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Promoting Green Deal Readiness in the Eastern Partnership Countries

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Promoting Green Deal Readiness in the Eastern Partnership Countries (PROGRESS)

State Organization “Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine”

REPORT ON UKRAINE
for Result I

WATER AND SOIL MANAGEMENT, GREENING, DECARBONISATION AND DIGITALISATION IN AGRICULTURE IN THE CONTEXT OF ADAPTATION TO CLIMATE CHANGE

(the study was conducted from January 2025 to December 2025)

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TITLE: ***Report on Ukraine for Result I: Water and soil management, greening, decarbonisation and digitalisation in agriculture in the context of adaptation to climate change***

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Abstract. The report examines Ukraine's progress in implementing the EU Green Deal within the PROGRESS project, focusing on regulatory, technical and technological alignment in agriculture and horticulture. It analyses value chains for apples, raspberries, strawberries and walnuts, emphasising sustainable use of water, soil and energy resources and assessing the impact of full-scale aggression. The study reviews irrigation systems, soil and land-use regulation, environmental practices in horticultural processing, and the integration of renewable energy sources. It also evaluates the digitalisation of Ukrainian agriculture. Based on international and domestic best practices, the report provides recommendations for resource management, irrigation restoration, soil recovery, decarbonisation and digital transformation.

KEYWORDS: EU Green Deal, climate change, sustainable agriculture, water and soil management, renewable energy, horticulture, digitalization, waste management.

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Abbreviations

UAV	Unmanned aerial vehicle
GDP	Gross domestic product
RES	Renewable energy sources
RE	Renewable energy
WFD	Water Framework Directive
GW	Gigawatt
DSTU	State Standard of Ukraine
EU	European Union
TPPS	Total primary energy supply
ICT	Information and communication technologies
IoT	Internet of Things
kW	Kilowatt
CMU	Cabinet of Ministers of Ukraine
hp	Horsepower
MW	Megawatt
mg	Milligram
Ministry of Agrarian Policy	Ministry of Agrarian Policy and Food of Ukraine
Ministry of the Environment	Ministry of Environmental Protection and Natural Resources of Ukraine
m/s	Metres per second
SMEs	Small and medium-sized enterprises
NAAS	National Academy of Agrarian Sciences of Ukraine
NCP	National Contact Point
NKREKP	National Commission for State Regulation in the Energy and Utilities Sectors
NUBIP	National University of Life and Environmental Sciences of Ukraine
UN	United Nations
GHG	Greenhouse gases
CAP	Common Agricultural Policy
Ltd	Limited liability company
UCAB	Ukrainian Agribusiness Club
FAO	Food and Agriculture Organisation of the United Nations
UN SDGs	United Nations Sustainable Development Goals
AECC	Agri-Environment-Climate Commitments
AGRIWATER	Innovative and Sustainable Measures for Water Retention in the Agricultural Landscape
AKIS	Agricultural Knowledge and Innovation System
BAS ERP	Business Automation Software: Enterprise Resource Planning
BCNC	Bacterial cellulose nanocrystals
BHA	Butylated hydroxyanisole
BRDO	Better Regulation Delivery Office
CAP	Common Agricultural Policy
CAPEX	Capital Expenditure
CEAP	Circular Economy Action Plan
CFC	Chlorofluorocarbon
CNF	Cellulose Nanofibre
DG AGRI	Directorate-General for Agriculture and Rural Development
EAFRD	European Agricultural Fund for Rural Development
EAGF	European Agricultural Guarantee Fund
EBA	European Business Association
EEA	European Environment Agency
EEIG	European Economic Interest Grouping
EU	European Union
FAME	Fatty Acid Methyl Ester
FAO	Food and Agriculture Organisation
F-gas	Fluorinated greenhouse gases

FMS	Farming Management System
FSDN	Farm Sustainability Data Network
GAEC	Good agricultural and environmental conditions
GelA	Type A gelatin
GPS	Global Positioning System
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
IACS	Integrated administration and control system
IEA	International Energy Agency
IEF	State Organisation “Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine”
IKI	International Climate Initiative
KNO3	KNO_3 - potassium nitrate
KSE	Kyiv School of Economics
LIBS	Laser-induced breakdown spectroscopy
MOF	Metal-organic framework
Mtoe	Million tonnes of oil equivalent
NDVI	Normalised difference vegetation index
NDWI	Normalised Difference Water Index
OECD	Organisation for Economic Co-operation and Development
OPEX	Operating expenses
PFAS	Per- and polyfluoroalkyl substances
pH	Hydrogen ion concentration
PROGRESS	Promoting Green Deal Readiness in the Eastern Partnership Countries
PVA	Polyvinyl alcohol
RDNA4	Fourth Rapid Damage and Needs Assessment
REC Caucasus	Regional Environmental Centre for the Caucasus
RECIEL	Review of European, Comparative & International Environmental Law
RES	Renewable energy sources
SAF	Sustainable Agribusiness Forum
SAP ERP	Systems, Applications and Products Enterprise Resource Planning
SDI	Subsurface drip irrigation
SFE	Supercritical fluid extraction
SMR	System of Mandatory Requirements
SMR	Statutory Management Requirements
SMRD	Soil Monitoring and Resilience Directive
SODIS	Solar Water Disinfection
TRACES	Trade Control and Expert System
UAE	Ultrasound-assisted extraction
UNIDO	United Nations Industrial Development Organisation
USAID	United States Agency for International Development
WFD	Water Framework Directive
WINWIN	Ukraine’s Digital Innovation Development Strategy to 2030

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SUMMARY

This report focuses on the implementation in Ukraine of the provisions and requirements of the EU Green Deal, which was implemented as part of the PROGRESS project. During the project, regulatory, legal, technical and technological issues relating to the implementation of the Green Deal provisions were examined, and value chains regarding adaptation to global warming and climate change were analysed. The study paid particular attention to horticulture, specifically the cultivation and processing of apples, raspberries, garden strawberries and walnuts. It summarised the current regulatory framework, the current state of affairs and best practices regarding the use of water, land and energy resources. The impact of full-scale aggression on the availability and level of use of water, land and energy resources in agriculture and horticulture has been analysed.

The current state of irrigation systems in Ukraine and the EU, the existing regulatory framework, and current practices for the regulation and use of water resources in agriculture have been investigated. Best practices in the management, regulation, and use of water resources, as well as strategies for their development in Ukraine, the EU, and other countries, have been summarised. A comparative analysis of Ukraine’s current regulatory framework with EU legislation has been carried out, and directions for their further harmonisation have been identified. Modern innovative methods of water treatment, as well as modern irrigation technologies and approaches to the efficient (minimal) use of water resources, have been examined.

The current state of land use in Ukraine and the EU has been investigated. A review and comparative analysis of regulatory acts on land in Ukraine and the European Union has been carried out, and directions for their further harmonisation have been identified. EU strategies for soil management and improvement have been examined. Best practices in land resource use within the EU and innovative methods of managing them in the context of global warming and climate change have been summarised.

Best environmental practices for the processing of horticultural products and waste management in EU countries and other countries around the world have been analysed. Particular attention is paid to innovative water-use technologies during processing, the introduction of eco-friendly packaging, the transition to eco-friendly refrigerants, as well as modern methods of utilising waste from the cultivation and processing of fruit and berries.

A separate section is devoted to the introduction of renewable energy sources (RES) into crop cultivation and processing technologies as a key area of decarbonisation within the framework of the Green Deal. The current state of solar, wind and bioenergy use in agriculture in Ukraine, the EU and other countries has been examined. Best practices in the use of RES in agriculture have been summarised and a comparative analysis of innovative technologies has been carried out.

The final section of the report is devoted to the challenges of digitalising Ukrainian agriculture, with a focus on horticulture. An analysis has been conducted of the regulatory and legal acts governing digitalisation in agriculture, as well as the information and educational infrastructure required for digitalisation. The experience of using digital tools and products to support and assist farmers in the EU has been summarised, and innovative agricultural technologies and agribusiness management methods that utilise digital devices and technologies have been examined.

Based on the analysis of the current regulatory framework, the study of international experience and the synthesis of domestic best practices, recommendations have been formulated regarding: 1) improving the management of water and land resources through changes to legislation and current practices; 2) the restoration and development of irrigation systems on an innovative, environmentally friendly basis; 3) measures for soil restoration following military operations; 4) the transition to adaptive and environmentally friendly processing practices; 5) the introduction of renewable energy sources into technological processes; 6) the expansion of digitalisation in crop production processes;7) raising farmers' awareness of the use of digital technologies.

1 LEGAL FRAMEWORK FOR THE USE OF WATER RESOURCES IN AGRICULTURE: CLIMATE CHANG AND FRUIT AND BERRY GROWING

1.1 The state of irrigation in agriculture in Ukraine and the EU

Irrigation plays a key role in agriculture, especially in water-scarce regions, given climate change and uneven rainfall. It increases crop productivity and thus contributes significantly to increased agricultural production and food supply. At the same time, irrigation is a significant factor in water abstraction. Agriculture accounts for a significant share of water abstraction and consumption in the EU and Ukraine. High water abstraction can lead to environmental problems, in particular, problems with availability arising during certain periods. In addition to problems with access to water for agriculture and other consumers, there are risks of soil salinisation due to irrigation with groundwater.

Water abstraction volumes for agricultural production depend on the following factors: the type of crops grown (examples of water-intensive crops are potatoes, grain maize, rice, fruit), the area under irrigation, irrigation technology, water prices, water supply restrictions, pumping equipment costs and climatic conditions. Agricultural producers may choose crops that require more water during the growing season or have growth periods that are more sensitive to soil moisture stress. Due to these factors, irrigated areas may vary, and the indicator of irrigated areas is more appropriate than the total area equipped for irrigation to reflect trends in irrigation.

Water supply in Ukraine and the EU. In conditions of moisture deficiency, frequent droughts, and soil degradation, the country's ability to maintain and develop irrigation systems is critical for food security. The most important factor in the functioning of irrigation systems is water supply. Freshwater resources per capita are considered an important indicator for measuring the sustainability of water resources. Ukraine is one of the least water-rich countries in Europe. In 2022, this indicator in Ukraine was 1.3 thousand cubic metres [1]. For EU countries, average water resources are about 8-9 thousand cubic metres per capita. In water-rich European countries, the amount of water per capita can reach 67.2 thousand cubic metres in Norway, about 30 thousand cubic metres in Croatia, 25 thousand cubic metres in Serbia, or 19.7 in Finland. According to the United Nations World Water Development Report, a country experiences water stress when its annual water resources are less than 1.7 thousand cubic metres per capita[2] ; among EU countries, this applies to Poland (1.6 thousand cubic metres), the Czech Republic (1.4 thousand cubic metres), Cyprus (0.4 thousand cubic metres) and Malta (0.1 thousand cubic metres)[3] . Thus, Ukraine has one of the lowest levels of water availability per capita in Europe and is fully affected by water stress.

Since the 1990s, the use of fresh water in Ukraine has decreased significantly, and its use for irrigation has decreased even more. In 1990, a total of 24,914 million cubic metres were used in the country, of which 27% was used for irrigation. In 2013, 8,407 million cubic metres were used, of which 21% was used for irrigation, and in 2023, only 3,043 million cubic metres were

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[1] Strategic Environmental Assessment Report. Ministry of Environment Reform Support Team. 2025. Zvit_SEO_OP_Vodnoyistrategiyi.docx

[2] According to the Falkenmark water stress indicator (IWS), the threshold values of total renewable water resources (surface water and groundwater) for the country (m3/year/person) are as follows: water stress — < 1700; water deficit — < 1000; absolute water deficit — < 500.

[3] Water statistics. Water statistics - Statistics Explained - Eurostat

used, of which 6% was used for irrigation. The volume of fresh water used for irrigation decreased from 6,813 million cubic metres in 1990 to 190 million cubic metres in 2023.

In the EU in 2016, 24% of all water abstraction was used for agriculture, mainly for irrigation, with about 6% of agricultural land being irrigated[4] . Currently, in Ukraine, compared to the EU, as mentioned above, agriculture uses a significantly smaller share of all freshwater abstracted (8.4%) and, accordingly, freshwater for irrigation.

Since 2021, there have been some changes in water use in agriculture, including for the cultivation of annual and biennial crops (predominantly cereals and industrial crops). During this time, the use of water resources and the discharge of wastewater in Ukrainian agriculture have significantly decreased (by 70% and 49%, respectively), which is due to Ukraine's loss of territory as a result of the full-scale invasion of the Russian Federation into Ukraine and the occupation of about 20% of its total territory, a reduction in production on irrigated land, and, to a lesser extent, a reduction in water use due to improvements in water use processes and a reduction in technical losses (Table 1.1).

Table 1.1 – Water use in agriculture, million cubic metres

	2021	2022	2023	2024	2024 to 2021, %
Agriculture, hunting and related services					
Taken from natural water bodies	1126	945.1	1323.1	764.9	67
including from underground water bodies, %	4.8	4.7	3.5	6	X
Total fresh water used	1041.9	388.8	256.5	312.8	30
including irrigation, %	92.7	36.3	74.1	78	X
Discharged into surface water bodies of return (waste) water	70.4	154.7	25.4	36	51.2
including contaminated, %	41	9.2	40.7	18.7	X
Reusable, repeated and sequential use	34.7	44.3	44	38	110.1
Cultivation of annual and biennial crops					
Taken from natural water bodies	33	–	208.1	261.0	78
including from underground water bodies, %	9.9	–	12	10	X
Total fresh water used	986.8	–	214.5	268.5	27.2
including irrigation, %	95.7	–	83.8	86.5	X
Discharged into surface water bodies of return (waste) water	63.1	–	19.1	36.0	57.1
including contaminated, %	45.7	–	54.2	18.7	X
Reusable, repeated and sequential use	32.9	–	43	37.9	115.4

Source: State Water Use Accounting. State Agency of Water Resources of Ukraine. https://www.davr.gov.ua/derzhavnij-oblik-vodokoristuvannya

* Information provided only for the type of activity "Agriculture, forestry and fisheries"

Data characterising water use in agriculture indicate a slight reduction in the use of water from underground water bodies (about 8,5%), while total freshwater use has decreased by more than 30% (in 2024 compared to 2021). This negative trend in the use of underground water sources

[4] Sustainable water use in agriculture: CAP funds more likely to promote greater rather than more efficient water use. Special Report. Sustainable water use in EU agriculture

is probably due to the difficulty of accessing other sources, while at the same time creating risks of depletion of these sources and deterioration of irrigated soil. In particular, the EU believes that the installation of new irrigation infrastructure that expands the irrigated area may increase pressure on freshwater resources if the system does not use rainwater or recycled water[5] .

Overall, in 2024, half as much wastewater was discharged into surface water bodies than in 2021 (Table 1.1). One of the factors was a general reduction in water use. At the same time, the volume of polluted wastewater decreased significantly (by 70%). A particularly significant reduction in the discharge of pollutants into water bodies was recorded at the beginning of the war in 2022. This can be explained by both the impact of the war on production activities and the reduction or suspension of environmental inspections, as according to environmentalists, the overall condition of water bodies in Ukraine has not improved[6] . There is a trend towards increased recycling, reuse and sequential use of water, but it is very unstable (compared to 2021, these volumes increased by 10% in 2024).

The use of water for growing field crops is a significant component of agricultural water consumption. In 2021, 95% of all water resources allocated to agriculture were used for irrigation. In 2024, this share decreased to 85.8% due to reduced access to water resources, including that caused by the destruction of the Kakhovka Dam. The situation regarding water use for field crop cultivation is the same as in agriculture in general, but compared to 2021, in 2024, the volume of water recycling, reuse and sequential use increased by 15%.

Irrigation in Ukraine*.* Irrigation is a key factor in the stability of agricultural production in Ukraine, especially in the context of climate change and military challenges. Ukraine has significant potential for the restoration and development of irrigation systems, which can ensure food security, export potential and integration into the EU. Until the 1990s, irrigated land covered 2.2 million hectares and was concentrated mainly in the south – Odesa, Kherson, Mykolaiv, Zaporizhzhia and Crimea. As a rule, irrigation was actually carried out on all these areas.

After the 1990s, irrigation systems began to decline in quantity and efforts to restore them were hampered by a lack of funding and modernisation, poor infrastructure management and high electricity costs. At the same time, both the total area under irrigation and the area actually irrigated were reduced. According to public monitoring of land relations and state accounting of water use, as presented in the Long-Term Plan for the Development of the Irrigation Complex of Ukraine[7] , in 2013, the area of irrigated land was 614 thousand hectares (28% of the total area of irrigated land). After the occupation of the Autonomous Republic of Crimea and part of the territory of Donetsk and Luhansk regions in 2014, the area of irrigated land decreased and, before the start of the full-scale invasion in 2021, amounted to 525 thousand hectares, or 32% of the total area of irrigated land. Due to the full-scale invasion in 2022, the occupation of part of the Kherson and Zaporizhzhia regions, and the destruction of the Kakhovka Reservoir in 2024, only 137,000 hectares (12% of the total irrigated area) were irrigated. As a result, the use of irrigation systems is constantly declining, which increases the risks of agricultural production in the context of climate change.

[5] Evaluation of the impact of the CAP on water. Final report DG AGRI and EEIG Alliance Environnement. DOI 10.2762/63371. Evaluation of the impact of the CAP on water - Publications Office of the EU

[6] Strategic Environmental Assessment Report. Ministry of Environment Reform Support Team. 2025. Zvit_ SEO_ OP_ Vodnoyi- strategiyi. docx

[7] Long-term plan for the development of Ukraine's irrigation complex until 2050. Verkhovna Rada of Ukraine. URL: https://zakon.rada.gov.ua/laws/show/280-2025-%D1%80#Text

The destruction of the Kakhovka Reservoir dam by Russian troops left 94% of irrigation systems in the Kherson region, 74% in the Zaporizhzhia region and 30% in the Dnipropetrovsk region without a source of irrigation for a long time. This, along with the occupation of southern Ukraine and intense military action in these regions, has had a huge impact on water use for irrigation. In 2021, 966 million cubic metres of water were used for irrigation, but in 2022, only 141 million cubic metres were used.

In the pre-war period, out of more than 40 million hectares of agricultural land in Ukraine, 1.7 million hectares were considered theoretically irrigable (compared to 2.2 million hectares in 1990). According to the State Agency for Water Resources, 460,100 hectares were irrigated in 2017 and 511,000 hectares of agricultural land in 2018. As of mid-2019, 492,200 hectares of land were irrigated[8] . According to the conclusion of the Institute of Water Problems and Land Reclamation, at that time, out of 31 million hectares of Ukrainian arable land, about 60% (18.6 million hectares) belonged to areas with a moisture deficit and required constant irrigation, and about 4.8 million hectares of land required periodic irrigation[9] . Currently, under the influence of military actions and climate change, the situation is only getting worse.

The main trends in changes in irrigated areas under field crops are reflected in Table 1.2. The State Statistics Service of Ukraine collects data on both the areas under agricultural crops and those areas that were irrigated. With the start of military operations, reporting until October 2025 was optional, but most enterprises submitted reports on the areas and gross yields of agricultural crops, fruits, berries, and grapes. Therefore, some conclusions can be drawn about production in general and on irrigated land. Compared to 2021, the area under grain crops has significantly decreased and has not yet recovered, while the area under oil crops has remained largely unchanged due to migration of production to the northwest (this process began before the war due to climate change, and the occupation and military actions accelerated it), the area under vegetable crops has significantly decreased by half, but there is a process of gradual recovery by transferring production to the north-west. In Ukraine, potato production (a very water-intensive crop) is concentrated in private farms, but in the pre-war period, enterprises (mainly in the north and west of the country) began to increase production. With the start of hostilities, the area under potatoes decreased by 14% and has not yet recovered.

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[8] Dew point: how to "cure" Ukrainian fields from dehydration (in Russian). Available at: https://latifundist.com/spetsproekt/491-tochka-rosy-kak-vylechit-ukrainskie-polya-ot-obezvozhivaniya

[9] Boyarkina, L., Borovyk, V., Shablya, O., Shariy, V., Bidnina, I. The current state of irrigated agricultural land in Ukraine. *Agrarian Innovations.* 2022. No. 16. Pp. 5–10. DOI: https://doi.org/10.32848/agrar.innov.2022.16.1

Table 1.2 – Harvested area under major crops in Ukrainian agricultural holdings, thousand hectares

	2021		2022		2023		2024	
	Total harvested area	*Share of irrigated area, %*	Total harvested area	*Share of irrigated area, %*	Total harvested area	*Share of irrigated area, %*	Total harvested area	*Share of irrigated area, %*
Cereals and legumes	**11744.9**	***1***	**8417.2**	***0***	**7723.2**	***0.5***	**7997.5**	***0.5***
of which								
wheat	5422.7	*1.2*	3974.9	*0.3*	3498.0	*0.3*	3728.9	*0.3*
corn	4398.2	*2*	3226.1	*0.9*	3070.4	*0.8*	3128.7	*0.7*
Barley	1322.2	*2.8*	839.3	*0.5*	691.4	*0.4*	624.1	*0.5*
Oil crops	**7743.1**	***2***	**7022.6**	***0.4***	**7712.1**	***0.4***	**8210.4**	***0.3***
of which								
soy	1139.5	*7.9*	1353.2	*0.6*	1655.5	*0.4*	2534.5	*0.4*
Winter rapeseed Spring rapeseed	991.1	*3.3*	1148.9	*0.5*	1424.8	*0.4*	1253.0	*0.3*
sunflower	5560.0	*1.1*	4466.8	*0.3*	4495.7	*0.3*	4325.4	*0.3*
Potatoes	19.3	*30.1*	16.6	*19.3*	14.8	*16.9*	15.2	*23.7*
Vegetable crops	**32.9**	***62***	**15.5**	***38.7***	**26**	***44.1***	**27.7**	***56.7***

Source: calculated by the author based on data from the State Statistics Service of Ukraine. https://ukrstat.gov.ua/operativ/operativ2022/sg/pvzu/arch_pvxu_reg.htm

In the pre-war period, the largest share of irrigated land among grain crops was used for growing corn and barley, as well as for oilseeds and soybeans. One-third of all potato fields and 62% of vegetable crops were also irrigated. This reduced the dependence of these crops on weather fluctuations and ensured stable yields over large areas.

