant capacity, as well as progressive degradation of the mining and transmission infrastructure.

The presented causes of an energy crisis should be inspected by the state, which under the programme for the protection of the crucial elements of infrastructure, the so-called critical infrastructure, is currently obliged to have procedures in place for monitoring and counteracting threats and limiting and mitigating their possible consequences.

Due to their very nature, the timing and scale of sudden events are difficult or even impossible to predict [50]. The assessment of such threats to Polish critical infrastructure, published in 2013 (the most up-to-date) by the Government Security Centre [51], indicates that the occurrence of sudden, catastrophic crisis situations in the Polish energy sector, due to natural, military, terrorist or political causes, is unlikely. As regards crude oil and natural gas supplies, Poland is most at risk of supply disruptions from the east. Events of this type have occurred several times since 1990, but never on a scale that would pose a real threat to national energy security. In each case, the shortfall was compensated by Poland's 90-day emergency stocks of crude oil, fuel or liquid gas and 30-day mandatory stocks of natural gas. In recent years, Poland's energy security has been additionally strengthened by the diversification of gas supplies, and from 2022 by the announced abandonment of supplies from the Russian Federation [52].

Damage to electricity transmission infrastructure due to weather is considered to be potentially the greatest national threat in this respect, as only 30% of electricity grids in Poland are located underground. Eliminating the threat in question would involve increasing this percentage to 50%, which would mean transferring approx. 150,000 km of currently operated overhead transmission lines into the ground. It should be mentioned that half of the power grid in Poland is over 40 years old (70% of the remaining lines will also reach this age within a decade), and their average wear level exceeds 80% [53].

With regard to the processes that may result in an energy crisis, a potential threat should be primarily associated with the fact that the energy resources on the Polish market are essentially in short supply. The exception is lignite, which produces 30% of the electricity consumed in Poland (Table 4).

Table 4. Electricity production in Poland in 2017–2019 by generation source.

Details	Electricity in GWh 2017	2018	2019
Total electricity production	165,852	165,214	158,767
coal-fired power plants	79,868	82,375	78,190
lignite-fired power plants	51,983	49,072	41,502
natural gas power plants	7172	9590	12,099
industrial power plants	10,057	10,022	10,178
main activity producer hydro-electric power plants	2767	2197	2456
wind sources	13,855	11,678	13,903
other renewable sources	150	280	441
Balance of energy foreign exchange	2287	5718	10,624
Domestic energy consumption	168,139	170,932	169,391
Production of electricity from renewable energy sources, excluding the production of pumped-storage power plants *	16,298	13,681	16,094

* Pumped-storage power plants are used to store electricity by converting it into the gravitational energy of water. Source: Own study based on [54].

Despite the fact that the domestic demand for lignite is fully satisfied, according to the Polish Geological Institute, Polish industrial lignite resources (technically and economically viable for extraction while complying with legal requirements, including those concerning environmental protection), based on 2019 extraction levels, are sufficient for only 19 years [55].

Nearly 50% of the domestic energy demand in Poland is satisfied by hard coal combustion. For economic reasons, domestic extraction of this resource, both for domestic consumption and for export, has been gradually reduced since the 1990s. For example, in 2019, domestic production of 61.6 million tons was supplemented by imports of 16.7 million tons, including 10.74 million tons from the Russian Federation. Imported coal, which is cheaper and has better quality parameters than domestic coal, is used mainly in households and local heating plants.

The actual coal consumption in Poland in 2019 was 68.8 million tons, as 4.4 million tons were exported and the rest stored. Domestic coal consumption included, inter alia, the production of coke and semicoke, 6.2 million tons of which were exported from Poland in 2019 [56]. In the event of losing access to imported hard coal, considering the 2019 consumption level, Polish mines would be able to fully satisfy domestic demand for this resource for nearly six decades, exploiting industrial developed deposits, and for ten years longer with respect to industrial undeveloped deposits [57]. However, the political consensus achieved in 2020 by the Polish government and trade unions assumes that the last coal mine in Poland will be decommissioned by 2049.