In 2022, with the reduction in total harvested area, there was a critical decrease in irrigated areas under major crops. While the area under grain crops decreased by almost 30%, the corresponding irrigated area redused by 75% and has been trending downward in recent years. The area under oilseeds has remained virtually unchanged, but 86% of the irrigated area (in the southern regions) has been lost and has not been restored. Irrigated land under potatoes has decreased by almost halfed, while land under vegetable crops, after a critical reduction of 3.5 times in 2022 compared to 2021, is gradually being restored.

One of the main factors was that significant areas of arable land in the Zaporizhzhia and Kherson regions were occupied, and, accordingly, the area of irrigated land decreased critically. In 2022, only 8.1% and 4.7% of irrigated land remained in production in the Zaporizhzhia and Kherson regions, respectively, in the territory controlled by Ukraine (i.e., no production took place on 80% of all irrigated land in Ukraine). Thus, the main losses in production in these regions were caused by military actions.

The destruction of the Kakhovka Hydroelectric Power Plant by Russian troops further exacerbated the situation, creating long- and medium-term risks for agricultural production, as virtually all irrigated land in the Zaporizhzhia and Kherson regions and more than a third of the Dnipropetrovsk region were located in the area affected by the Kakhovka Reservoir.

Therefore, the main challenges for the irrigation sector include infrastructure losses due to the war, namely the destruction of the Kakhovka Hydroelectric Power Plant and the shutdown of the North Crimean and Kakhovka canals, damage to or occupation of a significant part of the infrastructure in the south, and reduced access to water resources from the Dnipro River. Other important challenges for the sector include the high energy intensity of irrigation, climate change, in particular the increase in the duration of droughts and the reduction in the availability of water resources, as well as poor water quality, which threatens soil salinisation and pollution from wastewater[10].

According to the World Bank's official report "Fourth Rapid Damage and Needs Assessment" (RDNA4), the total cost of damage to Ukraine's irrigation and water resources sector is estimated at US$746.3 million, with agricultural sector losses estimated at US$872.3 million. In particular, the largest losses of profit from irrigated areas were recorded in Donetsk (US$171 million), Zaporizhia (US$168 million) and Sumy (US$157 million) regions. The amount of funds needed to restore this sector is US$10.9 billion[11] .

The state of irrigation in fruit* and berry *growing in Ukraine. Fruit and berry production in Ukraine is a traditional agricultural sector. However, intensifying climate change is reducing the ability to secure stable, guaranteed harvests. In these conditions, modern intensive production of fruit and berry products is not possible without the timely provision of moisture to plantings. In line with global trends in horticulture, there is a transition to the latest technologies based on the formation of plantations mainly on dwarf rootstocks with a significant number of plants per hectare (from 2.5 to 10 thousand pieces), which requires mandatory irrigation with the simultaneous application of nutrients. In other words, according to current trends, horticulture and berry growing must transform into predominantly irrigated farming. In addition, consumer market demands for fruit and berry quality have increased significantly, which depend largely on biogenic factors, including optimal moisture.

As mentioned above, given the shortage of water resources in Ukraine, their optimal use is becoming increasingly important. Therefore, the most effective approach will be to irrigate high-value crops, which include fruits and berries.

In Ukraine, the use of fresh water for growing fruits, berries and nuts accounts for a very small share of total water consumption (0.3% in 2023), and their share in water consumption for irrigation was about 3.5%. Thus, irrigation of fruit and berry crops has a very insignificant impact on water consumption. According to data from the State Agency of Water Resources of Ukraine, wastewater from the cultivation of fruits, berries and nuts is not discharged into surface water bodies, and water is reused in the cultivation of berries (although in 2024 this was reduced by a factor of 10) (Table 1.3).

Table 1.3 – General indicators of water use in horticulture, million cubic metres

[10] Nitrate Pollution of Groundwater in Ukraine. Ekodiya. https://ecoaction.org.ua/nitratne-zabrudn-pidzemn-vod-ukrainy.html?gad_source=1&gad_campaignid=23391644392&gbraid=0AAAAACVR_NQ2YZThDwLRNuSAETax74t0_&gclid=Cj0KCQjwve7NBhC-ARIsALZy9HUGV8q0HXO-NfMJLX9thBZv1GMFf_i-ZmVgW6kMcL8t6e-r-11Dk-caAg2IEALw_wcB

[11] According to Ukraine rapid damage and needs assessment (RDNA4). February 2022 – December 2024. World Bank. https://documents1.worldbank.org/curated/en/099022025114040022/pdf/P180174-ca39eccd-ea67-4bd8-b537-ff73a675a0a8.pdf

	2021	2023	2024	2024 to 2021, %
Cultivation of pome and stone fruits				
Total fresh water used	9.7	5.6	5.8	59
including for irrigation	9.4	5.4	5.6	59
Discharged into surface water bodies of return (waste) water	–	–	–	–
including contaminated	–	–	–	–
Reusable, reusable and sequential use	0.001	–	–	–
Growing berries, nuts, and other fruits				
Total fresh water used	2.7	3.0	3.7	137
including for irrigation	1.8	2	2.8	155.6
Discharged into surface water bodies of return (waste) water	–	–	–	–
including contaminated	–	–	–	–
Reusable, reusable and sequential use	0.067	0.072	0.006	9

Source: State accounting of water use. State Agency of Water Resources of Ukraine. https://www.davr.gov.ua/derzhavnij-oblik-vodokoristuvannya

Military actions have significantly affected the horticulture sector. According to the Ministry of Agrarian Policy, 25% of berry fields and 20% of orchards have been lost as a result of the war[12] . Since 2021, Ukraine has seen a 40% reduction in water use for growing pome and stone fruit crops. Berry farming has proven to be more resilient due to its greater potential for relocation and faster recovery. Therefore, compared to 2021, water consumption for irrigation in berry farming has increased 1.5 times.

Agricultural enterprises are not the main producers of fruit and berry products, but official information on irrigated areas in private households (the main producers of these products) is not collected. Therefore, we can only talk about trends that characterise agricultural enterprises. Official statistics show the gradual development of irrigation systems in horticulture in Ukraine. In 2015, irrigated land in Ukraine under fruit and nut plantations accounted for only 8,000 hectares, under vineyards – 4,700 hectares, and in 2021, the total area of irrigated land under perennial plantations in enterprises already amounted to 18,200 hectares, of which 15,200 hectares were orchards and berry fields, and 3,000 hectares were vineyards. In 2022, as a result of military operations and the occupation of the southern regions, this area decreased to 12,500 hectares, of which orchards and berry fields accounted for 10,900 hectares, and vineyards – 1,600 hectares.

In 2021, the largest areas of perennial plantations, including irrigated ones, in agricultural enterprises were apple orchards. In 2022, the area of apple orchards decreased by 21%, while the irrigated area fell more sharply – by 35% – and has not changed significantly since then. Currently, more than 20% of apple plantations are irrigated.

In the pre-war period, a quarter of the area under pome and stone fruit crops was irrigated, with the largest share of irrigated land under strawberries and wild strawberries (30.8%) (Table 1.4).

Table 1.4 – Area under perennial crops in agricultural holdings in Ukraine, thousand hectares

[12] https://www.vin.gov.ua/images/doc/vin/Dep-APK-2022/Prezentatsia.pdf?utm_source=chatgpt.com

	2021		2022		2023		2024	
	Total area	*Share of irrigated area, %*	Total area	*Share of irrigated area, %*	Area, total	*Share of irrigated area, %*	Area, total	*Share of irrigated area, %*
Fruit and berry crops	**58.4**	***2***	**44.3**	***24.7***	**42.1**	***25.9***	**41.44**	***29.5***
Cereal crops	33.9	*25.4*	26.5	*22.6*	25	*23*	24.6	*22.8*
of which:								
apple tree	32.5	*24.6*	25.6	*20.3*	24.3	*22.2*	23.9	*21.3*
Stone fruits	12.1	*24.8*	6.8	*19*	6	*17.6*	6.5	*26.2*
Berry crops	5.9	*45.8*	5.0	*42.0*	4.8	*52.1*	5	*56.0*
of which								
raspberries and blackberries	1.1	*18.2*	0	*50*	0.7	*57.1*	0.8	*75.0*
Strawberries and wild strawberries	1.3	*30.8*	0.5	*40*	0.7	*57.1*	0.6	*66.7*
Nuts	7.2	*18.1*	6	*24.2*	6.4	*40.6*	5.9	*40.7*
Grapes	**23.5**	***12.8***	**18.5**	***8.6***	**16**	***8.8***	**15.2**	***10.5***

Source: calculated by the author based on data from the State Statistics Service of Ukraine. https://ukrstat.gov.ua/operativ/operativ2022/sg/pvzu/arch_pvxu_reg.htm

In 2022, Ukrainian enterprises lost 22% of their pome fruit plantations, 44% of their stone fruit plantations, and 15% of their berry plantations, of which 27% were raspberries and blackberries, and 62% were strawberries. They also lost 8% of nut plantations and 23% of vineyards. Irrigated plantations were also lost, namely: 30% of pome fruit crops , 57% of stone fruit crops and 22% of berry crops, including 50% of strawberry crops. Almost half of the irrigated areas under vines were also lost. However, during this period, the irrigated areas under strawberries and raspberries doubled, and irrigated nut plantations increased by 23%.

In 2024, compared to the pre-war year, irrigated areas under strawberries and raspberries were fully restored, irrigated raspberry and blackberry plantations tripled, and irrigated nut plantations almost doubled. This indicates that gardeners understand the need for irrigation to obtain stable yields and high-quality products.

Thus, Ukraine's fruit and berry production is increasingly dependent on irrigation, especially in regions with low rainfall [13]. The introduction of modern irrigation systems is not only an economic necessity but also a guarantee of the competitiveness of Ukrainian gardeners in domestic and foreign markets. The main challenges to the spread of irrigation are the high cost of equipment, the lack of water resources, and the need to modernise old infrastructure.

Irrigation in the EU. In the EU, irrigable areas, i.e. areas where irrigation is possible, account for a significant part of agricultural land, but the areas that are actually irrigated are much smaller. In 2016, 9.1% of the agricultural land used in the EU was equipped for irrigation (15.7 million hectares), but only 6% was actually irrigated (10.3 million hectares). The data indicate that no country reported that all irrigable areas were irrigated (Table 1.5).

[13] The Development of Intensive Farming Systems on Irrigated Lands in Ukraine: Scientific and Technological Support: Methodological Recommendations / Edited by Corresponding Member of the National Academy of Agrarian Sciences of Ukraine R.A. Vozhegova. – Kherson: 2020. – 254 c. [in Ukrainian] URL: https://ovoch.com/assets/files/library/methodical/2020/2-mr-rozvitok-intensivnih-sistem_r-2020.pdf

Table 1.5 – Share of irrigable and actually irrigated areas in utilized agricultural areas in 2016, EU-28

Country	Total utilised agricultural area (thousand ha)	Irrigable area		Irrigable area	
		ha	*Share in agricultural land, %*	ha	*Share in agricultural areas, %*
Malta	11	3.7	*32*	3	*31.4*
Greece	4553.8	1352.3	*29.7*	1074.9	*23.6*
Cyprus	111.9	38.1	*34.1*	23.5	*21*
Italy	12,598.2	4113.2	*32.6*	2549.8	*20.2*
Spain	23,229.7	3637.7	*15.7*	3076.7	*13.2*
Portugal	3641.7	548.3	*15*	474.2	*13*
Netherlands	1796.3	522.6	*29.1*	201.4	*11.2*
EU-28	**1732079.9**	**15742.9**	***9.1***	**10311.7**	***6***
Denmark	2614.6	217.8	*8.3*	145.5	*5.6*
France	27,814.2	2690.7	*9.7*	1366.5	*4.9*
Germany	16,715.3	676.4	*4*	451.7	*2.7*
Hungary	4670.6	230.1	*4.9*	121.4	*2.6*
Bulgaria	4468.5	135.9	*3*	92.8	*2.1*
Romania	12,502.6	334.7	*2.7*	240.0	*1.9*
Sweden	3012.7	156.7	*5*	52.4	*1.7*
Slovakia	1889.8	73.6	*3.9*	28.3	*1.5*
Austria	2669.7	99.8	*3.7*	38.2	*1*
United Kingdom	16,673.3	473.7	*2*	171.0	*1*
Croatia	1563.0	29.7	*1.9*	16.1	*1*
Poland	14,405.7	271.0	*1.9*	132.7	*0*
Belgium	1354.2	24.1	*1.8*	10.3	*0*
Czech Republic	3455.4	45.9	*1.3*	25.0	*0.7*
Slovenia	488.4	5.5	*1.1*	3.5	*0*
Finland	2233.1	54.0	*2.4*	7.9	*0.4*
Estonia	995.1	2.7	*0.3*	1.9	*0*
Lithuania	2924.6	4.5	*0.2*	2.1	*0*
Latvia	1930.9	0	*0*	0	*0*
Ireland	4883.6	0	*0*	0	*0*
Luxembourg	:	:	*:*	:	*:*

Source: calculated based on data from Irrigable and irrigated area. Eurostat. DOI: 10.2908/ef_fsi_irri, https://ec.europa.eu/eurostat/databrowser/view/ef_fsi_irri/default/table?lang=en.

Between 2005 and 2016, irrigable areas in EU agricultural regions decreased by 3.5%, and irrigated areas by 6.1%. In 2016, the largest shares of irrigable areas in the EU were in Cyprus (34.1%), Malta (32.9%), Italy (32.6%), Greece (29.7%), the Netherlands (29.1%), Spain (15.7%) and Portugal (15.1%) (Table 1.6).

The share of irrigable and actually irrigated agricultural areas in agricultural land and their area varies greatly between countries, mainly due to the regional climate and the type of production. Full irrigation is necessary for agricultural production in southern European countries. Therefore, Spain and Italy had the largest areas actually irrigated in absolute terms (3.1 million and 2.5 million hectares, respectively) in 2016. However, the largest shares of actually irrigated agricultural land in 2016 (as well as land equipped for irrigation) were in Malta (31.4%), Greece (23.6%), Cyprus (21.0%), Italy (20.2%), Spain (13.2%) and Portugal (13.0%). The share of actually irrigated land was also high in the Netherlands, with11.2%. In Central and Western Europe, irrigation is used as an additional factor to improve crop production during dry summers. The type of agriculture also plays a role. Fruit and vegetables often require irrigation, and horticulture and vegetable growing occupy a major place in the Netherlands.

Droughts, high temperatures and reduced natural precipitation increase the need for irrigation and the pressure on water resources. Although irrigated areas are relatively small, they consume a significant proportion of agricultural water use – for example, in some areas irrigation can account for 80% of agricultural water use12.

Different countries have different levels of equipment, technology and funding. Some regions have outdated irrigation systems that are not very efficient. The main way to improve irrigation efficiency is through smart water use. This includes reducing losses, optimising irrigation and switching to innovative methods13. Significant efficiency improvements are possible because of modern systems. The main irrigation methods in EU agriculture are classic surface (gravity) irrigation, sprinkler irrigation and drip irrigation. Drip and micro-sprinkler irrigation are more efficient in water use but require a greater investment. Table 1.6 shows data on the use of different irrigation methods by EU farms in 2010.

Table 1.6 – Share of farms by main irrigation methods in EU countries, according to 2010 data.

Country	Total number of farms	Share of farms using irrigation methods in agriculture		
		Surface (gravity), %	drip, %	sprinkler, %
Belgium	42,850	0.96	1.28	4.29
Bulgaria	370,490	22.69	0.87	0.65
Czech Republic	22,860	0.57	1.36	2.67
Denmark	41,360	0.00	0.56	12.81
Germany	299,130	0	1.06	4.06
Estonia	19,610	0.00	0.51	0.61
Greece	723,060	20.73	26.19	19.51
Spain	989,800	16.36	20.61	6.50
France	516,100	1.12	3.79	11.69
Croatia	233,280	2.09	2.91	1.31
Italy	1,620,880	8.88	7.02	10.33
Cyprus	38,860	16.19	62.4 0	3.58
Latvia	83,390	0	0.14	0.29
Lithuania	199,910	0.03	0.03	0.02
Hungary	576,810	0.68	0.64	1.99
Malta	12,530	6.94	19.39	10.61
Netherlands	72,320	0.15	0.82	13.45
Austria	150	0.32	0.66	1.29
Poland	1,506,620	0.24	0.27	0.18
Portugal	305,270	32.07	6.95	12.28
Romania	3,859,040	0.20	0.09	0.22
Slovenia	74,650	0.16	0.52	0.32
Slovakia	24,460	0.70	0.25	0.74
Finland	63,870	0	0.92	3.23
Sweden	71,090	0.30	0.45	4.54
United Kingdom	185,200	0.09	0.22	1.16

Source: calculated based on data from Irrigation: number of farms, areas and equipment by size of irrigated area and NUTS 2 region. Eurostat. DOI: 10.2908/ef_poirrig, https://ec.europa.eu/eurostat/databrowser/view/ef_poirrig__custom_18838530/default/table

The most accessible and least efficient irrigation method – surface irrigation – was most widespread in 2010 in Portugal (32.07%), Bulgaria (22.69%), Greece (20.73%), Spain (16.36%), Cyprus (16.19%) and Italy (8.88%). These southern countries with hot climates have a constant need for irrigation to grow crops, but are not among the countries suffering from water stress, so in some regions there is no critical need to conserve water resources.

The use of drip irrigation was most commonly reported by farms in the same southern countries: Cyprus (62.4%), Greece (26.19%), Spain (20.61%), Malta (19.39%), Italy (7.02%) and Portugal (6.95%) (Table 1.6).

Sprinkler irrigation is most common as an additional factor for increasing the sustainability of crop production in southern countries, as well as in north-western European countries: Greece (19.51%), the Netherlands (13.45%), Denmark (12.81%), Portugal (12.28%), France (11.69%), Malta (10.61%) and Italy (10.33%). It should be noted that this irrigation method is also widespread in Sweden and Finland, where 4.5% and 3.2% of farms, respectively, reported its use.

Ukraine should pay attention to irrigation methods in the Czech Republic and Poland, as these countries are closest to Ukraine in terms of water availability and are also among the countries experiencing water stress, it is also necessary to take into account the experience of countries that grow crops that are important for Ukraine. In 2010, the Czech Republic used irrigation very sparingly (0.7% of agricultural land is irrigated), mainly for high-value crops (vegetables, vineyards, horticulture). Sprinkler irrigation was the most widely used, reported by 2.67% of farms, 1.36% reported using drip irrigation and 0.57% reported using surface irrigation. Poland is an important agricultural producer, but irrigation at that time was not widespread (0.9% of agricultural land was irrigated) and traditionally less developed than in Mediterranean countries. Surface irrigation was used by 0.24% of farms, drip irrigation by 0.27% and sprinkler irrigation by 0.18%.

Currently, some EU countries have already provided information on irrigation methods used as of 2023, indicating significant changes in some countries. As of 2023 in comparison to 2010 the area under surface irrigation has decreased significantly in France (by 20%) and halved in Cyprus, while it has tripled in Slovakia, increased 2.5 times in Croatia, and doubled in Romania. In the Netherlands, the area has increased 200-fold, which can be explained by climate change, the need for irrigation that is accessible to the country, or changes in reporting. The Netherlands also significantly reduced the area under sprinkler irrigation (16 times). However, some countries increased the corresponding areas: Romania by 3.5 times, Austria by 2.7 times, Croatia and Germany by almost 1.5 times. The area under drip irrigation has increased almost 6 times in Romania, 4 times in Austria, and 2–2.5 times in Germany, France, the Netherlands, Portugal, and Slovakia.

Therefore, the information on changes remains incomplete, but preliminary data indicate that countries are reviewing their irrigation method preferences. For example, the Netherlands has practically abandoned sprinkler irrigation in favour of surface irrigation (in the absence of water resource problems) and drip irrigation. Therefore, the exploration of trends in the use of different irrigation methods in the EU should be considered when planning the further development of the national irrigation system.

1.2 Legal regulation of water use in agriculture in Ukraine and the EU

1.2.1 Legal regulation of water use in agriculture in the EU

In the European Community, water security is a matter of safety and crisis preparedness, as prolonged anthropogenic pressure has had a critical impact on water resources due to intensive land cultivation, drainage of wetlands, construction of floodplains, straightening of rivers, active groundwater use, etc. This has disrupted the natural water balance, primarily due to the loss of water storage capacity in the landscape, and has deteriorated the quality of water resources. The need to improve the state of water resources has prompted the formation of a comprehensive Community water policy and the implementation of a set of documents.

The ***Water Framework Directive***[14] (WFD) provides the foundation for water policy in Europe, establishing rules that protect water resources, freshwater and marine ecosystems, and ensure the purity of water for drinking and bathing. The WFD is based on the definition of water not as a commercial product, but as a heritage that must be preserved, protected and treated appropriately.

The WFD is the main legislative act and is supported by two daughter directives on the quality and quantity of groundwater[15] and on the quality of surface water[16]. The WFD contains provisions on the deadlines for achieving its objectives, as well as provisions on exceptions. The annexes to the WFD contain detailed information on monitoring requirements, criteria for assessing the status of water bodies and the content of the River Basin Management Plan (RBMP).

The WFD standardises the principles of cost recovery and polluter pays (Article 9) and water tariffs, which must take into account the costs of supply and treatment, environmental and resource costs, and incentives for rational consumption. Article 9 also regulates the principles of water pricing policy for the efficient use of water resources.

The WFD stipulates that by 2010, all EU countries must have implemented economic mechanisms for water conservation.

The WFD also contains in Annex X a list of priority substances that Member States must monitor in surface waters, but the standards for these are set out in the Environmental Quality Standards Directive[17], which must be complied with in order to achieve good chemical status of surface waters in accordance with Article 4 of the WFD and point 1.4.3 of Annex V. The WFD also requires Member States to set and comply with environmental quality standards for pollutants characteristic of river basins, the monitoring of which contributes to the assessment of ecological status.

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[14] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. EUR-Lex. https://eur-lex.europa.eu/eli/dir/2000/60/oj

[15] Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. EUR-Lex. https://eur-lex.europa.eu/eli/dir/2006/118/oj/eng

[16] Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council. EUR-Lex. https://eur-lex.europa.eu/eli/dir/2008/105/oj/eng ; Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy Text with EEA relevance. EUR-Lex. https://eur-lex.europa.eu/eli/dir/2013/39/oj/eng

[17] Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council. EUR-Lex. https://eur-lex.europa.eu/eli/dir/2008/105/2013-09-13

The WFD is based on the basin principle of water resource management, i.e. water resources are managed by river basins – natural geographical and hydrological units, rather than administrative ones. This means that many Member States have to coordinate their actions, especially in the case of transboundary rivers. Article 5 of the WFD states that each Member State must ensure that, for each river basin or part of an international river basin district falling within its territory, an analysis of the characteristics, an assessment of the impact of human activity on the status of surface waters and groundwater, and an economic analysis of water use are carried out.

The key instruments for implementing the WFD are river basin management plans, developed through extensive public consultation and valid for 6 years (Article 13).

Every six years, it is also necessary to review the list of pollutants and standards of European significance relating to groundwater (Annex I to the Groundwater Directive[18]). This Directive supplements the WFD requirements on pollution trends and the quantitative status of pollutants.

The European Water Sustainability Strategy[19] 2025 aims to combat water scarcity, improve water management, expand access to clean water, stimulate innovation, restore the disrupted water cycle to protect communities and biodiversity, and strengthen the EU economy[20].

The Water Sustainability Strategy focuses on the following objectives:

– restoring and protecting the water cycle as the basis for water supply from source to sea. The key task is the effective implementation of the existing EU regulatory framework, namely the WFD, the Floods Directive[21], the Nitrates Directive[22] and the Nature Restoration Regulation[23];

– building a water-smart economy to boost competitiveness, attract investment and develop the EU water sector with a view to improving water efficiency and sustainable water management. The Water Efficiency First Recommendation[24] provides guidance on reducing water consumption and sets a Europe-wide target for improving water efficiency by 2030;

– ensuring clean and affordable water for all, as well as empowering consumers to ensure water sustainability. It highlights the need for support to ensure clean water and sanitation in certain regions and vulnerable population groups, as well as to improve water treatment to remove hazardous contaminants, pathogens and diseases.

– efficient use of resources, implementation of nature-based solutions (e.g. restoration of wetlands, meadows, wetland ecosystems).

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[18] Nitrates 50 mg/l, active substances of pesticides, including their relevant metabolites, degradation and reaction products – 0.1 µg/l, 0.5 µg/l (total). Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. EUR-Lex. https://eur-lex.europa.eu/eli/dir/2006/118/oj

[19] European Water Resilience Strategy. Circabc. https://circabc.europa.eu/ui/group/1c566741-ee2f-41e7-a915-7bd88bae7c03/library/b560bc22-6a61-4b63-b62b-a7fe890ea177/details

[20] Water resilience strategy. European Commission. https://commission.europa.eu/topics/environment/water-resilience-strategy_en

[21] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (Text with EEA relevance). EUR-Lex. https://eur-lex.europa.eu/eli/dir/2007/60/oj

[22] Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC). EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561542776070&uri=CELEX:01991L0676-20081211

[23] Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869 (Text with EEA relevance). EUR-Lex. https://eur-lex.europa.eu/eli/reg/2024/1991/oj

[24] Commission Recommendation on Water Efficiency First: Guiding Principles. European Commission. https://environment.ec.europa.eu/publications/commission-recommendation-water-efficiency-first-guiding-principles_en

The strategy combines **cohesion policy** (Box 1) with water management and provides for more than €24 billion in 2021–2027 to finance projects for wastewater treatment, drinking water supply protection, and flood and drought management.

> **Box 1. Cohesion policy (EU Cohesion Policy)** is the European Union's main instrument for reducing socio-economic disparities between its regions. The EU invests in less developed regions to bring them closer to richer and more competitive ones.
>
> Cohesion policy funds wastewater treatment systems, modernisation of water pipelines and reduction of water losses, protection against floods and droughts, and environmental projects (restoration of rivers, wetlands, forests). Within the framework of the Instrument for Pre-Accession Assistance and special cross-border cooperation programmes, Ukraine already receives funding under the cohesion policy format for the modernisation of treatment facilities in the Danube and Dniester basins

Measures planned for the implementation of the Strategy include:

– the establishment of a Water Sustainability Forum (twice a year) to exchange practices and monitor progress;

– integrated basin-based management with clear targets for member countries;

– setting mandatory water saving targets for sectors and regions;

– deployment of satellite monitoring (Copernicus) and early warning systems;

– creation of a European Water Observation Hub for real-time data collection.

– launching the European Water Academy to train specialists;

– supporting new technologies: PFAS (‘forever chemicals’) removal, smart irrigation, water reuse;

– programmes to support water-saving agribusiness and industry.

The water sustainability strategy supports the concept of the "natural sponge function" of landscapes as a basic element in restoring the natural ability of territories to retain, release and filter water. Restoring the natural sponge function of landscapes is a key element of the overall goal of restoring and protecting the water cycle and aims to use natural ecosystems effectively to increase water resilience.

The Water Resilience Strategy supports the concept of Sponge Facility, which is a special instrument or framework to support initiatives to restore sponge landscapes, ensuring these solutions are integrated into EU policies (agriculture, water, nature conservation, etc.).

As a supplement to the Water Sustainability Strategy, the European Commission has simultaneously published the Commission Recommendation on guiding principles for water efficiency[25], which sets out principles, priorities and targets for improving water efficiency in the EU by 2030 and, at the same time, is not legally binding. The annex to the Commission Recommendation on guiding principles for efficient water use contains key practices for efficient water use to implement the guiding principles of "Efficient water use first". These practices relate to better control of resources, efficient transport, storage and use, and proper management.

According to this Strategy, the goal of water conservation at the EU level is to improve water efficiency and reduce water consumption by 10% by 2030, for which countries must: reform tariff systems to reflect the real cost of water; encourage reuse and the transition to less

[25] Commission Recommendation on Water Efficiency First: Guiding Principles. European Commission. https://environment.ec.europa.eu/publications/commission-recommendation-water-efficiency-first-guiding-principles_en

water-intensive technologies; offer tax breaks or grants to businesses and households that implement water-saving practices.

EU challenges in water management:

– According to the latest European Commission report on the implementation of the WFD[26], the status of EU water bodies has not improved significantly, as only 39.5% of assessed EU surface water bodies are in good ecological status and 26.8% are in satisfactory chemical status.

– the European Commission's report covers only 20 Member States, as seven Member States did not provide information on time;

– Insufficient data quality and incompatibility due to inconsistent and incoherent monitoring methodologies.

Box 2. The European Commission report cites the Czech Republic's Strategic Plan for the Common Agricultural Policy, which focuses on improving water quality, as an example of best practice. It includes encouraging farmers to apply wide pesticide buffer strips around watercourses and increasing organic farming from 16% (above the EU average of approximately 10% in 2021) to 21.3% of agricultural land in 2030. (the EEA target is 25%).

Part of the EU's water policy is ***the Nature Restoration Regulation***[27]*,* which sets binding targets for the restoration of degraded ecosystems, especially those with the greatest potential for carbon capture and storage, as well as for preventing and mitigating the effects of natural disasters.

It requires Member States to restore the natural connectivity of rivers and the natural functions of associated floodplains, as well as to restore and rewet agricultural peatlands.

Its main provisions include:

– restoring at least 20% of land and marine areas by 2030 and all ecosystems in need of restoration by 2050;

– restoring at least 25,000 km of rivers to free-flowing status by 2030 by removing artificial barriers (dams, weirs, etc.).

This Regulation is a key legislative instrument for the restoration of freshwater landscapes — rivers, lakes, wetlands, river passability — and contains clearly defined restoration targets.

The main EU acts regulating the monitoring of water quality are:

The Water Framework Directive, which requires Member States to establish monitoring programmes for surface and groundwater; assess the ecological, chemical, quantitative and morphological status of waters and report to the European Commission every 6 years through River Basin Management Plans. Basic monitoring parameters include biological (phytoplankton, fish, macrophytes), chemical (pesticides, heavy metals) and hydromorphological (depth, flow) parameters.

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[26] Legal provisions of COM(2025)420 - 2025 Environmental Implementation Review Environmental implementation for prosperity and security. Eumonitor. https://www.eumonitor.eu/9353000/1/j4nvhdfcs8bljza_j9vvik7m1c3gyxp/vmovkfozc0xe?utm_source=chatgpt.com

[27] Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1991&qid=1722240349976

The ***Directive on environmental quality standards in the field of water policy****,* which establishes maximum permissible concentrations of priority substances in water (pesticides, metals, organic toxicants); regulates sampling and monitoring methods and supplements the WFD with specific control indicators.

The ***Drinking Water Directive****,* which provides for the monitoring of water intended for human consumption; introduces for the first time controls on microplastics, endocrine disruptors and PFAS chlorides and requires transparent publication of data for citizens with online access to results.

The ***Groundwater Directive***, which regulates the monitoring of groundwater pollution (nitrates, pesticides, salinity) and sets threshold values and monitoring programmes.

The ***Nitrates Directive****,* which aims to control pollution of water by agricultural fertilisers and requires regular monitoring of nitrates in rivers, lakes and groundwater.

The ***Marine Strategy Framework Directive****,* which applies to marine and coastal waters and provides for monitoring of 11 "descriptors" (including water quality, eutrophication, pollutants).

Key EU legislation regulating the protection of water resources from pollution:

The ***Water Framework Directive*** obliges countries to control and reduce pollutant emissions; establish programmes of measures for each river basin and develop lists of priority substances (metals, pesticides, organic toxicants).

The ***Directive on environmental quality standards in the field of water policy*** sets limit concentrations for 45 priority substances in water (e.g. cadmium, lead, nickel, pesticides, industrial chemicals).

The ***Directive on urban wastewater treatment*** requires the construction of treatment plants for all towns with a population of more than 2,000; biological treatment and, for sensitive areas, additional removal of phosphorus and nitrogen (to prevent eutrophication). It is planned to extend this directive by introducing new standards for the removal of micropollutants and pharmaceutical substances.

The ***Nitrates Directive*** aims to combat agricultural pollution (fertilisers, manure), establishes "Nitrate Vulnerable Zones" where farmers are required to limit the use of fertilisers, and, together with the WFD, supports the reduction of eutrophication in rivers and lakes.

The ***Groundwater Directive*** prohibits the direct discharge of pollutants into groundwater and sets threshold values for nitrates, pesticides, and other substances.

The ***Marine Strategy Framework Directive*** controls pollution of coastal and marine waters (oil spills, litter, chemicals) and aims to achieve "good environmental status" for EU seas.

This system is closely intertwined with the monitoring system and is structured as follows: it is based on the WFD, which established a number of specialised directives and regulations to regulate specific types of pollution (chemicals, wastewater, agricultural pollution, plastics, etc.). Thus, the EU regulates the fight against pollution through environmental standards, source control and special restoration programmes.

EU agricultural policy on water resources. The EU's Common Agricultural Policy (CAP) takes into account the high dependence of agriculture on water resources. On the one hand, agriculture is highly dependent on water and requires a stable and secure supply to ensure the health and well-being of crops, livestock and all forms of life in the agricultural ecosystem. On the other hand, it has a negative impact on water through unsustainable management practices, including pollution from pesticides, fertilisers, and chemical residues; intensive sedimentation caused by soil erosion; and excessive, irrational use. Climate change also creates additional challenges for agricultural water use due to increased risk of drought and increased water scarcity in some areas and flooding in others. All of this requires laying the groundwork for agriculture to make a significant contribution to EU water policy. Protecting water resources is a key aspect of the European Green Deal (EGD) to achieve zero pollution by 2030 and a sustainable food system. The CAP therefore includes strengthening the protection of water resources, supporting sustainable practices and bringing agriculture closer to the EGD objectives. Sustainable water management is important for all 10 social, environmental and economic objectives of the CAP.

The CAP contributes to improving water management and increasing water use efficiency through:

– *Conditionality rules*. According to these rules, CAP beneficiaries link their payments to a set of legally established requirements for statutory management requirements (SMR) and good agricultural and environmental conditions (GAEC). Conditionality rules directly related to water resources include requirements for control of water abstraction and reservoirs, as well as diffuse sources of phosphate pollution (SMR 1); the Nitrates Directive[28] (via SMR 2); protection of peatlands and wetlands (GAEC 2); buffer strips along watercourses (GAEC 4):

- *Eco-schemes*. Under the current CAP rules, eco-schemes support farmers who implement or maintain agricultural practices that contribute to the EU's environmental and climate objectives and include practices that support sustainable water management (Box 3).

> **Box 3.** Eco-schemes can support soil management practices such as crop diversification, reduced tillage, agroforestry and other practices that improve soil structure and enhance its water retention capacity, as well as practices aimed at improving nutrient management and rational use of pesticides.

– *Rural development measures:* through their strategic plans, EU countries can promote sustainable water management by supporting farmers who take additional steps towards sustainable water use (see Box 4). Investment measures can be used to cover the costs of capital changes, in particular for more efficient irrigation installations, as well as for the restoration of wetlands and peatlands and the creation of landscape features. Payments under the WFD support farmers who have to adapt their activities to water management plans within river basins.

> **Box 4.** Support is provided, for example, for increasing the organic carbon content of the soil, sowing more climate-adapted and/or water-resistant crops and varieties, and using smart water management and/or irrigation solutions.

The system of conditionality is governed by the following regulations:

- Rules for supporting strategic plans developed by EU countries under the common agricultural policy (Regulation (EU) 2021/2115[29]) (Delegated Regulation (EU) 2022/126[30]).

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[28] Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. EUR-Lex. https://eur-lex.europa.eu/eli/dir/1991/676/oj/eng

[29] Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development

- Rules on the financing, management and monitoring of the common agricultural policy (Regulation (EU) 2021/2116[31]) (Implementing Regulation (EU) 2022/128[32]).
- Rules for supporting strategic plans developed by EU countries under the common agricultural policy (Regulation (EU) 2021/2115[27]) (Delegated Regulation (EU) 2022/126[28]);

The activities of eco-schemes, AECC and investments are regulated by the rules for supporting Strategic Plans developed by EU countries under the common agricultural policy (Regulation (EU) 2021/2115).

However, it should be noted that each GAEC and SMR relates to water conservation in one way or another.

The impact on water resources of all components ***of the CAP conditions*** is detailed in Annex 1. Compliance with these conditions is mandatory for farmers seeking direct CAP payments. In this way, the EU links financial support to real environmental behaviour that affects the conservation and restoration of water resources.

Irrigation regulation in the EU. One way to manage water resources more efficiently in the EU is to promote water reuse. Water reuse is widely and successfully practised in several EU countries. However, this practice has not yet reached its full potential in the EU. The main barriers to the wider adoption of this practice in the EU are considered to be limited awareness of the potential benefits among stakeholders and the lack of support and a coordinated institutional framework for water reuse across countries.

This area is regulated by ***Regulation*** (EU) 2020/741[33] ***on minimum requirements for the reuse of water for agricultural irrigation***, which entered into force on 26 June 2023. and sets standards for water quality and monitoring, risk management, obtaining permits for the use of treated wastewater, and transparency of wastewater reuse projects. This Regulation is consistent with the EU Action Plan for the Circular Economy[34] and the European Water Protection Plan[35].

(EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013. EUR-Lex. https://eur-lex.europa.eu/eli/reg/2021/2115/oj

30 Commission Delegated Regulation (EU) 2022/126 of 7 December 2021 supplementing Regulation (EU) 2021/2115 of the European Parliament and of the Council with additional requirements for certain types of intervention specified by Member States in their CAP Strategic Plans for the period 2023 to 2027 under that Regulation as well as rules on the ratio for the good agricultural and environmental condition (GAEC) standard 1. EUR-Lex. https://eur-lex.europa.eu/eli/reg_del/2022/126/oj

31 Regulation (EU) 2021/2116 of the European Parliament and of the Council of 2 December 2021 on the financing, management and monitoring of the common agricultural policy and repealing Regulation (EU) No 1306/2013. EUR-Lex. https://eur-lex.europa.eu/eli/reg/2021/2116/oj

32 Commission Implementing Regulation (EU) 2022/128 of 21 December 2021 laying down rules for the application of Regulation (EU) 2021/2116 of the European Parliament and of the Council on paying agencies and other bodies, financial management, clearance of accounts, checks, securities and transparency. EUR-Lex. https://eur-lex.europa.eu/eli/reg_impl/2022/128/oj

33 Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse (Text with EEA relevance). EUR-Lex. https://eur-lex.europa.eu/eli/reg/2020/741/oj/eng

34 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Closing the loop - An EU action plan for the Circular Economy. EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52015DC0614

35 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Blueprint to Safeguard Europe's Water Resources. EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52012DC0673

Irrigation is also directly regulated by ***Delegated Regulation (EU) No 2024/1765***[36], which specifies technical requirements for risk management, including the classification of irrigation methods and the conditions for water storage and transport.

An explanatory technical document on the implementation of this practice is *the Technical Guidance - Risk Management for Water Reuse in Agricultural Irrigation Schemes in Europe*[37], which provides guidance on the establishment of a Risk Management Plan as referred to in Article 5 of the *Water Reuse Regulation* 2020/741, as well as technical assistance in implementing the key elements of risk management set out in Annex II of the Regulation.

Tools for ensuring efficient water use in the EU

In Europe, water scarcity is a serious problem in southern regions, and water quality deterioration is widespread. Investments in wastewater treatment have reduced point source pollution, but studies show that non-point source pollution from agriculture is not decreasing. The problem of water efficiency can be addressed through policy instruments such as water pricing, water markets and institutional cooperation, as well as water use quotas.

The water-pricing policy in the EU is one of the key economic mechanisms used to rationalise water use, encourage efficient water management and comply with environmental requirements. Its application is primarily regulated by the WFD, Article 9 of which states that Member States shall take into account the principle of recovery of costs of water services, including environmental and resource costs, taking into account the economic analysis[38] carried out in accordance with Annex III and, in particular, in accordance with the polluter pays principle, and water pricing policies provide appropriate incentives for users to use water resources efficiently and thus contribute to the achievement of the environmental objectives of this Directive.

Pricing in irrigation shall be based on the following principles[39]:

- The polluter pays principle, i.e. the price of water for irrigation shall include economic cost, including actual costs of extraction, transport and infrastructure maintenance; environmental cost, inlcuding potential damage to the environment; resource cost, including losses associated with the scarcity of the resource;

- A differentiated approach to tariff setting, namely a) volumetric pricing, i.e. the price depends on the amount of water consumed; b) block tariffs, where a lower rate is set for the base volume and a higher rate for excess volume; c) seasonal tariffs, where the price is higher during periods of shortage (summer season); d) the use of regulated subsidies for sustainable agriculture or small farmers;

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[36] Commission Delegated Regulation (EU) 2024/1765 of 11 March 2024 supplementing Regulation (EU) 2020/741 of the European Parliament and of the Council with regard to technical specifications of the key elements of risk management. EUR-Lex. https://eur-lex.europa.eu/eli/reg_del/2024/1765/oj/eng

[37] Maffettone, R. and Gawlik, B., Technical guidance - water reuse risk management for agricultural irrigation schemes in Europe, EUR 31316 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-59112-2, doi:10.2760/590804, JRC129596. https://publications.jrc.ec.europa.eu/repository/handle/JRC129596

[38] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. EUR-Lex. https://eur-lex.europa.eu/eli/dir/2000/60/oj

[39] Communication from the Commission to the Council, the European Parliament and the Economic and Social Committee - Pricing policies for enhancing the sustainability of water resources. Document 52000DC0477. EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52000DC0477

- Based on water balance and water scarcity, whereby in regions with water stress, the cost of water for irrigation is higher to encourage conservation.

The pricing instrument for promoting efficient water use for irrigation has both positive effects on producers' activities and certain risks. Among the positive effects are the following: a more rational water use; an acceleration of the transition to drip or micro-irrigation; and a reduction of water losses in irrigation systems. At the same time, producers face challenges such as: increased costs; the need to modernise infrastructure; and the risk of increased social inequality without well thought-out subsidies.

In Spain, you can choose one of the following pricing schemes[40]:

- A fixed rate per hectare calculated as the total costs incurred by farmers divided by the total irrigated area. This is the most common option in areas irrigated by surface water resources. Overall, fixed rates apply to 82% of areas irrigated by surface water;
- A volume-based tariff, which is mainly used in areas irrigated by groundwater and applies to 13% of the irrigated area. Volume-based tariffs are applied per cubic metre supplied andper hour of irrigation.
- A two-tier tariff, combining a volume tariff to cover variable costs and a fixed tariff per hectare for investment and management costs, is applied to 5% of irrigated cropland. Two-tier tariffs are more common in areas where metering devices are available and electricity costs are significant.

In Italy, irrigation water is rarely metered, and water abstraction charges are based on the area of irrigated land. Italian farmers pay much less than other users. The charges cover only part of the operating and technical maintenance costs. Investment or depreciation costs are not taken into account[41]. For example, some companies in northern Italy that supply water under pressure have a binomial tariff: (a) per hectare and (b) a volume charge [42]; [43].

In **France**, tariffs are predominantly volumetric and include an environmental tax, the proceeds of which go to environmental programmes. The criteria used to set tariffs vary significantly across basins, depending on a range of characteristics (drought risk, user type, capital costs, property rights, etc.). Pricing systems range from "average costs" to "marginal costs" used with quota systems. Under the French Water Law, river basin management authorities set the applicable rate for each river basin.