As regards crude oil, its processing and consumption in Poland is almost entirely based on imported resources and products. In 2019, crude oil imports to Poland amounted to 26.6 million tons, which accounted for 98.3% of domestic demand. Most crude oil (61.5% in 2019) is imported from the Russian Federation [58]. In the event of a disruption in crude oil supplies from the Russian Federation, it could, theoretically, be fully supplied to Polish refineries by sea via the Gdańsk oil terminal whose handling capacity exceeds 35 million tons [54]. The largest customer for products obtained from processing crude oil is the transport industry, which in Poland, as in other industrialised countries, consumes more than a half of this volume [59].

Domestic production of natural gas in Poland meets the fourth part of the total demand of the national economy. Industrial domestic deposits are estimated to have a 14-year life, based on 2019 exploitation levels. For technological reasons, the annual level of domestic gas production may be boosted to a very limited extent [54,55]. The vast majority of natural gas (76.6% in 2019) is imported to Poland through the Russian pipeline system from the territories of the Russian Federation and Central Asia. The remaining imports are carried out through western and southern pipelines and by sea through the terminal in Świnoujście. Gas supplied by sea (in liquefied form—LNG) comes from Qatar, the USA and Norway [60].

In 2018, an estimate of the size of global oil reserves, assuming a projected average annual production growth rate of 1.4%, indicated that global production needs could be satisfied for 48 years [61]. Similarly, the identified and exploitable natural gas reserves, with an average annual production growth of 1.9%, should satisfy the world's production needs for 54 years [62]. The global consumption of crude oil and natural gas, examined over several dozens of years, indicates that the fluctuations of their prices, reaching even several hundred percent, reported in various periods, have not been able to disturb the systematic growth of demand for these resources [63–66]. Therefore, it may be assumed that the conversion of these fossil fuels into food was also carried out in the analysed period under conditions of widespread availability and accessibility (cheapness) of the energy obtained from these fuels.

It should be stressed that in the 21st century, enough food is produced in the world to feed 10 billion people, despite the fact that more than half of the best arable land is used to graze animals raised for meat, as well as for plantations of crops with little or no nutritional value such as agave, tea, cocoa, cotton, tobacco, or oils for biofuel production. In most highly industrialised countries, between 30 and 40% of the food produced or purchased is wasted. The cost of the waste is undoubtedly the greatest inefficiency in the global food system. On the other hand, nearly one billion people experience hunger or malnutrition. It is not economically viable to produce food for people whose earnings are less than one dollar a day [67].

Poland, with a nominal GDP per capita exceeding USD 15,000, and comprehensive social support systems, provides its citizens with universal access to affordable food [68]. It should be stressed, however, that relying on hard coal and lignite as the basic resources of the electricity sector, Poland may maintain a relatively high rate of energy self-sufficiency for no more than a decade or so. As indicated, it is a country dependent on both natural gas and oil imports.

According to the European Commission's plans, by 2050 at least 80% of electricity in the European Union should come from renewable sources. Poland is unable and, according to statements by the Polish government, does not intend to meet the minimum 15% target for renewable energy sources (RES) in final energy consumption for at least several years [69]. Among EU countries with a similar level of wealth to Poland, Lithuania (25.84%), Estonia (29.21%), Croatia (27.29%) and Romania (24.7%) already achieved this goal in 2017 [70]. In percentage terms (data from Table 4), renewable energy generation (excluding the production of pumped-storage power plants) in Poland in 2017, 2018 and 2019 was 9.8% and 8.3% and 10.1% respectively.

4. Discussion

Food production and distribution entail considerable energy consumption and high vulnerability to reduced energy access. Moreover, energy shortages in this area have more serious consequences than shortages in other spheres of human activity, with the exception of water supply. Possible energy deficits resulting from the essential energy needs in food production and distribution mentioned at the beginning of this paper may be compensated by acquiring new energy sources and/or reducing energy demand. Among the energy sources used today, i.e., fissile materials, wind, biomass and biogas, geothermal waters and solar radiation, as well as waves of sea currents and tides, for objective reasons, only the first three sources may be taken into consideration on a scale providing actual support to food production and distribution in Poland.