Thus, four main groups of the most common water tariffs can be identified: fixed-fee tariffs, volume-based tariffs, two-part tariffs, and price formation in water markets. When the sole objective is to recover costs, fixed tariffs are used. Volume-based tariffs are used when efficient water use is considered. Dual tariffs are used when a combination of fixed and volume-based tariffs is envisaged. Water markets are used in some developed countries where water is traded.

40 Helga Pereira, Rui Cunha Marques; Irrigation water tariffs: lessons for Portugal. Water Policy 1 October 2020; 22 (5): 887–907. doi: https://doi.org/10.2166/wp.2020.005
41 Researchers found significant differences in water consumption for the same crops between two regions: one uses a fixed fee per hectare, while the other uses a block system
42 Elias Giannakis, Adriana Bruggeman, Hakan Djuma, Jerzy Kozyra, Jürg Hammer; Water pricing and irrigation across Europe: opportunities and constraints for adopting irrigation scheduling decision support systems. Water Supply 1 February 2016; 16 (1): 245–252. doi: https://doi.org/10.2166/ws.2015.136
43 Albiac, J.; Calvo, E.; Kahil, T. and Esteban, E. 2020. The challenge of irrigation water pricing in the Water Framework Directive. Water Alternatives 13(3): 674-690. https://www.water-alternatives.org/index.php/alldoc/articles/volume-13/issue-3-1/587-a13-3-5/file

With regard to the introduction of water quotas and a comparison of their effect with water pricing, research by European scientists shows39 that the use of water quotas is more effective than water pricing because economic losses are lower. However, from a social point of view, the use of water prices as a source of revenue collected by basin management is more beneficial to society as a whole. Revenues from water charges can be used for other purposes to improve the well-being of society.

Water quotas are often preferred to purely economic regulation, such as water pricing, for several reasons. They are fair (water quotas ensure that each user receives a fair share of the available water, regardless of their ability to pay), transparent (they are easier to understand and implement than water prices, which can be complex and difficult to justify to users) and effective (water quotas can be more effective than water prices because they give users a clear signal about how much water they can use).

Water pricing should be implemented alongside other measures or in combination with other economic instruments that promote flexibility in water allocation and minimise economic losses.

The issue of water resources is cross-sectoral and urgent. As climate change accelerates, farmers need to restore irrigation systems and create new ones, but without restoring the natural water cycle, there will be no water for irrigation.

It is therefore important to consider environmentalists' position on restoring irrigation systems, which farmers need. Specifically, it is necessary to restore the disrupted water cycle using a "source to sea" approach, restore the natural "spongy" function of soils so that they can absorb and retain water, and create infiltration zones that help retain water during heavy rains.

In other words, a comprehensive approach to water management is needed: a "smart" water economy that involves the use of modern technologies, digitalisation and combating leaks, a state strategy to combat droughts, as well as pilot projects on water efficiency and the use of closed water cycle technologies. This is the basis of the European Water Resilience Strategy.

1.2.2 Legal regulation of water use in agriculture in Ukraine

Given the severe water shortage in Ukraine, the problem of crop irrigation must be addressed in a comprehensive manner. Namely, given the limited and exhaustible nature of water sources, significant water consumption and losses during the operation of outdated irrigation systems, as well as the generally inefficient use of water resources, particularly in terms of the choice of irrigation technologies and irrigated crops. Thus, in each specific case, it is necessary to assess the feasibility and acceptable scale of use of surface and alternative water sources[44] – underground, wastewater, saline – and the development of appropriate technologies (including purification and desalination). The operation of irrigation systems must provide for strict water conservation, which is achieved through the introduction of modern water-saving irrigation technologies (primarily micro-irrigation, in particular drip[45] and sprinkler[46]), innovative modernisation of the relevant infrastructure and

[44] This is partly reflected in the Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Regarding the Implementation of Integrated Approaches to Water Resources Management Based on the Basin Principle", where, in particular, Article 13^2refers to river basin management plans, and Article 13^4 refers to the development of water management balances with an assessment of the availability and usability of water resources and state accounting of surface waters (Article 26) (https://zakon.rada.gov.ua/laws/show/1641-19#Text)

[45] Drip irrigation is currently recognised as one of the most common irrigation methods in Ukraine (https://sad-ogorod.in.ua/ua/stati/kapelnoe-oroshenie-ua/)

the use of water-saving soil cultivation technologies (no ploughing, mulching, use of cover crops, etc.). An integral part of a comprehensive approach to ensuring the development of irrigation based on sustainability and climate resilience is the priority use of drought-resistant and less water-intensive crops and hybrids in Ukrainian agriculture, refraining from sowing moisture-loving crops in areas of critical moisture and significantly limiting such sowing in areas that are currently sufficiently moist (which, given current climate trends, may also become arid regions in the future). In line with the above, state policy on irrigation development should be formulated.

Regulatory and legal support in the field of irrigation reclamation and water resources management. Activities in the field of irrigation reclamation, as one of the main areas of water resource use, are determined and regulated in Ukraine by strategic documents that outline the goals and directions of development of the water management complex, as well as other regulatory and legal acts (laws, resolutions, etc.) that ensure the implementation of strategic objectives by establishing rules, norms and obligations for water users. Namely, Ukraine's Water Strategy for the period up to 2050[47], the Irrigation and Drainage Strategy for the period up to 2030[48] and the plan for its implementation[49], the Water[50] and Land[51] Codes, the Subsurface Code[52], the laws "On Environmental Protection"[53], "On Environmental Impact Assessment"[54] , "On Land Reclamation"[55], "On Water Drainage and Wastewater Treatment"[56], "On Water User Organisations and the Promotion of Hydrotechnical Land Reclamation"[57], as well as Resolutions of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for Developing a River Basin Management Plan"[58], "On standards for environmentally safe irrigation, drainage, irrigation management and water disposal"[59], " On approval of the Procedure for the use of funds provided for in the state budget to provide state support to agricultural producers using reclaimed land and water user organisations"[60], Order of the Cabinet of Ministers of Ukraine dated 25

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46 Mobile sprinkler systems (or sprinkler machines) are widely used, particularly in Ukraine, as they enable fine sprinkling and irrigation of non-standard shaped fields, including in fruit and vegetable growing (https://agro-sintez.com.ua/product-category/silskogospodarska-tehnika/doshuvalni-mashini/). The effectiveness of such systems is significantly increased when GPS control is used.

47 Resolution of the Cabinet of Ministers of Ukraine No. 1134-r of 9 December 2022 "On the Approval of the Water Strategy of Ukraine for the Period until 2050". https://zakon.rada.gov.ua/laws/show/1134-2022-%D1%80?find=1&text=%D0%B7%D1%80%D0%BE%D1%88%D0%B5%D0%BD%D0%BD%D1%8F#w1_1

48 Resolution of the Cabinet of Ministers of Ukraine No. 688-r dated 14 August 2019 "On Approval of the Irrigation and Drainage Strategy in Ukraine for the Period until 2030". https://zakon.rada.gov.ua/laws/show/688-2019-%D1%80#Text

49 Resolution of the Cabinet of Ministers of Ukraine No. 1567-r dated 21 October 2020 "On Approval of the Action Plan for the Implementation of the Irrigation and Drainage Strategy in Ukraine for the Period until 2030". https://zakon.rada.gov.ua/laws/show/1567-2020-%D1%80#Text

50 Water Code. https://zakon.rada.gov.ua/laws/show/213/95-%D0%B2%D1%80#Text

51 Land Code. https://zakon.rada.gov.ua/laws/show/2768-14#Text

52 Code of Ukraine on Subsurface Resources. https://zakon.rada.gov.ua/laws/show/132/94-%D0%B2%D1%80#Text

53 Law of Ukraine "On Environmental Protection". https://zakon.rada.gov.ua/laws/show/1264-12#Text

54 Law of Ukraine "On Environmental Impact Assessment". https://zakon.rada.gov.ua/laws/show/2059-19#Text

55 Law of Ukraine "On Land Reclamation". https://zakon.rada.gov.ua/laws/show/1389-14#Text

56 Law of Ukraine "On Water Drainage and Wastewater Treatment". https://zakon.rada.gov.ua/laws/show/2887-20#Text

57 Law of Ukraine "On Water User Organisations and Stimulation of Hydrotechnical Land Reclamation". https://zakon.rada.gov.ua/laws/show/2079-20#n2

58 Resolution of the Cabinet of Ministers of Ukraine No. 336 of 18 May 2017 "On Approval of the Procedure for Developing a River Basin Management Plan". https://zakon.rada.gov.ua/laws/show/336-2017-%D0%BF#Text

59 Resolution of the Cabinet of Ministers of Ukraine No. 766 of 2 September 2020 "On standards for environmentally safe irrigation, drainage, irrigation management and water disposal". https://zakon.rada.gov.ua/laws/show/766-2020-%D0%BF#Text

60 Resolution of the Cabinet of Ministers of Ukraine No. 1070 of 11 October 2021 "On Approval of the Procedure for the Use of Funds Provided for in the State Budget for the Provision of State Support to Agricultural Producers Using Reclaimed Land and Water User Organisations". https://zakon.rada.gov.ua/laws/show/1070-2021-%D0%BF#Text

March 2025 "On approval of the long-term development plan for the irrigation complex of Ukraine until 2050"[61], other regulatory and legal acts, as well as international treaties of Ukraine.

A brief description of the key provisions of these documents is provided in Annex 2.

Compliance of Ukrainian water legislation with European approaches

EU water legislation focuses on ensuring an integrated approach to water resource management and protection: clear environmental priorities are defined with specific mechanisms for their implementation (primarily river basin management plans – RBMPs); effective economic instruments are established (in particular, strict adherence to the "polluter pays" principle); and the public is widely involved in basin planning.

In recent years, Ukraine has significantly intensified the process of implementing European principles in the field of water resources management into domestic legislation. This primarily concerns the key provisions of the EU Water Framework Directive[62], which are reflected, in particular, in amendments to the Water Code of Ukraine (regarding RBMP), in the Water Strategy of Ukraine (regarding the definition of strategic goals of state policy in the field of water use, protection and restoration of water resources and indicators for achieving such goals), in the Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Long-Term Development Plan for the Irrigation Complex of Ukraine until 2050" (in terms of taking into account European principles for ensuring sustainable use of water resources, etc.) and other documents.

In accordance with the European approach to the basin management principle, nine river basin districts[63] were identified in Ukraine, basin councils were established to involve the public in discussing actions, the procedure for developing RBMPs[64] was established, and relevant plans for 2025-2030 (for the Dnieper, Danube, Dniester, Southern Bug and other river basins) with measures aimed at ensuring the "good" ecological status of water resources[65]. At the same time, experts recognise that this process is incomplete, in particular due to a lack of funding and other institutional weaknesses (insufficient clarity and effectiveness of legal norms, lack of qualified specialists, insufficient transparency in institutions' activities, etc.). In other words, although basin management is being implemented in Ukraine, the process is slow.

Water resource quality monitoring is also carried out in Ukraine. The former Ministry of Environmental Protection and Natural Resources of Ukraine reported the creation of four modern laboratories and the introduction of a system for assessing the condition of water bodies in accordance with European criteria[66]. However, the number of modern laboratories

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61 CMU Order No. 280-r of 25 March 2025 "On Approval of the Long-Term Development Plan for the Irrigation Complex of Ukraine until 2050". https://zakon.rada.gov.ua/laws/show/280-2025-%D1%80#Text

62 Establishes the basic provisions for integrated water resources management based on the basin principle.

63 Khilchevskyi V., Grebin V.V. Hydrographic and hydroeconomic zoning of Ukraine's territory, approved in 2016 - implementation of the WFD provisions / Hidrolohiia, hidrokhimiia i hidroekolohiia. – 2017. – T. 1(44)

64 Resolution of the Cabinet of Ministers of Ukraine No. 336 of 18 May 2017 "On approval of the Procedure for developing a river basin management plan". https://zakon.rada.gov.ua/laws/show/336-2017-%D0%BF#Text

65 River Basin Management Plans for Ukraine for 2025-2030. https://www.eu4waterdata.eu/images/pdf/Summary%20factsheets/ukrainian/Full_Pack_UKR_compressed_reduced.pdf

66 The implementation of river basin management plans is the implementation of the requirements of the EU Water Framework Directive. https://mepr.gov.ua/realizatsiya-planiv-upravlinnya-richkovymy-basejnamy-tse-implementatsiya-vymog-vodnoyi-ramkovoyi-dyrektyvy-yes/

is insufficient, and the rest have mostly outdated equipment. The Ministry also noted that the RBMP provides for the implementation of nature-based solutions and measures against pollution of domestic water resources. International experts who assessed the content of the final RBMP projects after public consultations and approval by the CMU noted in their report that, in general, Ukrainian RBMPs meet the requirements of the WFD[67]. At the same time, it was noted that there was a lack of data for conducting relevant studies on the status of water bodies and environmental risks. Only 5% of surface water bodies were monitored, and information on groundwater is even more limited. This problem is partly due to military operations, but even before the war, the monitoring network needed to be expanded. The lack of representative data makes it impossible to conduct informed assessments of the condition of groundwater bodies and associated risks. In addition, even such data in Ukraine is often unavailable to the public in real time, unlike in the EU, where a unified monitoring system with open data is in place.

Therefore, in Ukraine, unlike in the EU, the coverage of diagnostic monitoring of water quality is significantly lower[68], and the data obtained is not always transparent.

As part of the fight against water pollution, Ukraine adopted the above-mentioned Law "On Water Drainage and Wastewater Treatment", which establishes, in particular, requirements for wastewater treatment and the obligations of economic entities engaged in such water drainage, as well as requirements for the drainage and treatment of surface wastewater. And in the Procedure for the reuse of treated wastewater and wastewater sludge, subject to compliance with the maximum permissible concentrations of pollutants [69], it is emphasised that after treatment, wastewater is directed to agricultural land where "technical, fodder and grain crops, ornamental plantings, perennial and annual grasses that are not used for grazing" (II.1). The reuse of wastewater is prohibited in cases of inadequate treatment, as well as for irrigation of areas where berries and vegetables are grown for raw consumption, as well as medicinal herbs or plants (II.5). In general, according to estimates by the former Ministry of Environmental Protection and Natural Resources, "92% of RBMP measures are aimed at the construction, reconstruction and modernisation of treatment facilities and sewerage networks"[70]. However, according to the results of a coordinated audit on Goal 6 of the UN SDGs, the share of domestic wastewater safely treated in Ukraine in 2022 was only 50.2% (compared to 77.4% in Poland, for example)[71].

At the same time, the requirements for wastewater quality in Ukraine (DSTU 7369:2013)[72], referred to in the above-mentioned Procedure for the reuse of treated wastewater, are not identical to the requirements for the reuse of treated urban wastewater for agricultural irrigation

[67] Memo on the first Ukrainian river basin management plans. https://mepr.gov.ua/wp-content/uploads/2025/01/Conclud-note_RBMPs_UA_20241129_UA-1.pdf

[68] State monitoring of water in 2025. https://buvrzt.gov.ua/monitoring.html

[69] Order of the Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine No. 341 of 12 December 2018 "On approval of the Procedure for the reuse of treated wastewater and wastewater sludge subject to compliance with the maximum permissible concentrations of pollutants". https://zakon.rada.gov.ua/laws/show/z0075-19#Text

[70] The implementation of river basin management plans is the implementation of the requirements of the EU Water Framework Directive. https://mepr.gov.ua/realizatsiya-planiv-upravlinnya-richkovymy-basejnamy-tse-implementatsiya-vymog-vodnoyi-ramkovoyi-dyrektyvy-yes/

[71] Joint report on the results of a coordinated audit on Goal 6 of the United Nations Sustainable Development Goals. https://rp.gov.ua/upload-files/IntCooperation/IntAudits/2024/SDG6_JR_ua.pdf

[72] Wastewater. Requirements for wastewater and its sludge for irrigation and fertilisation. DSTU 7369:2013. https://ksv.do.am/GOST/DSTY_ALL/DSTU2/dstu_7369-2013.pdf

approved in the EU Regulation (EU) 2020/741[73] (based on the previously adopted Water Framework Directive of 2000[74] and the Waste Water Treatment Directive of 1991[75] (both – with amendments from 2014)). The aforementioned regulation (Annex I) specifies the requirements for irrigation water quality in terms of its microbiological and chemical indicators. Thus, four minimum quality classes of treated water have been established, each corresponding to specific categories of irrigated crops and irrigation methods, as well as pollutant content. The minimum frequency of scheduled monitoring of treated water for agricultural irrigation for each specified pollutant has also been established. Most of this is not included in DSTU 7369:2013. Accordingly, the current Ukrainian standards for the quality of treated wastewater used for irrigation need to be harmonised with the current European standards.

From June 2025, the Verkhovna Rada is expected to consider Draft Law "On the protection of waters from pollution caused by nitrates from agricultural sources"[76], developed in fulfilment of Ukraine's obligations in the field of European integration and to ensure the environmental safety of water resources. This draft law provides for the establishment of a procedure for identifying areas vulnerable to nitrate accumulation; the approval of an Action Programme for such areas or the entire territory of Ukraine; the establishment of criteria for identifying water bodies that are or may be subject to pollution; and the development of voluntary Rules of Good Agricultural Practice[77]. So far, however, there is insufficient control over nitrate discharges into water bodies in the field of agricultural pollution regulation in Ukraine.

With regard to the implementation in Ukraine of the rules of conditionality relating to water resources, the following can be stated:

— SMR 1 Directive 2000/60/EC of 23 October 2000 of the European Parliament and of the Council establishing a framework for Community action in the field of water policy: Article 11(3), point (e)[78]: implemented;

— SMR 2 Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (Articles 4, 5): not implemented. The draft Law on the protection of waters against pollution caused by nitrates from agricultural sources, as mentioned above, is awaiting adoption. There is no process for identifying areas vulnerable to nitrate accumulation, although the methodology has already been adopted;

— GAEC 4 Establishment of buffer strips along watercourses to protect river channels from pollution and runoff: regulated but not complied with.

In the context of irrigation development, Ukraine's institutional and regulatory achievements include, in particular, the introduction of water user organisations, the approval of an

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73 Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse (Text with EEA relevance). https://eur-lex.europa.eu/eli/reg/2020/741/oj/eng

74 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. https://eur-lex.europa.eu/eli/dir/2000/60/oj/eng

75 Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. https://eur-lex.europa.eu/eli/dir/1991/271/oj/eng

76 Draft Law on the protection of waters against pollution caused by nitrates from agricultural sources https://itd.rada.gov.ua/billinfo/Bills/Card/44711

77 The Committee on Agrarian and Land Policy discussed a draft law on the protection of waters from nitrate pollution. https://www.rada.gov.ua/news/news_kom/262625.html

78 Point (e) control of the abstraction of fresh surface and groundwater, as well as the discharge of fresh surface water, including a register or registers of water abstraction and the requirement to obtain prior authorisation for water abstraction and discharge. These control measures shall be reviewed periodically and, if necessary, updated. Implemented in the Water Code of Ukraine (Article 65 Special features of special water use and use of water bodies for the needs of agriculture and forestry).

irrigation development plan until 2050, and standards for environmentally safe irrigation (regulated by CMU Resolution No. 766 (2020), which sets limits for irrigation, drainage and water disposal). However, in order to fully comply with EU standards, it is necessary to: implement water quality regulations, in particular through the adaptation of EU regulations (2020/741, 2024/1765) into Ukrainian legislation; harmonise laws with the WFD, the Nitrates Directive, the Groundwater Directive, in particular, to limit pollution (in Ukraine, wastewater treatment requires permits, but without strict standards, while in the EU, there are standardised mandatory quality requirements for treated wastewater, so the adoption of a treatment certification scheme is recommended); protect groundwater.

Thus, in combating water pollution, Ukraine is making progress in harmonising its domestic and European approaches. At the same time, there are serious concerns about ensuring adequate control of water pollution in Ukraine and the lack of mechanisms to hold polluters accountable against the backdrop of corruption in environmental inspections, which results in the ignoring of illegal discharges by enterprises into water bodies. In the EU, the "polluter pays" principle is applied in practice, and water usage fees encourage the economic use of resources. Unlike in the EU, water fees in Ukraine do not encourage water conservation, and the lack of funding for water protection measures is partly due to the ineffectiveness of the system of penalties for polluters.

There was also public discussion of RBMP projects in Ukraine. Public participation in the discussion of such projects was declared in legal documents, announced and actually implemented, including with the involvement of civil society organisations. However, to a certain extent, these meetings remained formal, and the real influence of local communities in basin councils remains limited.

All of the above testifies to Ukraine's accelerated progress in harmonising its domestic water legislation with EU directives, primarily in terms of basin management, monitoring and combating water pollution. However, this process is far from complete and requires a systematic approach, further investment and institutional reforms. In general, according to experts, the current hydromeliorative reform in Ukraine "mainly addresses property and administrative-functional issues, but leaves environmental and natural resource problems unaddressed"[79]. There is a lack of comprehensive regulatory and legal support for the restructuring of the irrigation system, taking into account the urgent environmental and natural resource problems of water use, which are mainly only declared in the absence of effective mechanisms for their solution.

In particular, river basin management plans contain only actual volumes of water abstraction and discharge by agriculture, but without a reasonable assessment of the needs of the agricultural sector and the possibilities for meeting them[80]. In addition, domestic legislation lacks clarity regarding the introduction of modern water conservation technologies. Thus, the main focus in the reuse of water, including for irrigation, is on the process of treating such water before discharge, while there is no clearly defined procedure for the use of treated water and incentives for its users, as set out in the relevant EU documents, including those

[79] Grygorieva, H.A. Irrigation and food security in the context of water scarcity: legal issues and prospects. Scientific Bulletin of Uzhhorod National University, 2024. Series LAW. Issue 83: part 2. pp. 84-96. https://doi.org/10.24144/2307-3322.2024.83.2.12 .

[80] See, for example, the Dnipro River Basin Management Plan for 2025-2030. https://davr.gov.ua/fls18/PURBDnipro7_ukr.pdf

on stimulating the development of a circular economy[81]. The solution to the problem of reducing the water needs of agricultural production (which is one of the tasks of Ukraine's Water Strategy) is not supported by measures to encourage the cultivation of drought-resistant and low-moisture crops, at least in regions where farming is risky. Ukraine also lacks a clear action plan for water conservation amid increasing climate change, whereas in the EU drought adaptation strategies are integrated into water legislation.

From all of the above, we can conclude that Ukraine lacks a systematic approach to solving the problem of irrigation, which, in the context of modern climate change, would balance the growing needs of farmers for water resources and the existing degrading possibilities for meeting them. A systematic approach to irrigation management should include addressing a range of issues, namely, limited water supply; pollution of water resources; outdated irrigation infrastructure and inefficient irrigation technologies; insufficient use of water-saving technologies in agricultural production; and suboptimal selection of irrigated crops.

1.3 Best practices in irrigation in agriculture in the context of climate change adaptation, particularly in fruit and berry growing

In accordance with a systematic approach to irrigation development, best practices should ensure *the rationalisation of water supply sources, the economical use of water resources and the maintenance of their good ecological condition*. The implementation of such practices should be combined with the widespread use (especially in areas of risky farming) *of agricultural technologies that help retain moisture in the soil* (minimisation of tillage, mulching, cover crop cultivation, agroforestry, other anti-erosion measures); *optimisation of crop rotation*, in particular, the refusal of agricultural producers to grow moisture-intensive crops; *reduction in the use of chemical fertilisers and pesticides* and an increase in the use of organic fertilisers and biological protection products – to reduce the level of water pollution. To conserve water resources, it is also necessary to continuously monitor the water balance of individual territories, standardise financial incentives for farmers to comply with water-saving practices, and introduce real sanctions for improper water use.

Reducing the use of chemicals in agriculture and introducing appropriate agrotechnological measures were considered at an earlier stage in the study of best practices for climate adaptation and greening of agricultural production. Therefore, let us take a closer look at water sources and modern, most water-efficient irrigation practices (which are drip and sprinkler irrigation).

Water sources for irrigation and approaches to their use. Irrigation sources can be surface water (rivers, lakes, reservoirs), groundwater, rainwater, desalinated seawater, and treated wastewater. The main sources of irrigation water in Ukraine are surface water (whose volumes are constantly decreasing due to both climate change and the growing imbalance between water abstraction and natural replenishment) and groundwater.

In Ukraine, the use of water for agricultural irrigation from surface sources in daily volumes of up to 5 m^3 does not require a special permit (Article 48 of the Water Code), while the extraction of water for irrigation from underground sources without a special permit is limited

[81] See, for example, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A new Circular Economy Action Plan For a cleaner and more competitive Europe COM/2020/98 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

to 300 m^3 per day from each water intake (Article 23 of the Subsurface Code). Against the backdrop of declining freshwater resources, the importance of underground sources for irrigation in Ukraine, as in the rest of the world, is increasing. At the same time, water from underground sources, especially from deep (artesian wells), is of strategic importance, and its use for irrigation purposes is not justified. However, the use of groundwater, i.e. water from shallower wells near the surface of the aquifer, is also dangerous, as it can lead to a disruption of the hydrological balance and environmental threats due to uncontrolled water abstraction and the associated pollution. This, in turn, provokes extreme weather events and a corresponding increase in the negative effects of climate change on people and the environment. This is all the more dangerous because modern climate change is accompanied by a decrease in surface runoff and infiltration feeding of groundwater and underground waters. Domestic scientists have established that if climate change continues in line with current trends, "the volume of additional water withdrawal (extraction) from Ukraine due to increased total evaporation will continue to grow, and by 2050 it will increase by 80 km^3 compared to 1990, and by 2100 – by almost 150 km^3. Such a decrease in water supply will lead to further dehydration of Ukraine's territory and, accordingly, a decrease in available surface and groundwater reserves"[82]. At the same time, key Ukrainian legislation on water supply does not specify the permitted depth for drilling wells, although drilling companies' websites state that no special permit is required to drill wells up to 20 m deep[83]. In practice, however, water wells, especially on private plots, are drilled to greater depths and are not subject to any controls. In addition, water from wells is usually highly mineralised and salinated, so its use for irrigation worsens the condition of the soil, reducing its fertility.

Global experience confirms that intensive and uncontrolled irrigation from underground sources ultimately leads to a critical shortage of water, even for the domestic needs of the local population. Problems of depletion due to such irrigation of aquifers, lowering of groundwater levels and deterioration of their quality have already been encountered in India (which is recognised as the world's largest consumer of groundwater, 90% of which is used for irrigation)[84], in African countries[85] and in a number of other countries. Therefore, water extracted from wells will not be able to solve the problem of agricultural water supply in Ukraine, although it is currently widely used by both agricultural enterprises and households.

Rainwater and desalinated water are also used for agricultural irrigation. Desalination of groundwater or seawater for widespread use in irrigation is still a distant prospect for Ukraine, primarily due to the high cost and insufficient environmental justification of such technologies, which are, however, widely implemented in a number of water-deficient countries, primarily in Israel (mainly using reverse osmosis)[86], Australia, Saudi Arabia, Kuwait and other countries in the Middle East, as well as in North Africa.

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[82] In the context of modern climate change, the level of moisture in Ukraine is the main factor limiting crop productivity and agricultural potential. http://naas.gov.ua/slide/v-umovakh-suchasnikh-zm-n-kl-matu-r-ven-zvolozhennya-na-teritor-ukra-ni-golovnim-chinnikom-yakiy-obm/

[83] How deep can a well be drilled without a permit in Ukraine? https://akvastroy.com.ua/uk/yaku-glybynu-sverdlovyny-mozhna-buryty-bez-dozvolu-v-ukrayini/

[84] Strongly heterogeneous patterns of groundwater depletion in Northwestern India. https://doi.org/10.1016/j.jhydrol.2021.126492

[85] Reinventing the wheel: Adapting a traditional circular irrigation system to 'modern' agricultural extensions in Algeria's Sahara. DOI:10.30682/nm2205c

[86] Israel's experience: how wastewater is transformed into a water resource that develops the country. https://ukraine-oss.com/dosvid-izrayilyu-yak-stichni-vody-peretvoryuyutsya-na-vodnyj-resurs-yakyj-rozvyvaye-krayinu/

Critical water scarcity encourages the use of treated wastewater for irrigation[87]. Here, as in water desalination, Israel is also considered the world record holder[88]. For example, in Israel, water reuse has long been one of the key solutions in ensuring sustainable irrigation. There, 100% of wastewater is treated, and 93% of it is used for agricultural needs[89]. Wastewater provides at least 50% of the country's irrigation water needs and is an important component of Israel's strategy to address water shortages and support agricultural production in this arid region[90]. Pre-treated (mechanically, as well as using biological or chemical methods) water from domestic sewage is injected into the aquifer using a special technology that prevents the injected water from mixing with the natural water in the aquifer[91]. Further purification occurs as a result of natural filtration without any external influence on the process. The result is a significant amount of high-quality treated water suitable for irrigation, including agricultural irrigation, which is also supplied to local farmers at an affordable price.

Water reuse technologies (except for rainwater harvesting), like desalination technologies, are also costly, and their effectiveness is largely determined by the availability of appropriate technological infrastructure, the regularity and thoroughness of wastewater quality monitoring at all stages of the treatment and use process, and the assessment of their impact on soil conditions. Therefore, such water use practices are financially supported by states to encourage their wider dissemination by increasing their accessibility to agricultural producers. For example, up to 40% of Israeli farmers' costs for purchasing the latest irrigation systems, software, and innovative equipment, etc., are subsidised by the state[92]. At the same time, local farmers are allocated quotas for agricultural production and water consumption at fixed prices for each crop.

India also actively uses wastewater for irrigation, although the volumes of treated wastewater there are relatively small (28% of urban wastewater[93]). The choice of treatment system is determined by the conditions of a specific project, in particular, water quality requirements, the availability of land for treatment facilities, energy resource needs, the availability of funding, etc.

Despite the fairly widespread practice of wastewater irrigation, its use has significant caveats. For example, in Israel, evidence has been gathered on the damage to soil and crops from salinisation caused by wastewater irrigation. To be environmentally sustainable and acceptable for agricultural production, wastewater reuse programmes must ensure an extremely high quality of treated wastewater[94].

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87 So-called grey water (runoff from dishwashing, showers, washing machines, etc.) is not used for agricultural irrigation. After treatment, it is usually used only for irrigating non-food crops.

88 Israel's national water company, Mekorot, is the leading water management organisation, providing 70% of the country's total water consumption, including for agricultural irrigation, using the most advanced technologies, particularly in the field of desalination and water reuse.

89 The Israeli example of irrigated agriculture development. https://www.ifr.darg.gov.ua/index.php?lang_id=1&content_id=1322&lp=48

90 Rethinking the sustainability of Israel's irrigation practices in the Drylands. https://doi.org/10.1016/j.watres.2015.12.016

91 Israel's experience: how wastewater is transformed into a water resource that develops the country. https://ukraine-oss.com/dosvid-izrayilyu-yak-stichni-vody-peretvoryuyutsya-na-vodnyj-resurs-yakyj-rozvyvaye-krayinu/

92 The Tiny Giant. Ukraine and Israel are reliable partners in many areas, but it is always worth striving for more. https://biz.nv.ua/ukr/bizinterview/ukrajina-i-izrajil-vedut-peregovori-pro-vprovadzhennya-deshevogo-10-sekundnogo-testu-na-koronavirus-50112139.html

93 India is adopting advanced sewage wastewater treatment tech, but must choose those that best meet local needs. https://www.downtoearth.org.in/waste/india-is-adopting-advanced-sewage-wastewater-treatment-tech-but-must-choose-those-that-best-meet-local-needs-92863

94 Rethinking the sustainability of Israel's irrigation practices in the Drylands. https://doi.org/10.1016/j.watres.2015.12.016

In China, wastewater irrigation was, to a certain extent, considered until recently as an alternative solution to the problem of water scarcity for agricultural irrigation, particularly in northern China[95]. However, the associated problems gradually became apparent, primarily serious pollution and the destruction of agricultural land (its compaction, accumulation of heavy metals and organic pollutants, etc.).

Therefore, innovative wastewater treatment technologies are becoming increasingly important in ensuring the effective use of alternative water sources. These primarily include biotechnologies (water treatment using bacteria that break down organic pollutants), membrane systems (membranes are used to separate water components for disinfection; biological treatment can be combined with membrane filtration) and nanotechnologies (removal of pollutants using nanofilters, nanosorbents, nanocatalysts).

Another innovative approach is the use of sunlight to purify water. The most common is the use of photocatalysts activated by sunlight to break down organic pollutants in water. For small farms, the SODIS (Solar Water Disinfection) method is effective – placing transparent plastic containers with water under ultraviolet radiation from the sun for several hours to destroy bacteria, parasites, etc.

At the same time, it is not only high-tech solutions that demonstrate high efficiency in irrigation. For example, the Israeli company Tal-Ya-s Mitra has developed and is actively implementing around the world an easy-to-use reusable plastic (biodegradable) tray for collecting dew, which is then directed to the roots of the plant[96]. This irrigation system is fully compatible with drip and other types of irrigation, and also makes optimal use of rainwater. Water and fertiliser use is reduced by at least 50%. The trays also block weed growth and protect plants from extreme temperature fluctuations. Investments in this product pay off for farmers within one season through savings on water and fertiliser, as well as increased yields. Such systems are widely implemented, particularly in the cultivation of fruit crops.

Water-saving irrigation technologies. Drip irrigation is considered the most effective method of irrigation[97]. Water use efficiency with drip irrigation is 95-100%, while with sprinkler systems it is 80-85%, and with basin and furrow systems it is 60-70%. With drip irrigation technology[98], water is supplied directly to the plant's roots with uniform distribution along the entire irrigation line.

Significantly more effective than conventional drip irrigation is its combination with fertigation (simultaneous use of fertilisers), as this ensures constant availability of fertilisers near the plant root zone, as opposed to periodic feeding with large doses[99].

Subsurface drip irrigation (SDI) has also become widespread worldwide. It involves low-pressure irrigation, where drip tubes are buried beneath the soil surface near plant roots, reducing water consumption by a quarter compared to overhead sprinklers. This saves water and increases crop yields by eliminating an important component of water loss, namely evapo-

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[95] Impacts of sewage irrigation on soil properties of a farmland in China: A review. DOI:10.32604/phyton.2018.87.040

[96] Unlocking nature's potential through the power of simplicity. https://www.tal-ya.com/; The top 12 ways Israel is feeding the world. https://www.israel21c.org/the-top-12-ways-israel-feeds-the-world/

[97] Israeli hydraulic engineer S. Blass is considered the "father" of the modern drip irrigation system. In 1959, he proposed the design of the first tube with drippers, and in 1963, he patented the world's first dripper. It was in this country that drip irrigation technology was further refined. In Ukraine, the well-known Israeli company Netafim offers equipment for drip irrigation systems for open and closed ground, including gardens.

[98] What is the best irrigation system in the world? https://bishche.figa.cx.ua/maysternist/yaka-sistema-polivu-naykrashha-v-sviti.html

[99] Irrigation services and solutions. https://www.netafim.com.ua

ration, and reducing the number of weeds (their germination is significantly reduced in arid regions) and diseases (due to less moisture in the above-ground parts of plants). In addition to evaporation, surface runoff (which contributes to the preservation of water quality) and deep soil infiltration (which contributes to less leaching of nutrients and chemical compounds) are significantly reduced or completely eliminated, which also reduces unproductive water consumption[100]. According to many years of observations, scientists also consider improved fertiliser and pesticide management to be one of the advantages of SDI: more accurate and timely application through the system contributes to greater efficiency and, in some cases, reduced use; in addition, restrictions on fertiliser application due to weather conditions (strong winds, surface moisture, etc.) are largely eliminated. SDI systems are also recognised as ideal for implementing automation and advanced irrigation management technologies.

One of the main obstacles to implementing SDI systems is their high initial cost compared to other irrigation systems. Such large investments may not be justified in areas with uncertain water and fuel availability, especially given unfavourable commodity price forecasts. In addition, SDI systems require careful and timely maintenance and repair, as well as qualified specialists to perform these tasks.

Subsurface drip irrigation is usually positioned as a high-tech, automatically controlled technology used by medium and large-sized agricultural producers. At the same time, there are several inexpensive, easy to organise, but effective methods of subsurface drip irrigation that are also suitable for very small farms, in particular, jug or bottle irrigation.

Sprinkler irrigation is particularly effective for watering large areas. In this case, water is sprayed using sprinklers in the form of rain or jets. This method of irrigation ensures uniform moisture distribution and also allows for the simultaneous application of soluble fertilisers.

Modern irrigation methods are combined with the use of intelligent irrigation controllers (smart sensors/detectors), which, based on the use of the most accurate meteorological data with a high degree of detail, form specific watering schedules for each plot[101]. Mobile applications make it easy to control the smart irrigation system from anywhere.

One of the innovative solutions for water-saving irrigation practices, including in fruit and berry growing, is water recirculation in greenhouses, which is achieved by installing a recirculation pump that returns unused nutrient solution to the irrigation system. This practice enables significant water and fertiliser savings, as well as reduced contaminated water runoff.

In order to increase the resistance of agricultural crops to adverse climatic conditions, geneticists can use minichromosome technology, which improves plant characteristics, in particular their drought resistance, without changing their genes. This technology helps to create crops that require less chemical protection and fertilisers, achieve bioenrichment and increase the nutrient content in plants.

The latest laser technologies in agricultural production, aimed at improving soil condition and increasing the resistance of agricultural plants to drought, deserve special attention[102]. For

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[100] Lamm F. R. Advantages and disadvantages of subsurface drip irrigation. https://www.researchgate.net/publication/228854922_Advantages_and_Disadvantages_of_Subsurface_Drip_Irrigation

[101] E.N. Lofton. Smart Irrigation Controllers and Their Importance in Water Conservation. https://ucanr.edu/blog/smart-water-living-urban-water-efficiency-socal/article/smart-irrigation-controllers-and-their

[102] The role of laser technologies in agriculture: improving efficiency and sustainable development. https://www.teyuchiller.com/uk/the-role-of-laser-technology-in-agriculture.html

example, LIBS laser technology[103] is used for fast and accurate analysis of soil composition for nutrients, contaminants, etc., enabling farmers to develop individual soil management strategies to optimise soil condition. Laser biostimulation, used in the treatment of seeds or plants, increases their resistance to environmental stress factors, including drought. To ensure effective irrigation, laser levelling (high-precision levelling) of the land is carried out, which optimises the distribution of water on it and minimises its loss. Laser weeding technology is aimed at destroying weeds without the use of herbicides, which helps to reduce the use of agrochemicals. The cost of implementing laser technologies can be significant and depends on many factors (type, power, laser performance, equipment functionality, manufacturer).

One of the modern alternative methods of combating drought and moisture deficiency is the inoculation of plant roots, i.e. artificially stimulating their immunity with chemical or biological preparations that allow plants to develop in the absence of moisture[104]. The treatment of corn, wheat and sunflower seeds for this purpose is already widespread in countries with arid climates, in particular the United States, Brazil, Argentina and Australia. Gradually, such practices are gaining popularity in Ukraine as well.

1.4 Proposals for the restoration and development of irrigation in Ukraine

The restoration and development of irrigation should take place in the context of optimising water resource management. In view of the above, in order to improve the efficiency of irrigation and water resource management in Ukraine, as well as to harmonise domestic water legislation with EU guidelines, it is necessary to focus primarily on:

in the field of water resource management

- restoring natural water landscapes, primarily regenerating wetlands (for which it is necessary to develop appropriate legislative and regulatory support and attract funding for project implementation), removing artificial barriers to free river flow, restoring natural floodplains, purifying water and restoring its biodiversity;
- strengthening control over the use of water resources, for which an electronic water use monitoring system should be introduced;
- improving the quality of water resources, primarily by supporting the introduction of modern technologies for their purification and the modernisation of treatment facilities, as well as strengthening control over the pollution of surface and underground water sources, in particular through the formation of an extensive system for their monitoring and appropriately equipped laboratories;
- ensuring the inevitability of penalties for violations of water legislation and introducing the "polluter pays" principle into water use practice (for which appropriate clarifications should be made, in particular, to the Water Code of Ukraine);
- strengthening institutional capacity in water resources management, in particular through the involvement of grant funding and highly qualified personnel;
- expanding public control over water resources management, in particular through transparency and openness of data, broader public participation in decision-making, etc.;

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[103] New LIBS analytical method for determining the elemental composition of materials. https://lityo.com.ua/novij-analitichnij-metod-libs-dlya-viznachennya-elementnogo-skladu-materialiv

[104] Artificial stimulation of drought resistance in plants can save the harvest, according to experts. https://superagronom.com/news/12395-shtuchne-stimulyuvannya-posuhostiykosti-roslin-moje-vryatuvati-urojay--dumka

in the field of irrigation

- objective regional assessment of water balances reflecting available water resources, including those available for irrigation, and regional agricultural needs, determined on the basis of water-saving agricultural production structures, formed taking into account the level of water availability in the regions, as well as the drought resistance and water requirements of agricultural crops;
- forming a list of priority measures in the field of agricultural production for the conservation of water resources in connection with the intensification of the negative effects of climate change and regulating their implementation by agricultural producers as a mandatory condition for receiving state support (in particular, following the example of European SMR 1, SMR 2, GAEC 4);
- adopting the law "On the protection of waters from pollution caused by nitrates from agricultural sources" and implementing its provisions, as well as identifying areas vulnerable to nitrate accumulation in accordance with the approved methodology;
- ensuring effective incentives for water conservation in irrigation, in particular by amending the "Procedure for the use of funds provided in the state budget for state support to agricultural producers using reclaimed land and water user organisations" regarding financial incentives for the introduction of water-saving practices and principles of ecological water use[105] and partial reimbursement to farmers of the cost of water for irrigation of agricultural land and crops, the volumes and list of which are determined by the regional water-saving structure of agricultural production;
- introducing an effective tariff system for irrigation water in order to encourage its economical use, which will involve (following the example of EU countries) standardising the principle of full cost recovery: operational, depreciation, environmental and resource costs; introduction of block tariffs, in which the basic volume of water consumption is paid at a lower rate, and the volume exceeding it – at a higher rate; standardisation of the right of irrigation system users (at the community/basin level) to set local tariffs within the state price corridor;
- widespread implementation of circular approaches to water reuse in agriculture, including through the dissemination of the practice of using treated wastewater in irrigation systems, which requires ensuring a higher degree of treatment of such water, in particular, harmonising the quality standards in force in Ukraine with the relevant European standards, as well as implementing the provisions of Commission Delegated Regulation (EU) 2024/1765 on the technical characteristics of key risk management elements in water reuse (including the classification of irrigation methods, water storage and transport conditions, etc.) into domestic water legislation;
- investing, including jointly with agribusiness, in the most effective modern projects to modernise irrigation infrastructure to ensure water conservation ;
- ensuring sustainable soil management, in particular with a view to improving soil structure, water regime and moisture retention (restoring the natural spongy function of soils);
- raising awareness among agricultural producers and the general population about the importance and methods of water conservation, the need for wider implementation of water-saving irrigation practices, increasing the reuse of treated wastewater, etc.

[105] First and foremost, reimbursement of part of the investment in drip irrigation and fertigation, modernisation of pumping stations, installation of meters and automated control systems, precision and smart farming, insulation of irrigation channels, protection of coastal strips, etc.

2 GOOD AGRICULTURAL AND ENVIRONMENTAL CONDITIONS IN AGRICULTURAL PRODUCTION AS COMPONENTS OF SOIL MANAGEMENT

2.1 Compliance of Ukrainian legislation with EU standards for good agricultural and environmental conditions (GAEC)

Ukraine has quite extensive legislation on land, in particular, the Land Code of 2001, the Law "On Soil Protection" of 2003, the Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Concept of the State Target Programme for Land Use and Protection" of 2022, and the Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for Monitoring Land and Soil" of 2024. However, the problem of soil degradation has not been adequately addressed.