Energy deficiency may be selective or comprehensive. In the former case, the greatest challenge is to obtain the equivalent of petroleum-based fuels used for powering agricultural machinery. The average annual estimated consumption of diesel fuel in Polish agriculture was 1.88 billion litres in 2010–2015, accounting for a five percent share of diesel fuel consumption in Poland [71]. The most obvious alternative to diesel seems to be biofuel derived from oilseed plants [72]. In Europe, the weighted average (relative to crop types) amount of fuel obtained per hectare is approx. 1230 litres [73]. Assuming that the annual diesel demand of Polish agriculture is fully satisfied by biofuels, this would require 1.53 million ha of land to be cultivated for this purpose, which would account for 14.1% of the total sown area in 2019.

Replacement of agricultural vehicles powered by combustion engines with electrical vehicles may be considered as an alternative solution to biofuels, which, in the long run, may compensate for the shortage of oil-based fuels used in agricultural production. Such machines are produced by several manufacturers, mainly from the USA and China. Assuming an average calorific value of 10,950 kcal per litre of diesel [74], powering electric vehicles that would substitute diesel vehicles currently in use would require an additional 9968 GWh of electricity to be generated in Poland each year, i.e., generating 6.3% more electricity than in 2019. The above calculation is based on the estimates of the Office of Energy Efficiency & Renewable Energy of the U.S. Department of Energy [75] indicating that an electric vehicle converts about 60% of the electricity supplied by the power grid into the so-called “power at the wheels”. Diesel-powered vehicles, which by far prevail in Polish agriculture, convert up to 25% of the energy of the fuel consumed into power at the wheels [76], which means that the energy efficiency of electric vehicles is at least 2.4 times higher than that of diesel-powered vehicles.

The amount of power calculated based on the above relationship, which corresponds to the annual operation of diesel engines transferred to the wheels fueled by 1.88 billion litres of diesel, could be produced by 1160 wind turbines if it is assumed that the average amount of power produced annually by a wind turbine in Poland is 8.6 GWh [77].

As regards the long-term comprehensive energy shortages in food production and distribution, it should be stressed that a significant reduction in the current high level of labour mechanization, and failure to prepare agriculture for such conditions, for the majority of the population would mean a return to a lifestyle marked by exhausting manual labour and impoverishment. The sheer inability to enhance crop productivity by mineral fertilisers and chemical herbicides would undoubtedly be an obstacle to achieving adequate levels of agricultural production. The yield of modern crop varieties can be halved in such conditions [78] and, at the same time, require increased labour inputs, as shown by comparative studies conducted on organic farms [79]. The increase in labour input would be 10% for cereals, between 20% and 40% for potato and between 30% and 80% for vegetables.

However, the main constraint on agricultural production, when motor vehicles are not available for long periods of time, is the lack of alternative tractive power available today, which in the 1950s was provided by horses. The population of these animals in Poland has decreased from 2.8 million in 1950 to 271 thousand in 2019, of which 131 thousand are so-called coldbloods, i.e., horses for farming and slaughter purposes, 94 thousand are noble horses, and the remaining 46 thousand are ponies. In 2019, only 15,000 horses in Poland were used seasonally or part-time in agriculture and forestry, while the remaining cold-blooded horses were bred mainly for meat, and almost entirely for export [80].

An example explaining the reason for the decreasing number of farm horses is the comparison of direct costs of ploughing one hectare using horses versus using a medium-sized tractor. In 2020, a kilogram of oats cost in Poland an average of PLN 0.60, and a farm horse consumes approx. 10 kg of oats per day. During a ten-hour working day, approx. 0.5 ha can be ploughed with a pair of horses and a single-furrow plough, so ploughing one hectare in two days would require the purchase of oats for fodder at the cost of PLN 24. A medium power tractor can be used to plough 2.5 ha per day, and with a fuel cost of approx. PLN 5 per litre and a fuel consumption of 15 litres per hectare, the cost of fuel necessary to plough one hectare with a tractor is PLN 75. Assuming, in a simplified manner, that a ploughman and a tractor driver are paid the minimum wage, i.e., PLN 16 per hour (author's estimation based on the minimum wage binding in Poland in 2020), the cost of human labour would amount, in the case of a 20 h horse ploughing, to PLN 320 and would be five times higher than in the case of the labour cost of a tractor driver, who would plough one hectare with a tractor in 4 h. The comparison of the total cost of a ploughman's work and feeding a horse, with the cost of a tractor driver's work and tractor fuel, indicates that farm work with the use of draught animal power is 2.5 times more expensive.