A significant part of Ukraine's soil and land has suffered military degradation caused by combat operations during the war. According to the Audit Chamber's report on the audit results, 17.4 million hectares were affected by intense hostilities, and 13.9 million hectares are potentially mined territory (about 23% of the area). At the current rate, it will take more than 80 years to completely clean up the contaminated agricultural land[106]. Soil damage was also caused even before the start of hostilities in 2022 due to irrational, monocultural use: almost 16 million hectares of agricultural land were eroded, i.e. 38% (20% underwent significant degradation, the rest was under threat, according to FAO estimates[107]).

The issue of soil is addressed in a fragmented manner within the framework of various policies: agricultural policy, with regard to soil on agricultural land; environmental policy, protection of natural resources, in particular land and water, as well as regulation of industrial emissions; climate policy, with regard to land use. Soil protection is a cross-sectoral issue that requires an integrated approach across all lands.

It should be emphasised that in the domestic legal field on land issues, including the above-mentioned acts, the term "soil health" is completely absent (only "soil fertility" is mentioned). Meanwhile, in the EU, this term has become widespread following the adoption of new soil-related acts. The principles and measures for achieving healthy soil conditions need to be properly regulated in line with the current EU approach.

Sustainable soil management is the new norm (standard) in the EU. The 2020 Farm to Fork Strategy, which is central to the European Green Deal (EGD), states that the mission in the area of soil health will focus on developing solutions to restore soil health and functions. The EU's strategic approaches to soil (the EU Soil Strategy to 2030 from 2021[108], the Soil Monitoring and Resilience Directive (SMRD); Proposal from 2024[109]) are based on **the**

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[106] Report on the results of the audit of activities (effectiveness) on the topic "Humanitarian demining of agricultural land in Ukraine: restoring safety and agricultural production." Accounting Chamber. 26 August 2025. https:// rp. gov. ua/ upload- files/ / /2025/21-2_2025/ _21-2_2025.

[107] The war significantly worsens the situation with soil degradation. 9 December 2022: https:// . ua/news// viyna- zn-- - z- - gruntiv

[108] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. EU Soil Strategy for 2030. Reaping the benefits of healthy soils for people, food, nature and climate. COM/2021/699 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699

[109] Soil Monitoring and Resilience (Soil Monitoring Directive) 13.3.2025 European Parliament legislative resolution of 10 April 2024 on the proposal for a directive of the European Parliament and of the Council on Soil Monitoring and Resilience (Soil Monitoring Law). P9_TA(2024)0204 – Soil Monitoring and Resilience (Soil Monitoring Directive) – European Parliament legislative resolution of 10 April 2024 on the proposal for a directive of the European Parliament and of the Council on Soil Monitoring and Resilience (Soil Monitoring Law) (COM(2023)0416 – C9-0234/2023 – 2023/0232(COD)) (Ordinary legislative procedure: first reading); Position of the Council at first reading with a view to the adoption of a Directive of the European Parliament and of the Council on Soil Monitoring and Resilience (Soil Monitoring Law) – Adopted by the Council on 29 September 2025. https://data.consilium.europa.eu/doc/document/ST-9474-2025-REV-1/en/pdf

concept of soil health[110] as a new paradigm for sustainable soil management. Soil health is transboundary in nature, playing a crucial role in the nutrient, carbon and water cycles.

The EU Soil Strategy for 2030 aims to achieve neutral land degradation, prevent land degradation and restore soil health, achieve net-zero greenhouse gas emissions in the land use sector, minimise nutrient losses and reduce the use of chemical pesticides. Soil management in the EU Strategy is considered in the broad context of realising the multifunctional role of soil with maximum effect for people, food, nature and the climate.

The Soil Monitoring and Sustainability Directive (SMRD) – the first specific piece of legislation on soil – provides for the establishment of a clear system for monitoring all soils, identifying and remediating contaminated sites, establishing rules for sustainable soil management and defining best land practices. The ultimate goal of this Directive is to ensure the healthy state of all EU soils by 2050. Once the Directive enters into force, Member States will have three years to implement the new rules into national legislation and define their plans for sustainable soil management practices in line with EU objectives.

The EU's Common Agricultural Policy (CAP) guides the development of EU agriculture towards sustainable soil management, namely through the application of the good agricultural and environmental condition (GAEC) standard[111]. The 2023 CAP reform strengthened the GAEC requirements by updating them and adding two new ones (now 9 in total). The GAEC standards aim to contribute to solving water problems, protecting soil, preserving biodiversity, mitigating the effects of climate change and adaptation. Although GAECs were introduced for soil management, their impact is broader: GAECs 1, 2 and 3 relate to climate change; GAEC 4 – water; purely soil – GAEC 5, 6 and 7, biodiversity – GAEC 8 and 9 (Annex III to Regulation (EU) 2021/2115). The implementation of GAEC is determined by Member States in their National Strategic Plans for the CAP based on specific needs.

Due to the need to increase the EU's agricultural production capacity in the changed conditions caused by the war and to reduce the administrative burden on farmers, derogations from certain GAEC standards were regulated in 2022-2024 – most of them underwent significant changes towards relaxing the requirements, and some were cancelled. According to EU Regulation 2024/1468[112] on amendments to GAEC standards, in particular, the requirement to set aside a proportion of arable land for uncultivated land to preserve biodiversity has been abolished, and the requirements for soil management, maintaining minimum soil cover, crop rotation, and maintaining permanent pastures. EU Member State governments have been given greater flexibility to set specific agri-environmental requirements, taking into account agro-climatic conditions. The requirements of two GAEC standards remain unchanged, namely the ban on stubble burning and the establishment of buffer strips along watercourses.

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[110] Healthy soils are in good chemical, biological and physical condition, enabling them to provide ecosystem services that are vital for humans and the environment, such as safe, nutritious and sufficient food, biomass, clean water, nutrient cycling, carbon storage and habitats for biodiversity. - Proposal for a Directive of the European Parliament and of the Council on Soil Monitoring and Resilience (Soil Monitoring Law). https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52023PC0416

[111] Regulation (EU) 2021/2115 uses the term "standards of good agricultural and environmental conditions of land (GAEC)". In Regulation (EU) 2024/1468, GAEC is defined as the good agricultural and environmental condition (GAEC) standard. This is clearly a new interpretation of GAEC, with an expanded interpretation not only as standards for land, but also for other natural resources and the environment.

[112] Regulation (EU) 2024/1468 of the European Parliament and of the Council of 14 May 2024 amending Regulations (EU) 2021/2115 and (EU) 2021/2116 as regards good agricultural and environmental condition standards, schemes for climate, environment and animal welfare, amendment of the CAP Strategic Plans, review of the CAP Strategic Plans and exemptions from controls and penalties. https://eur-lex.europa.eu/eli/reg/2024/1468/oj/eng

In the Proposal for a Regulation amending Regulations (EU) 2021/2115 and 2021/2116 of 2025 the European Commission proposes, in particular, that farmers whose entire farm is certified as organic (in accordance with Regulation (EU) 2018/848) be considered to comply with GAEC standards 1, 3, 4, 5, 6 and 7; to amend GAEC 1 on permanent pasture; to clarify the application of GAEC 4, which aims to protect river courses from pollution and runoff, giving Member States more flexibility to adapt it[113]. The simplifications proposed by the European Parliament in October 2025 mean that not only farms certified as organic should automatically be considered to comply with certain GAEC requirements, but also those where parts are certified as organic; as well as farms located in special nature conservation areas; have an area of less than 50 hectares[114].

The Strategy for the Development of Agriculture and Rural Areas in Ukraine for the period up to 2030, dated 2024, states for the first time that in order for producers to be able to comply with GAEC, the necessary minimum requirements must be determined based on the experience of EU Member States. A summary checklist of the compliance of current Ukrainian legislation with the defined EU GAEC standards for the period 2021-2027 is provided in Annex 3, and a summary assessment of compliance is presented in Table 2.1.

Table 2.1 – Generalized level of compliance of the norms of current legal acts of Ukraine with the specified EU GAEC standards for the period 2021-2027[115]

Assessment of the level of compliance	GAEC	Area covered by EU GAEC
Compliant	GAEC 3 GAEC 4	Prohibition of stubble burning on arable land. Establishment of buffer strips along watercourses.
Mostly compliant	GAEC 2	Protection of wetlands and peatlands.
Less compliant with	GAEC 5 GAEC 7	Soil management, reducing the risk of soil degradation and erosion. Crop rotation.
Not compliant	GAEC 1 GAEC 6 GAEC 8 GAEC 9	Maintenance of permanent pastures. Minimal soil cover during the most sensitive periods. Maintaining non-productive functions to improve biodiversity. Prohibition on conversion or ploughing up of permanent pastures in Natura 2000 areas.

Source: compiled from: Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013. https://eur-lex.europa.eu/eli/reg/2021/2115/oj#ntr1-L_2021435EN.01014601-E0001; expert assessment of the authors regarding the level of compliance.

Thus, Ukraine has specific requirements for farming that are to some extent consistent with the EU's GAEC, but, *first,* these requirements are not linked to the system of state support for agricultural producers. In fact, only the "stick" approach is used to ensure compliance – violations of the established norms are punished, including economically, through the imposition of fines.

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113 Proposal for a Regulation of the European Parliament and of the Council amending Regulation (EU) 2021/2115 as regards the conditionality system, types of intervention in the form of direct payment, types of intervention in certain sectors and rural development and annual performance reports and Regulation (EU) 2021/2116 as regards data and interoperability governance, suspensions of payments annual performance clearance and controls and penalties. COM/2025/236 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52025PC0236

114 Parliament ready to start talks about simplifying EU agriculture laws. 08-10-2025. https://www.europarl.europa.eu/news/en/press-room/20251003IPR30659/parliament-ready-to-start-talks-about-simplifying-eu-agriculture-laws

115 Popova, O. (2025). Conditionality of support for farmers under the EU CAP: changes and lessons for Ukraine. Economy of Ukraine. 68. 07(764). 67-88. https://doi.org/10.15407/econo myukr.2025.07.067

Secondly, some of the regulated provisions do not correspond to the essence of European standards, for example, GAEC 2 on the protection of wetlands and peatlands. The standard provides for the reduction and adaptation of agricultural practices in these areas[116]. In Ukraine, however, the use of drained land with peat soils for agriculture using special methods is regulated[117].

Thirdly, requirements for standards of good agricultural and environmental condition of soil, which are particularly important for Ukraine, need to be regulated, regarding soil management, reduction of the risk of soil degradation and erosion. Legal norms regarding crop rotation are currently limited, with Resolution No. 164 of 2010[118] still in force, but Resolution No. 1134 of 2011 on the development of land management projects that provide ecological and economic justification for crop rotation and land management[119] has been repealed. Attention should be paid to land management in order to improve biodiversity in Ukraine.

Before the war, Ukrainian agricultural landscapes were overburdened with cultivated land, with agricultural development accounting for 68.5% and ploughing accounting for 54.3% of the territory (Table 2.2). However, there are no legal norms regarding the preservation and maintenance of natural landscape elements on agricultural land (in particular, a ban on ploughing field strips, cutting hedges, trees in fields, etc.). Field protection forest strips have been massively destroyed by hostilities and need to be restored. At the same time, forest cover was extremely low even before the war, accounting for only 17% of Ukraine's territory (compared to almost 32% in Poland and France).

Table 2.2 – Structure of the land fund in 2010-2020 and projected for 2030-2032, %

Years	Agricultural development of the territory	Ploughing of territory	Ploughed agricultural land	Hayfields and pastures in the area	Share of forests and forest-covered areas
2010	68.9	53.8	78.1	13	17.6
2015	68.8	53.9	78.4	13	17.6
2020	68.5	54.3	79.3	12.5	17.7
Plans for 2030-2032	63.5	44	69	15.8	-

Source: Agriculture of Ukraine in 2022: statistical collection. – Kyiv: State Statistics Service of Ukraine. – 2023. – p. 47; data as of 2030-2032. – Law of Ukraine "On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period until 2030" of 2019 No. 2697; Order of the Cabinet of Ministers of Ukraine No. 70 of 19 January 2022 "On Approval of the Concept of the National Target Programme for Land Use and Protection".

It is quite obvious that the pre-war targets of reducing agricultural development by 5% and ploughing by 10% will not be achieved in wartime conditions. As of 2024, 9.85 million hectares of agricultural land in 10 regions of Ukraine were inaccessible due to large-scale military operations, i.e. 48.1% of the total area in these regions prior to the invasion (according to data from the KSE Centre for Food and Land Use Research)[120]. The problems

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[116] According to the EU Nature Restoration Law of 2024 (Regulation (EU) 2024/1991), member states must restore 50% of drained peatlands used in agriculture by 2050. Since peatlands contain large amounts of carbon (more than forests), they are recognised as the most effective terrestrial ecosystems for carbon storage.

[117] Resolution of the Cabinet of Ministers of Ukraine "On the Apclear that the pre-war targets of reducing agricultural development by 5% and ploughing by 10% will not be metproval of the Strategy for the Formation and Implementation of State Policy in the Field of Climate Change for the Period until 2035 and the Approval of the Operational Plan of Measures for its Implementation in 2024-2026" of 2024 No. 483. https://zakon.rada.gov.ua/laws/show/483-2024-%D1%80#Text

[118] Resolution of the Cabinet of Ministers of Ukraine "On Approval of Standards for the Optimal Ratio of Crops in Crop Rotations in Different Natural and Agricultural Regions" dated 11 February 2010 No. 164. https://zakon.rada.gov.ua/laws/show/164-2010-%D0%BF#Text

[119] Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for Developing Land Management Projects that Provide Ecological and Economic Justification for Crop Rotation and Land Management" dated 2 November 2011 No. 1134 – repealed by Resolution of the Cabinet of Ministers of Ukraine No. 563 dated 10 May 2022. https://zakon.rada.gov.ua/laws/show/563-2022-%D0%BF#n66

[120] Land fund dynamics: how Ukraine's land resources have changed since 24 February 2022. https://kse.ua/wp-content/uploads/2024/03/Agroviglyad_2_ukr.pdf

of restoring land resources that have suffered large-scale military degradation in the context of armed aggression against Ukraine have intensified.

EU requirements for good soil conditions in protective practices after 2027

In the EU, after 2027, it is proposed to abolish the standards of good agricultural and environmental conditions (GAEC) in order to simplify the conditionality/conditional nature of financial support for farmers under the CAP. It is envisaged to strengthen incentives for farmers to implement agricultural practices for soil health, climate promotion, water management, and biodiversity conservation, replacing GAEC with protective practices, according to the Proposal for an EU Regulation establishing the conditions for the implementation of the Common Agricultural Policy for the period 2028-2034[121]. Protective practices take into account the content of GAEC standards.

A farm stewardship system will be introduced as a requirement for receiving financial support for farmers' incomes from the EU and national budgets. This system includes minimum requirements for environmental and social conditions (conditionality), as well as protective practices for soils and rivers to protect them from pollution. The minimum requirements for farm management rules (Statutory Management Requirements, SMR) and protective practices rules – three types of which are listed in the Proposal for an EU Regulation, Annex I (Table 2.3).

Table 2.3 – Protective practices proposed for support under the EU CAP from 2028 and their link to GAEC

General objectives	Specific objectives of conservation practices	Related to GAEC*
Protection of carbon-rich soils, landscape features and permanent pastures on agricultural land	Protection of carbon-rich soils, including protection of wetlands, peatlands and landscape features	GAEC 1 GAEC 2 GAEC 8
	Protection of environmentally sensitive permanent pastures on agricultural land within the Natura 2000 network	GAEC 9
Protecting soil from erosion, maintaining soil potential, maintaining soil organic matter and protecting against stubble burning on arable land	Protecting soil from erosion, depending on the conditions of the specific plot	GAEC 5
	Preserving soil potential: - protecting soils during periods of greatest sensitivity - crop rotation or crop diversification	GAEC 6 GAEC 7
	Preserving soil organic matter through crop residue management, including a ban on stubble burning on arable land	GAEC 3
Protection of watercourses and groundwater from pollution and runoff	Protecting watercourses and groundwater from pollution and runoff, in particular by establishing buffer strips along watercourses	GAEC 4

* Expert assessment by the authors.

Source: compiled from: Proposal for a Regulation of the European Parliament and of the Council establishing the conditions for the implementation of the Union support to the Common Agriculture Policy for the period from 2028 to 2034. Brussels, 16 July 2025. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52025PC0560&qid=1753798247771

The proposed conservation practices for 2028-2034 are defined as comprehensive targets that take into account GAEC standards, but without setting quantitative indicators. EU

[121] Proposal for a Regulation of the European Parliament and of the Council establishing the conditions for the implementation of the Union support to the Common Agriculture Policy for the period from 2028 to 2034. Brussels, 16 July 2025. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52025PC0560&qid=1753798247771

Member States will accordingly determine the conservation practices that farmers must comply with in order to receive financial support. These practices will be included in the National and Regional Partnership Plans of each EU country.

Thus, the standardisation and promotion of the implementation of GAEC standards and protective practices in domestic agricultural practice from 2028, harmonised with those in force in the EU, is an important task for Ukraine. However, there are undoubtedly differences in the scale and possibilities of financial support for agricultural producers in implementing these standards. Support for producers should be combined, where possible, with European programmes and preparations for a hybrid model in order to maintain efficiency, profitability, economic viability and innovation[122]. This will determine the readiness of Ukrainian agricultural producers to comply with EU rules on sustainable agriculture, including as a basis for granting them subsidies under the CAP after Ukraine's accession to the EU.

2.2 Eco-schemes as a tool for good soil management in the EU

The EU's Common Agricultural Policy (CAP) for 2023-2027, compared to the previous programming period, is even more focused on sustainable land use, encouraging farmers to protect the climate, landscapes and the environment, and ensuring animal welfare. Ecoschemes are a new element of the CAP that encourages environmental and climate action and are essentially a new type of environmental contract with farmers. They are a more flexible scheme of payments to farmers and landowners, designed to support those who implement or maintain farming practices that contribute to the EU's environmental and climate goals. It is a financial instrument that rewards the conservation of natural resources and the provision of public goods to the population that are not reflected in market prices.

It is envisaged that eco-scheme measures will be voluntary for farmers, so they must go beyond the mandatory requirements set out in the conditionality system in the CAP 20232027. The conditionality system requires farmers and landowners to comply with statutory management requirements (SMRs) (applicable to all farmers, regardless of whether they receive CAP support) and standards for good agricultural and environmental condition (GAEC) (applicable only to farmers receiving CAP support).

Eco-schemes are regulated by Article 31 of Regulation (EU) 2021/2115, which states that active farmers who voluntarily commit to certain climate- and environment-friendly practices receive a subsidy for complying with the requirements of the scheme[123]. In order to receive support under eco-schemes, agricultural producers must carry out the relevant activities; be guided by the priorities set at national/regional level in the CAP strategic plans; contribute to the achievement of the European Green Deal objectives, and their level of activity must go beyond the requirements and commitments set by the conditionality system. At the same time, experts note that the existence of three parallel environmental and climate instruments – direct support programmes (conditionality systems, eco-schemes) and rural development programmes – will

[122] Vysotsky: Our goal is to prepare for a hybrid model of support for farmers after joining the EU on 6 August 2024. *Latifundist.com*. https://latifundist.com/novosti/65249-visotskij-nasha-tsil--gotuvatisya-do-gibridnoyi-modeli-pidtrimki-agrariyiv-pislya-vstupu-v-yes

[123] Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32021R2115

create difficulties for producers, and emphasise the lack of clear alignment with the environmental objectives of the Paris Agreement and the Convention on Biological Diversity[124].

Interventions in the form of direct payments, general requirements and a list of eco-schemes are defined in the CAP strategic plans of EU member states. Eco-schemes in the area of "Agriculture and agroecology" include a significant list of practices, including extensive grazing; biodiversity conservation; crop rotation with legumes; direct sowing; natural or sown plant cover; water management, etc. Support for eco-schemes consists of an annual payment per hectare, which can be subsidised and meets the general and specific requirements for each eco-scheme. A significant budget has been allocated for this new type of scheme. It is planned to spend at least 25% (€48.5 billion for 2023-2027) of the direct payment budget to scale up such measures, with Member States able to go beyond the budget and spend more[125].

This new mechanism focuses on a list of areas of activity defined at the EU level and can be used to support practices such as organic farming, agroecological practices, precision farming, agroforestry or carbon farming, as well as improving animal welfare.

The National Strategic Plans of the EU Member States identify 158 eco-schemes. Most countries have developed several eco-schemes to achieve a specific objective. Six Member States (Czech Republic, France, Hungary, Ireland, Netherlands and Slovakia) have identified a single multidimensional eco-scheme that combines practices of varying degrees of ambition. In this case, farmers are often required to choose or implement practices that apply to all their agricultural land. Two CAP Strategic Plans (the Netherlands, Hungary) offer eco-schemes based on points, where points are assigned to different practices according to their likely positive impact; this encourages farmers to choose the practices that best meet the environmental and climate needs of their farms and regions. Some plans (e.g. Lithuania, Ireland, and Poland) require farmers to implement more than one eco-scheme or a minimum number of practices, for example, on arable land, to ensure synergies and increase environmental value.

Of the 158 eco-schemes, 18% provide payments that exceed basic income support for sustainability; payments for eco-schemes are a supplement to basic support. The remaining 82% provide payments to compensate for additional costs and income losses incurred by farmers as a result of environmental commitments. Eco-schemes, as additional payments to basic income support for sustainability, include requirements for the conservation of biodiversity, non-productive landscape features, adherence to a 'whole farm approach' and non-land use practices.

Agricultural practices that can be applied as eco-schemes.

Practices that already exist in EU standards[126] :

- *Organic farming* (Regulation (EU) 2018/848);

- *Integrated pest management (IPM):* Directive 2009/128/EC127 has made the application of IPM principles mandatory since 2014. These practices include the establishment of buffer strips with

[124] Heyl K, Döring T, Garske B, Stubenrauch J, Ekardt F. The Common Agricultural Policy beyond 2020: A critical review in light of global environmental goals. *RECIEL*. 2021; 30: 95–106. https://doi.org/10.1111/reel.12351

[125] A Greener and Fairer Cap. Agriculture and rural development. European Commission. https://agriculture.ec.europa.eu/document/download/89b607ec-8a43-4073-bafd-f2493da7699e_en

[126] Sustainable agricultural practices and methods. List of potential agricultural practices that eco-schemes could support. https://agriculture.ec.europa.eu/cap-my-country/sustainability/environmental-sustainability/sustainable-agricultural-practices-and-methods_en

management practices and without the use of pesticides, mechanical weed control, increased use of pest-resistant varieties and species, and strips of land that are not treated with agrochemicals at the edge of agricultural land and natural areas that are valuable for maintaining biodiversity.

Other practices

- *Agroecology:* crop rotation with legumes, mixed multi-crop planting; use of cover crops between rows of trees in orchards, vineyards, olive groves, etc.; use of winter cover crops and nutrient-retaining crops; low-intensity livestock farming; use of crops that are more resistant to climate change; mixed systems of permanent pasture use to preserve biodiversity (pollinating insects, birds and animals); improved rice cultivation schemes to reduce methane emissions (e.g. alternating wet and dry methods); practices and standards established by organic farming regulations.

- *Agroforestry:* establishing and maintaining landscape diversity on agricultural land; managing landscape diversity; creating and maintaining biodiversity-rich grazing systems.

High nature value farming: leaving strips of land uncultivated to support biodiversity (pollinating insects, birds, etc.); sheep farming on natural pastures and between permanent crops; creation and improvement of semi-natural habitats for wild animals and plants; reduction of fertiliser use; low-intensity field crop cultivation.

- *Carbon farming:* regenerative agricultural practices; restoration of wetlands and peatlands; practices for growing crops on soils with high moisture content; maintaining minimum groundwater levels in winter; sustainable management of plant residues (incorporation into the soil, sowing on previous plant residues, etc.); restoration, maintenance and extensive use of permanent pastures.

- *High-precision farming:* soil nutrient management; innovative approaches to minimising nutrient losses; maintaining optimal soil pH for nutrient uptake; circular agriculture; high-precision crop cultivation methods to reduce fertiliser, water and plant protection product use; improving irrigation efficiency.

- *Improved soil nutrient management:* implementation of nitrate pollution prevention measures that go beyond conditionality commitments; prevention of water, air and soil pollution by excess nutrients (soil sampling, creation of nutrient traps, etc.).

- *Protection of water resources:* efficient water use management – transition to less water-intensive crops, change of planting dates, optimised irrigation schedules, etc.

- *Other soil-friendly practices:* planting and effective maintenance of forest strips to prevent erosion; creation or maintenance of terraces and strip cropping[128].

- *Other practices related to greenhouse gas emissions:* use of feed additives to reduce emissions from intestinal fermentation; improved manure handling and storage practices.

In the EU***, eco-schemes aimed at soil conservation*** (improving natural fertility, carbon farming) account for 30% of the total number of eco-schemes; those aimed at preserving biodiversity and landscape features account for almost 20%, and eco-schemes aimed at

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[127] Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides. *EUR-Lex.* https://eur-lex.europa.eu/eli/dir/2009/128/oj/eng

[128] Strip cropping is a farming method in which a field is divided into long, narrow strips that alternate between different crops. This method is used to control soil erosion by planting erosion-resistant crops (e.g. grasses) in alternation with crops that are prone to erosion (e.g. maize or soybeans). The strips are placed across the slope to reduce water and wind runoff, conserve moisture and improve soil quality.

livestock grazing and pasture management account for 15%. Eco-schemes supporting organic farming and pesticide management each account for 6%. Only a few strategic plans include eco-schemes targeting peatlands and wetlands (2%) and animal-related measures (5%).

Poland's experience with the implementation of eco-schemes, in particular for improving soil management.

In Poland, significant focus is on developing carbon farming, aligning with the EU's CAP for 2023-2027. A key instrument of this policy is eco-schemes as voluntary financial mechanisms that encourage farmers to adopt environmentally and climate-friendly practices. According to the country's National Strategic Plan for 2023–2027, financial resources amounting to €25.2 billion have been allocated. Of this, €17.3 billion from the EU budget is earmarked for direct payments, of which at least 25% should be allocated to eco-scheme payments, in line with the European Commission's recommendations. In 2023, five ecoschemes were introduced[129] :

- carbon farming and nutrient management;
- areas with honey plants;
- water retention on permanent pastures;
- integrated crop production;
- organic crop production.

In addition, from 2024, farmers could apply for payments under the "Land excluded from production" eco-scheme, and from 2025 under the "Seed material: elite and certified categories" eco-scheme. Practices that support carbon farming are included in the CAP Strategic Plan 2023-2027 under the eco-scheme "Carbon Farming and Nutrient Management". This is one of the most comprehensive eco-schemes in Poland, supporting a range of practices that promote increased carbon sequestration in the soil, capture atmospheric CO_2,and reduce its emissions.

In Poland, the main mechanism for promoting practices that affect farmers' incomes by increasing soil fertility and rational fertiliser application, as well as improving crop quality, is the carbon farming eco-scheme. Under this eco-scheme, farmers can choose from eight practices that best suit their needs. The practices covered by this eco-scheme include[130] :

- Extensive use of permanent pastures with livestock – maintaining meadows and pastures through grazing, which helps to increase the organic matter content in the soil.
- Winter cover crops or catch crops – sowing cover crops in the autumn-winter period to protect the soil from erosion and increase its fertility.
- Development and adherence to a fertiliser application plan:

  a) basic option – preparation of a fertiliser application plan taking into account the needs of agricultural crops;

  b) liming option – additionally includes liming to improve soil pH.
- Crop diversity – growing different crops to increase biodiversity and improve soil structure.

[129] Rosa, A., Pawłowska, A., & Dudek, M. (2025). Eco-Scheme—Carbon Farming and Nutrient Management—A New Tool to Support Sustainable Agriculture in Poland. *Sustainability*, *17*(11), 5067. https://doi.org/10.3390/su17115067

[130] Area-based eco-schemes. Ministry of Agriculture and Rural Development. https://www.gov.pl/web/rolnictwo/ekoschematy3

- Mixing manure into the soil within 12 hours of application – rapid mixing of manure with the soil limits ammonia emissions and increases fertiliser efficiency.
- Application of natural liquid fertilisers using methods other than spraying – applying liquid fertilisers in a way that reduces nutrient losses.
- Simplified tillage systems – using methods that minimise soil disturbance, such as no-till farming, which maintains higher levels of organic carbon in the soil.
- Straw incorporation – leaving and mixing straw into the soil after harvest to enrich the soil with organic matter.

Each of the above practices is evaluated using a point system. Subsidies for the implementation of individual practices are calculated based on the number of points assigned to them. In 2023, 1 point was worth PLN 104.89. The greatest interest was not in the practices with the highest scores, but in those that were easiest for farmers to implement. Since the launch of the "Carbon Farming and Nutrient Management" eco-scheme, 79.6% of applications from existing eco-schemes have been submitted for this area. The three most popular practices in Poland were straw incorporation, winter cover crops and manure mixing on arable land within 12 hours of application[131].

Payment rates for eco-schemes were set in 2024 for payments to farmers in 2023. The rates for the implementation of individual practices under the "Carbon farming and nutrient management" eco-scheme depend on the number of points per hectare of area approved for support, the cost of 1 point as indicated above, and amount to the following sums depending on the practice[132]:

- extensive use of permanent pastures with livestock maintenance: 5 points; PLN 524.45/ha;
- winter cover crops or intermediate crops: 5 points; PLN 524.45/ha;
- development and compliance with a fertiliser application plan – basic option: 1 point; PLN 104.89/ha;
- development and compliance with a fertiliser application plan – option with liming: 3 points; PLN 314.67/ha;
- diverse crop structure: 3 points; PLN 314.67/ha;
- mixing manure into the soil within 12 hours of application: 2 points; PLN 209.78/ha;
- application of liquid natural fertilisers by methods other than spraying: 3 points; PLN 314.67/ha;
- simplified cultivation systems: 4 points; PLN 419.56/ha;
- mixing straw with soil: 2 points; PLN 209.78/ha.

The payment rates for other eco-schemes are as follows:

- plots with honey plants: PLN 1,256.77/ha;
- integrated crop production: PLN 1,363.77/ha;
- biological protection of agricultural crops: PLN 419.64/ha;
- water retention on permanent pastures: PLN 292.27/ha.

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[131] Rosa, A., Pawłowska, A., & Dudek, M. (2025). Eco-Scheme—Carbon Farming and Nutrient Management—A New Tool to Support Sustainable Agriculture in Poland. *Sustainability*, *17*(11), 5067. https://doi.org/10.3390/su17115067

[132] Area-based eco-schemes – payment rates for 2023 higher than expected. Ministry of Agriculture and Rural Development. https://www.gov.pl/web/rolnictwo/ekoschematy-obszarowe--stawki-platnosci-za-2023-r-wyzsze-od-zakladanych

The experience of Germany and the Netherlands in applying eco-schemes.

In Germany, seven eco-schemes have been approved, with payments ranging from €40 to €1,300 per hectare[133]. The German Association for Soil Protection has proposed a model for eco-schemes in which farmers can freely choose from a list of nineteen practices: nine for arable land, seven for pastures, and three for permanent crops. Acceptable practices range from simple measures integrated into production, such as maintaining pasture grazing, to higher requirements, such as refraining from using mineral fertilisers and synthetic pesticides for green fallow, flower strips or grass strips, where agricultural land is taken out of production. Practices are assessed on a points basis according to their environmental value. For example, grazing is awarded one eco-point per hectare, while flower strips are rewarded with ten eco-points per hectare. Each eco-point is valued at €50. According to calculations by the German Federal Ministry of Food and Agriculture, the average payment under the eco-scheme is €66 per hectare.

The Netherlands has developed a single eco-scheme under which farmers can choose from 22 practices, each assessed for its environmental and climate value[134]. To join the scheme, farmers must score a certain number of points and reach a certain payment level to determine which level they fall into – bronze, silver or gold. A modelling tool helps with decision-making. Regional differences are reflected in the threshold score (calculated on the basis of lost income and costs incurred for each eco-activity).

All measures contribute to the five objectives set by the government based on EU Regulation 2021/2115[135]: climate; soil and air; water; landscape; and biodiversity. Practices are assessed according to their contribution to each of these objectives. For example, the practice of "organic farming" scores 4 points (out of a maximum of 5) for the soil objective, but scores 0 points for the climate objective and 2 points for the water objective, while "permanent pastures" give 4 points for soil and climate goals and 1 point for landscape and biodiversity. It should be noted that 20 of the 22 practices proposed give points for soil goals.

The calculation of compensation that can be obtained from eco-activities is not straightforward. For each practice adopted, a certain number of points related to the specified objectives are awarded. As mentioned above, depending on the total number of points and the calculated aggregate financial value for the farmer, a level (bronze, silver or gold) is determined. Each level has a different payment: bronze – €60/ha, silver – €100/ha and gold – €200/ha. Prior to the introduction of the points system in 2023, minimum requirements were published so that farmers would know in advance how to estimate the expected payments[136].

Eco-schemes are therefore a new tool within the EU's CAP. They are intended to support previously unused environmental and climate-friendly practices on Member States'

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[133] Agroforestry in Germany. EURAF. https://www.euraf.net/2023/01/20/germany/#utm_source=chatgpt.com

[134] Design and Implementation of Eco-schemes in the new CAP Strategic Plans. https://eu-cap-network.ec.europa.eu/sites/default/files/publications/2024-01/report-1-tg-ecoschemes.pdf

[135] Regulation (EU) No 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013. URL: (EU) No 1305/2013 and (EU) No 1307/2013. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32021R2115

[136] Jongeneel, R. and Gonzalez-Martinez, A. (2023), Implementing the EU eco-scheme in the Netherlands: A results-based points system approach. EuroChoices, 22: 20-27. https://doi.org/10.1111/1746-692X.12388

agricultural land, or to increase the area on which such practices are used, or both. In some cases, support under past agri-environment-climate measures in rural development (sometimes including support for organic farming) has been partially or fully transferred to eco-schemes. Some eco-schemes support practices that were mandatory under past 'greening' requirements, or that are implemented under GAEC standards, but on a more ambitious scale – for example, more ambitious crop rotations than those required under GAEC 7, or areas beneficial to biodiversity that go beyond the requirements of GAEC 8.

The importance of eco-schemes is reinforced by the fact that a significant part of them is focused on soil management with the aim of improving soil structure and increasing the capacity of soils to accumulate organic matter (carbon sequestration). Such practices include long-term crop rotation, leguminous crops, crop diversification, reduced tillage (e.g. no-till farming), catch crops, green cover in permanent crops, straw incorporation, etc. At the same time, proper soil management also includes practices to preserve biodiversity and landscape features, in particular, ecological management of agricultural land, pesticide management, meadow management, and nutrient management. Among the latter, it is worth noting the use of precision farming, the prohibition of mineral fertilisers, restrictions on the use of fertilisers or the establishment of requirements for their application to the soil, and the encouragement of the use of organic fertilisers such as manure, slurry or compost.

European experience shows that eco-schemes, as tools for encouraging farmers to adopt climate-oriented practices, are promising but still imperfect. In particular, there is a lack of comprehensive implementation of all measures and practices, and the amount of subsidies received does not depend on the complexity of their implementation, etc. However, the overall conclusion of European experts is that this tool has significant potential to encourage farmers to take environmental and climate action.

Eco-schemes are not implemented or financially supported in Ukraine. Nevertheless, progressive agricultural enterprises apply relevant practices for environmental and economic reasons. Therefore, it can be argued that there is potential to scale up the participation of agricultural producers in eco-schemes, provided financial support is available, as in the EU CAP eco-schemes. Therefore, proper institutionalisation of the promotion of eco-schemes in the national agricultural sector is needed, which is important for Ukraine in the process of European integration and for domestic agricultural producers' access to environmental payments in the future.

2.3 Proposals for soil management in Ukraine

– *Move from a fragmented soil management policy to a comprehensive approach that takes into account its multifunctionality* – its importance for food security, the preservation of healthy water resources, biodiversity, climate change mitigation and the development of a circular economy. Soil issues are currently addressed in various policy areas: agricultural policy (soil on agricultural land); environmental policy (protection of natural resources, including land and water, regulation of industrial emissions); and climate policy (appropriate land use). A comprehensive and integrated approach to soil protection and ensuring its healthy condition is needed. **It is proposed to develop and approve a national soil management strategy** and an action plan for its restoration.

– *The principles and mechanisms for ensuring soil health should be regulated in national legislation* as the basis for a sustainable soil management policy. Current legislation regulates certain elements of soil management, but there is no regulation of the soil health system. This should align with the EU Soil Strategy for 2030, adopted in 2021, which sets out achieving neutral land degradation, restoring healthy soils, and the net removal of greenhouse gases in the land-use sector. As a candidate for EU membership, Ukraine **should implement the relevant EU Strategy at the national level** and introduce it into agricultural practice.

– *Formulate a government programme to prioritise and restore* land plots that have suffered large-scale military degradation (mined, contaminated, degraded) *to a condition suitable for use for specific purposes*, with measures for their restoration (conservation, re-profiling, recultivation, etc.). Prioritisation concerns the order of land restoration (based on Croatia's experience, agricultural land, tourist regions and border areas were cleaned up first). There is a gap in the absence of a document that would systematically regulate the procedures for identifying, assessing, isolating, cleaning and returning contaminated land to use; there is no state policy that would combine mine action, soil monitoring and restoration into a single process. An important part is the balanced reintegration of decontaminated land into agricultural use, namely ensuring legal support, supporting farmers and attracting investors. **It is proposed to develop and approve a national strategy for the management of militarily degraded soils** and an action plan for their restoration as a way to accelerate the solution of the problem of these soils, since the development of a strategy for the management of all soils will require more time.

– *Implement an appropriate soil monitoring system in Ukraine*, consolidated and harmonised with the soil monitoring system in the EU, with the Soil Monitoring and Sustainability Directive (SMRD). With a proper soil monitoring system in place, it will be possible to ensure progress towards sustainable soil management, the dissemination of best land practices, optimal fertiliser application and the use of irrigation to ensure soil sustainability. Currently, Ukraine has adopted the Cabinet of Ministers Resolution "On Approval of the Procedure for Land and Soil Monitoring" No. 848 of 2024. After the adoption of the EU Soil Monitoring and Sustainability Directive (SMRD), Member States will have three years to implement it. **It is proposed to implement the EU Directive on Soil Monitoring and Sustainability at the national level** and to develop a plan for sustainable soil management practices and achieving healthy soil.

– *In the post-war period, a balance should be struck between increasing agricultural productivity and protecting and restoring soil and land.* It is important to standardise and transition to sustainable/good agricultural practices that have long been used in the EU. It is worth focusing on GAEC standards until 2027, taking into account their simplification in the EU, and on soil protection practices that will replace GAEC standards for 2028-2034. Soil protection practices to reduce soil degradation and erosion, crop rotation, etc., are important for Ukraine. **It is proposed to define national protective practices** in line with EU guidelines and **include them in the mechanism of financial support for agricultural producers within the framework of state programmes.** The requirements for protective practices should be incorporated into post-war recovery projects for the domestic agricultural sector.

– *Standardise and implement eco-schemes in agricultural practice as a tool for proper soil management and the achievement of environmental and climate goals*. It is important to develop domestic eco-schemes and identify mechanisms for promoting targeted best practices, taking into account the EU's CAP targets and the experience of EU member states. Experience with eco-schemes shows that agricultural producers are more actively involved in practices that are easy to manage and understand. Complex practices should also be included in eco-schemes, and their scoring and financial support should be high in order to ensure the economic interest of domestic agricultural producers in their implementation in agricultural activities. **It is proposed to define and standardise national eco-schemes**; it is feasible to include the implementation of these measures in the operational plan for the implementation of the Strategy for the Development of Agriculture and Rural Areas for the period up to 2030. In the future, eco-schemes will become part of the National and Regional Partnership Plan, which will be developed to finance the agricultural sector, including taking into account the access of Ukrainian agricultural producers to payments under the EU CAP, as the EU envisages the development of this Plan by each member country from 2028.

3 Processing of horticultural products in the context of the European Green Deal

3.1 European Green Deal on Sustainable Recycling and Waste Management

In the documents developed to implement the European Green Deal, significant attention is paid to the transition to the ecological processing of agricultural raw materials. Great attention is also paid to the management of waste generated during the production, circulation and consumption of food products.

The problem of waste is quite acute today. The population of the planet is constantly growing, and accordingly, the production of consumer goods, including food, is increasing. A joint report from the environmental organisation World Wide Fund for Nature (Switzerland) and the retail company Tesco (Great Britain) for 2021 notes that globally, the volume of food waste is 2.5 billion tons annually[137]. It is estimated that annual food resource losses are at the level of 1.6 billion tons[138]. This is approximately a third of total production. The scale of the problem is also evidenced by the following eloquent fact. Every year on Earth, the production from 1.4 billion hectares of agricultural land does not reach the consumption stage and is lost[139].

The large amount of waste generated during the production, circulation, and consumption of food products poses a threat to the environment and public health. A significant part of the packaging has a long decomposition period and accumulates in landfills, as well as chaotically outside them. According to some estimates, food waste is responsible for 8-10% of all GHG[140].

Spoiled vegetables and fruits, as well as waste after their processing, have high biodegradability and fermentation capacity. When they enter rivers and lakes, they cause eutrophication of the water. This leads to mass deaths of fish and other aquatic organisms. Cyanobacteria poison rivers and lakes with toxins. These toxins cause skin rashes, asthma, liver damage, nervous system damage, and other negative health effects in humans.

Measures to reduce food waste and maximise its recycling are provided for in the EU Code of Conduct on Responsible Food Business and Marketing Practices. This code was developed in 2021 by the European Commission together with associations, EU companies, international organisations, and non-governmental institutions. The Code entered into force in July 2021. It was signed by representatives of 65 European companies and associations. Among them were such well-known companies as: Coca-Cola, Danone, Ferrero, Metro AG, Mondelez, Nestle, PepsiCo, and Unilever.

The participants in the agreement voluntarily undertook a number of commitments: 1) to keep records and reduce greenhouse gas emissions; 2) to reduce water use for production needs; 3) to reduce waste; 4) to fully recycle waste; 4) to implement environmentally friendly packaging solutions; 5) to increase the shelf life of products; 6) to obtain raw materials from suppliers that have certificates from environmental institutions (Fairtrade, Rainforest Alliance, etc.).

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[137] Kaushik, R., Morya, S., Bashir, O., Bhadha, J.H. and Kasankala, L.M. (2025), Valorization of Fruit Waste Through Reutilization Approach: A Comprehensive Review. *eFood*, 6: e70073. URL: https://doi.org/10.1002/efd2.70073

[138] Grasso, S., Fu, R., Goodman-Smith, F., Lalor, F., & Crofton, E. (2023). Consumer attitudes to upcycled foods in US and China. *Journal of Cleaner Production*, 388, 135919. URL:https://doi.org/10.1016/j.jclepro.2023.13

[139] Sharma, A., Jyoti, A., More, A., Gunjal, M., Rasane, P., Kumar, M., Kaur, S., Ercisli, S., Gurumayum, S. a Singh, J. (2025), Harnessing Fruit and Vegetable Waste for Biofuel Production: Advances and Scope for Future Development. *eFood*, 6: e70051. URL: https://doi.org/10.1002/efd2.70051

[140] Grasso, S., Fu, R., Goodman-Smith, F., Lalor, F., & Crofton, E. (2023). Consumer attitudes to upcycled foods in US and China. *Journal of Cleaner Production*, 388, 135919. URL: https://doi.org/10.1016/j.jclepro.2023.13

The Code of Conduct for Promoting Environmental Standards among Food Producers was developed in the implementation of the EU Farm to Fork Strategy. In addition, section 2.3 of the strategy states that the European Commission will encourage producers to reduce packaging and food waste. The European Commission will support innovative approaches to packaging solutions using environmentally friendly, reusable and recyclable materials. Section 2.5 of the strategy declares the European Commission's intention to halve per capita food waste in retail and households by 2030. In addition, the European Commission will integrate food loss and waste prevention policies into other EU policies.