The above reasoning indicates that a significant increase in the number of draught horses, treated as a possible reserve work force in case of a long-term energy crisis, would undoubtedly require systemic aid from the state. In addition, it would be necessary to design and produce tools for the widespread reuse of horses in agriculture. However, knowledge about the use of farm horses is still considerable in European countries [81], and with the application of modern technical achievements in agriculture, and advances in the design and manufacture of machinery, the efficiency of farm horses could be higher than in the past.

5. Conclusions

At present, securing food production by a state is both a very difficult and critically important task. Due to globalisation of production processes and complicated supply chains of both food itself and the means for its production, even in countries with food surpluses the supply of food to a population depends on the appropriate level of energy supplies. In the vast majority of cases, it is produced from fossil sources.

Any permanent or long-term disruption of the continuity of supply may result in energy shortages and, in consequence, disruptions in the production and distribution of food. Due to humanitarian reasons, effects of this threat should be considered more serious than shortages in other spheres of human activity, except for water supply. In this situation, it is the responsibility of countries to attempt to find alternative sources of energy for agricultural production and ways to ensure their citizens access food resources with an adequate level of calorific value. In addition, it should be noted that the globalisation of energy markets makes local energy trading less relevant, thus transforming modern agriculture from local production into national and global activities.

For at least several reasons, contemporary Poland is a good example to analyse possibilities in this respect. As demonstrated in this paper, food production and distribution in Poland entail considerable energy consumption and high vulnerability to reduced energy access. More than 90% of energy is produced from coal, which adds to the severity of the problem given the trend away from the indiscriminate use of this resource.

Additional factors characterising the conditions in Poland are the land ownership structure, tradition and a large food trade surplus. While the last factor mentioned allows only temporary reduction of the risk and its minimisation in the future, the first two offer prospects for building a national food security system.

In this case, small Polish farms have the advantage of being more flexible and quicker to adapt to changed conditions; for example, to replace mechanised means of production by draught animal power or equipment driven by natural power (water mills, windmills, etc.). To this end, it is necessary, at least in part, to restock draught animals (mainly horses) and to utilise them as a driving force in agricultural production.

Moreover, this solution is in line with tradition. Due to the role they have played in history and tradition, horses are held in high regard in Polish society. For centuries the horse was identified with attachment to farming and symbolised the Polish struggle for independence. The Polish cavalry was considered to be one of the best military formations in Europe, a symbol of the struggle for independence in the 19th and 20th centuries, and the last regular cavalry unit was disbanded in 1947. Therefore, it may be expected that in times of a food crisis it would be easier to re-establish horse-drawn farming in Poland than in the case of other countries with an established tradition of mechanised agriculture.

As may be expected, the introduction of devices powered by alternative sources to those commonly used today will be problematic. Agricultural machinery using biofuel, electric or hydrogen energy would require a technologically advanced, and therefore expensive, infrastructure. As regards electric vehicles, it is also necessary to solve the problem of the energy sources used to charge energy carriers, such as batteries or fuel cells, that power these vehicles [82].

The proposed changes in agricultural production would certainly require significant investments and modification of food production methods. However, during severe energy shortages, they could ensure a minimum food supply for the entire Polish population and restore full food self-sufficiency, while in the event of the threat of a long-term energy crisis they could avert a humanitarian crisis.

The solutions discussed in this article are certainly difficult and expensive to implement. Their application would require political will on the part of the government, giving up existing habits, and significant investments. Nevertheless, in the face of a significant threat of a humanitarian crisis resulting from a long-term energy shortage, they deserve serious consideration as a solution for Poland, and a model to use by other countries with agricultural production of a similar type.

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