In the implementation of the EU Farm to Fork Strategy, in November 2022, the European Commission proposed amendments to certain directives on packaging and packaging waste[141]. The proposal notes that packaging volumes are constantly increasing. Low levels of reuse and recycling significantly hinder the achievement of a low-carbon circular economy. Packaging must be labelled in such a way that consumers know how to handle it after use. Efforts should be made to: 1) reduce the amount of packaging used; 3) eliminate packaging where possible; 4) use reusable packaging. In line with the Green Deal, the Circular Economy Action Plan (CEAP) requires stricter packaging requirements. By 2030, it must be reused or recycled.

3.2 Best practices for ecological recycling in the EU and other countries

Achieving sustainable development goals is possible with the joint efforts of the state, business, and households. Environmental costs increase costs and reduce companies' profits. Therefore, in addition to the desire of entrepreneurs themselves to introduce environmental standards, there must be state support for the greening of production.

A large transnational business was the first to start this work. Compared to medium and small companies, large businesses have greater financial and innovative resources. Powerful processing companies have already accumulated useful experience in implementing "green" technologies. The following measures are being taken at the production site: 1) electricity supply is being switched to renewable sources; 2) the use of packaging made from fossil hydrocarbons is being reduced; 3) the use of reusable packaging is increasing; 4) greenhouse gas emissions are being recorded; 5) the transition to electric vehicles is being carried out; 6) the infrastructure for charging electric vehicles is being developed; 7) the use of environmentally friendly refrigerants is increasing.

For many years, refrigeration and air conditioning systems used chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC). These chemical compounds destroyed the Earth's ozone layer. Environmentally friendly alternatives to these refrigerants are substances that can be roughly divided into two categories: natural and artificial.

Natural refrigerants include: propane (R-290), isobutane (R-600a), ammonia (R-717), and carbon dioxide (R-744). The positive properties of propane and isobutane are zero impact on the ozone layer and minimal greenhouse effect. At the same time, these gases are flammable, which requires special handling conditions. In turn, ammonia has a long service life in industrial refrigeration systems. It is characterised by zero impact on the ozone layer

[141] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0677

and zero greenhouse effect. But a significant disadvantage of this refrigerant is its high toxicity. This toxicity poses a great danger to humans in the event of a man-made accident. Carbon dioxide, as a natural refrigerant, does not deplete the ozone layer, but it does contribute to the greenhouse effect.

Synthetic refrigerants include: 1) hydrofluoroolefins, HFOs; 2) hydrofluorocarbons, HFCs; 3) mixed refrigerants.

Hydrofluoroolefins, in particular R-1234yf, R-1234ze, are a new generation of refrigerants. They have zero impact on the ozone layer and low global warming potential (Lower-GWP HFCs). Although hydrofluorocarbons do not deplete the ozone layer, they do have a significant impact on global warming.

Thus, today, among both natural and synthetic refrigerants, there is no substance that meets all environmental, technical, and safety requirements. However, modern innovative refrigerant models are more advanced than outdated options, and food industry companies are gradually switching to them.

The second important direction of ecologization of agricultural raw material processing is the rational use of water in industrial processes. In this context, many technologies have been developed that are aimed at: 1) minimising water use; 2) self-sufficiency in water resources; 3) repeated, cyclical use of water. In particular, Dry Cleaning Technologies are used to clean production equipment, premises, work shoes and clothing with minimal water use. Dry ice blasting is used to clean food processing equipment. Foam cleaning is used to clean the shoes of technical personnel in production areas. Thus, minimal amounts of water resources are used to clean production facilities.

In conditions of general water shortage and uneven distribution of precipitation over time (short-term heavy rains between long periods of drought), rainwater harvesting is of great importance. The main purpose of rainwater is for irrigation. However, it can also be used as technical water for processing on farms that process fruits and berries.

Modern systems for collecting and storing rainwater use modular tanks[142]. These containers can be stacked to form tanks of varying sizes and purposes. In particular, this applies to rainwater harvesting and the accumulation of process water. The modular tank is equipped with an environmentally friendly polypropylene membrane. The membrane ensures the tightness of the structure and long-term storage of water, including drinking water. The modules are made of corrugated steel sheet with zinc coating and have a service life of 25 years. The tanks are resistant to wind gusts up to 45 m/s and are protected from pathogenic bacteria and water bloom. The tanks are equipped with shut-off valves and water flow control sensors.

Other innovative technologies for water use in the food industry include: 1) Smart CIP (Clean-in-Place) Systems; 2) Water-Efficient Steam Generation and Condensate Recovery; 3) Advanced Water Monitoring and IoT-Based Systems.

Modern technologies for the rational use of water resources are used in the work of large food industry companies. In particular, Nestlé uses Membrane Filtration technology to purify

[142] LLC «Aquapolymer Engineering». URL: https://aquapolymer.com.ua/

and reuse wastewater[143]. Types of this technology include: reverse osmosis, ultrafiltration, nanofiltration, etc.

In addition, Nestlé is implementing the following environmental measures at its enterprises and institutions: 1) investing in research to reduce emissions; 2) using environmentally friendly raw materials (oil, cocoa, coffee) that were produced without significant greenhouse gas emissions; 3) increasing the shelf life of food products; 4) increasing the share of electricity from renewable sources; 5) introducing reusable packaging; 6) reducing the use of plastic that is not recycled or made from oil.

Danone carries out the following environmental measures: 1) modernizes production to reduce the environmental footprint of agricultural raw material processing; 2) implements measures to reduce the consumption of natural resources; 3) monitors the carbon footprint of production; 4) assesses the carbon footprint of agricultural raw material suppliers; 5) organizes internal environmental audits with the involvement of international experts from ERM and Veolia, etc.

PepsiCo is implementing the following environmental protection program: 1) modernises wastewater treatment systems; 2) actively works to introduce modern energy-saving technologies; 3) reduces consumption of natural resources; 4) reduces the amount of solid household waste.

The T.V.Fruit Group (Ukraine) processes fruit pomace into biofuel. Wood waste (chips), cherry pits, and pellets from sunflower and corn processing waste are also used for heating. Thanks to the transition to organic fuel, the company abandoned natural gas. The company transports juice concentrate in reusable containers: tanks and barrels.

Useful experience in the ecological processing of small volumes of fruit has been accumulated in Armenia. The Lukashin Agricultural Association consumer cooperative is located in the village of Lukashin, Armavir Region, Armenia. The cooperative includes 42 farms. The cooperative produces dried fruits: dried apples, apricots, peaches, pears, figs, and grapes. Approximately 15 tons of dried fruits are produced per year. The products are supplied to the domestic market as well as for export. The cooperative installed convective solar dryers and a solar water heater. This reduced fossil fuel consumption. Water reuse was introduced into the production process. After this measure, water consumption during the production process decreased by 30%.

Advanced processing practices are implemented by the Yans Closed Joint Stock Company. The company is located in the village of Akori, Lori region of Armenia. The company grows and freezes raspberries. Raspberries are grown on an area of 7 hectares. The average harvest is 80 tons. The remoteness of markets makes it difficult to sell fresh raspberries, which stimulates their processing. Raspberries are frozen to a temperature of -30 ºC to -50 ºC within a few minutes. The solar panel fully provides the electricity needed for freezing and storing berries.

Today, some of the most common packaging materials for fruit are the synthetic polymers polyethylene and polypropylene. These packaging materials have strong protective and durable properties. However, they have a number of non-environmental features: 1) are made from oil or natural gas; 2) are not biodegradable; 3) have limited possibilities for secondary use; 4) accumulate in landfills.

[143] Water-Saving Technologies in Food Processing: Advancing Sustainability in the Industry. URL: Water-Saving Technologies in Food Processing

Alternatives to traditional synthetic polymers include: 1) nanotechnology-based packaging materials; 2) starch-based polymers; 3) edible films and coatings based on natural polymers; 4) blends of traditional polymers with biodegradable materials.

Nanotechnology has enabled the creation of fundamentally new types of fruit packaging. Nanocoatings, nanofilms, and nanofibers in combination with environmental monitoring nanosensors, are highly effective in protecting fruit from oxygen, moisture, and microbes.

Research centres have already proposed several nanomaterials for packaging fruits and berries. Zinc oxide (ZnO) nanoparticles effectively inhibit bacterial growth and are used for apple preservation. Silver nanoparticles AgNPs create effective antimicrobial protection and extend the shelf life of strawberries. Also, for strawberry storage, a nanomaterial based on a composite of copper oxide (CuO) and zinc oxide (ZnO) nanoparticles in a PVA/starch/glycerol mixture has been proposed. Table 3.1 shows the shelf life of fruits and berries in traditional packaging and in packaging based on nanomaterials. Table 3.2 shows the positive effect for antibacterial protection of fruit from switching from traditional packaging to nanomaterial-based packaging.

Table 3.1 – Storage life of fruit in traditional packaging and in packaging based on nanomaterials, days

Product	Type of nanomaterial	Traditional packaging	Packaging based on nanomaterials
Strawberry	Renewable cellulose (CNF)	2	4
Strawberry	Gelatin nanocomposite	2	21
Apples, cut into pieces	Nanoemulsion of clove essential oil	1	1
Apples	Methylcellulose-chitosan nanofibre	2	7
Apples, sliced	Cellulose nanocrystals	4	11

Source: Awlqadr, F.H., Altemimi, A.B., Omar, A.M.A., Saeed, M.N., Qadir, S.A., Faraj, A.M., Al-Manhel, A.J.A., Salih, T.H., Hesarinejad, M.A. and Vieira, I.R.S. (2025), Advancing Sustainability in Fruit and Vegetable Packaging: The Role of Nanotechnology in Food Preservation. eFood, 6: e70060. URL: https://doi.org/10.1002/efd2.70060

Table 3.2 – Antibacterial properties of films and coatings based on nanoparticles

Product	Method	Film/coating type	Type of nanoparticles	Effect
Strawberry	Coating	Gelatin nanofibres with BHA	Silver nanoparticles	Shelf life increased by 10 days, microbial activity and decomposition rate decreased
Apples	Coating	Gordein-chitosan nanofibres with quercetin	Silver nanoparticles	Improved colour retention and thermal stability[1]
Strawberries	Film	PLA/chitosan/carbon nanotube nanocomposite	Carbon nanotubes	Shelf life extended by 8 days, weight loss and spoilage reduced, firmness improved, titratable acidity and ascorbic acid content preserved
Strawberries	Film	Pullulan/PVA nanofibres with MOF porphyrin nanoparticles loaded with thymol	Silver nanoparticles	Shelf life extended to 7 days due to antimicrobial action, degradation inhibition and rot prevention
Apples	Coating	Emulsions based on bacterial cellulose nanocrystals (BCNC)/fish gelatin (GelA)	Nanoparticles based on nanoemulsion	Reduced microbial degradation

[1] Ability to retain shape, taste, and nutritional properties during heat treatment

Source: Awlqadr, F.H., Altemimi, A.B., Omar, A.M.A., Saeed, M.N., Qadir, S.A., Faraj, A.M., Al-Manhel, A.J.A., Salih, T.H., Hesarinejad, M.A. and Vieira, I.R.S. (2025), Advancing Sustainability in Fruit and Vegetable Packaging: The Role of Nanotechnology in Food Preservation. eFood, 6: e70060. URL: https://doi.org/10.1002/efd2.70060

Packaging made from starch-based polymers is currently one of the most common alternatives to traditional plastic. The positive features of this packaging are its biodegradability and good mechanical properties. Among the disadvantages, it should be noted that it has weak protective properties. The protective properties of this type of ecological packaging can be improved by adding plasticisers or mixing with other polymers.

A promising type of ecological packaging for fruits and berries is edible films and coatings. These types of packaging are made from natural polymers, in particular, pectin, carrageenan, and xanthan gum[144]. Wraps and coverings are applied directly to the surface of fruits and vegetables, forming a protective layer against oxygen and moisture. After appropriate processing, the wrap and covering can be consumed with food, which reduces packaging waste.

Certain types of packaging materials based on nanotechnology are already used in the USA, China, and India. In Ukraine, starch-based packaging materials are becoming widespread in supermarket chains. However, traditional packaging based on polyethylene, polypropylene and other similar non-environmentally friendly synthetic polymers continues to hold a strong position. The problem can be solved with biodegradable packaging materials that are not inferior to traditional synthetic polymers in terms of performance and cost.

3.3. Best waste management practices from the EU and other countries

The circular economy involves the full use of waste, including the cultivation and processing of fruit. Today, fruit waste is mainly processed into compost (fertiliser) or used as feed for farm animals and poultry. Other areas of use of fruit waste are: 1) extraction of useful biologically active substances, starch, pectin, natural pigments, dietary fibre; 2) upcycling food; 3) biofuel production; 4) production of organic packaging for food products, 5) production of biochar; 6) production of natural adsorbents for water purification.

Fruit processing waste includes: peels, trimmings, stalks, shells, seeds, cores, stems, leaves, and pomace. In addition, waste includes overripe and mechanically damaged fruits and berries.

Peels and pomace are raw materials for the production of substances with antioxidant properties[145]. Fruit processing waste is a source of polyphenols (quercetin, catechin, chlorogenic acid), phytosteroids, pigments, flavonoids, organic acids, and essential oils.

Biologically active substances extracted from fruit processing waste have shown high effectiveness in the prevention and treatment of numerous chronic diseases. They have anti-inflammatory, antiviral, and antibacterial effects, and are also used to treat and prevent cardiovascular diseases. Biologically active substances help reduce cholesterol and uric acid levels in blood serum[146].

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[144] Awlqadr, F.H., Altemimi, A.B., Omar, A.M.A., Saeed, M.N., Qadir, S.A., Faraj, A.M., Al-Manhel, A.J.A., Salih, T.H., Hesarinejad, M.A. and Vieira, I.R.S. (2025), Advancing Sustainability in Fruit and Vegetable Packaging: The Role of Nanotechnology in Food Preservation. *eFood*, 6: e70060. URL: https://doi.org/10.1002/efd2.70060

[145] Antioxidants are natural or artificial substances that slow down oxidation processes. They prevent exacerbations of chronic diseases, slow down tissue aging, and are used in the pharmaceutical and cosmetic industries.

[146] Sha, S. P., D. Modak, S. Sarkar, et al. 2023. "Fruit Waste: A Current Perspective for the Sustainable Production of Pharmacological, Nutraceutical, and Bioactive Resources." *Frontiers in Microbiology* 14: 1260071. URL: https://doi.org/10.3389/fmicb.2023.1260071

Biologically active substances can be extracted from fruit waste using a number of new technologies: 1) ultrasound-assisted extraction (UAE); 2) pressurised liquid extraction (PLE); 3) supercritical fluid extraction (SFE), etc.

Apple processing waste is a source of many substances used in the food, pharmaceutical, cosmetic, fuel, and chemical industries. In particular, polyphenols extracted from apple pomace improve the condition of the cardiovascular system by reducing the level of uric acid in the blood serum. Flavonoids, phenolic acids, carotenoids, anthocyanins and other substances contained in apple pomace have antimicrobial, antiviral and other medicinal properties (Table 3.3). In addition, apple processing waste produces pectin, essential oils, dietary fibre, natural ingredients for cosmetic products, materials for the production of ecological packaging, and biofuel.

Table 3.3 – Therapeutic properties of substances extracted from apple processing waste

By-product	Major bioactives	Extraction method	Solvent	Therapeutic effect
Pomace	Phloretin, phloridzin, catechin, chlorogenic acid	Ultrasound-assisted extraction	Water	Antioxidant, antimicrobial, cytotoxic, anti-inflammatory
Peel	Chlorogenic acid, procyanidin B2	Micro-matrix solid phase dispersion	57% Methanol in water	Antiallergic, antimicrobial, antifungal
Seed	Linolenic acid, oleic acid, phloridzin, amygdalin	Folin–Ciocalteu method	Ethanol	Anticancer, antioxidant

Source: Kaushik, R., Morya, S., Bashir, O., Bhadha, J.H. and Kasankala, L.M. (2025), Valorisation of Fruit Waste Through Reutilisation Approach: A Comprehensive Review. *eFood*, 6: e70073. URL: https://doi.org/10.1002/efd2.70073

Fruit pomace has a balanced ratio of soluble and insoluble fibre, improved hydration properties, and increased fermentability. Fruit pomace contains phytochemicals. All this gives fruit pomace a unique opportunity to enrich food products (Table 3.4). To do this, fruit pomace is dried, ground, and added to food products. In particular, they are added to bakery products, pasta, sausages, fermented milk products, confectionery, etc.

Table 3.4 – Effect of adding apple pomace to food

Product	Waste type	Addition result
Wheat bread	Apple pomace powder	Increased polyphenol and antioxidant content; reduced protein and fat levels; preserved sensory quality of 10% apple pomace powder
Sausage products	Dried apple pomace	Increased fibre and phenolic content; reduced fat and calorie content
Cakes	Pomace	Increase in fibre from 0.5% to 14.2%

Sources: Kaushik, R., Morya, S., Bashir, O. , Bhadha, J.H. and Kasankala, L.M. (2025), Valorisation of Fruit Waste Through Reutilisation Approach: A Comprehensive Review. *eFood*, 6: e70073 . URL: https://doi.org/10.1002/efd2.70073 ; Grispoldi, L. ; Ianni, F.; Blasi, F.; Pollini, L.; Crotti, S.; Cruciani, D.; Cenci-Goga, B.T.; Cossignani, L. Apple Pomace as Valuable Food Ingredient for Enhancing Nutritional and Antioxidant Properties of Italian Salami. Antioxidants 2022, 11, 1221. URL: https://doi.org/10.3390/antiox11071221

The use of dried fruit pomace as an ingredient in food products is an example of creating upcycled food. Upcycle food is one of the areas of rational utilisation of food waste. Food waste from production, circulation, and consumption does not end up in landfills; instead, it is processed into new food products.

For example, the company ReGrained (USA) processes brewing waste into snack flour[147]. Nibs (UK) processes waste from apple juice production into granola and crackers. Dole (Thailand) processes substandard fruit into snacks. CJ CheilJedang (South Korea) makes snacks from substandard rice. The company Salt & Straw (USA) makes ice cream from soy milk production waste (okara). Crust Group (Singapore) collects leftover bread from restaurants and processes it into beer. Planetarians (USA) makes vegan meat from leftover yeast.

Processed foods are gaining popularity worldwide. Their production and sales are increasing. In 2021, the global processed food market was worth $53.7 billion[148]. It is expected to grow to $97.0 billion by 2031. The European processed food market will grow to $116 million by 2032. This will be driven primarily by consumption in Germany, France, and the United Kingdom.

In May 2021, the Upcycled Certified system was introduced. As of April 2025, 324 certificates were issued to upcycle food producers. According to the Upcycled Food Association, since 2021, certified upcycled food production has prevented 390 thousand tons of food waste from going to landfills annually. Since the largest share of all food waste is fruit processing waste[149], the production of upcycled food based on it is quite promising.

An important area of use for fruit waste is the production of biofuels: biomethane, bioethanol, biohydrogen, biodiesel, biobutanol. Research has shown that fruit processing waste can also be used to produce jet fuel[150]**.** In recent years, significant efforts have been made to produce bioethanol from biomass with a high lignocellulose content. This material is very common in nature. With the help of anaerobic bacteria such as Clostridium and Enterobacter, the breakdown of organic matter into hydrogen and volatile fatty acids under dark fermentation conditions produces biohydrogen. Watermelon seeds, apple pits, and peach pits can be used to extract oil, which can then be processed into biodiesel. Biogas from fruit waste is produced by anaerobic digestion and pyrolysis.

The European Union is one of the world centers of the environmental movement. It has accumulated extensive experience in waste management. The EU has created: 1) a waste monitoring system; 2) a legislative and regulatory framework for waste management; 3) information centres for stakeholders; 4) coordination associations to coordinate the actions of government, business, environmental structures and households. The implementation of the planned activities made it possible to obtain noticeable results, as well as identify problematic issues.

According to Eurostat, in 2022, there was 132 kg of food waste per person in the EU[151]. Households generated 55% of all food waste, processing – 19%, restaurants – 11%,

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[147] From Scraps To Snacks: Exploring The Rise Of Upcycled Food Products. URL**:** https://sigmaearth.com/from-scraps-to-snacks-exploring-the-rise-of-upcycled-food-products/ **;** Meet ReGrained, a company turning trash into delicious, nutritious treasure. URL: Meet ReGrained, a company turning trash into delicious, nutritious treasure | 2018-04-06 | Food Business News

[148] From Scraps To Snacks: Exploring The Rise Of Upcycled Food Products. URL**:** https://sigmaearth.com/from-scraps-to-snacks-exploring-the-rise-of-upcycled-food-products/

[149] Kim, I. J., S. Park, H. Kyoung, M. Song, and S. R. Kim. 2024. "Microbial Valorization of Fruit Processing Waste: Opportunities, Challenges, and Strategies." *Current Opinion in Food Science* 56: 101147. URL: https://doi.org/10.1016/j.cofs.2024.101147

[150] Sharma, A., Jyoti, A., More, A., Gunjal, M., Rasane, P., Kumar, M., Kaur, S., Ercisli, S., Gurumayum, S. and Singh, J. (2025), Harnessing Fruit and Vegetable Waste for Biofuel Production: Advances and Scope for Future Development. *eFood*, 6: e70051. URL: https://doi.org/10.1002/efd2.70051

[151] Preventing waste in Europe. Progress and challenges, with a focus on food waste. URL: Preventing waste in Europe - Publications Office of the EU

agriculture – 8%, and trade – 8%. In 2022, greenhouse gas emissions from waste processing amounted to 109.7 million tons of CO_2 equivalent (excluding waste-to-energy processing). This accounted for approximately 3% of all greenhouse gas emissions. In Europe, the food system accounts for more than 22% of the negative impact on the environment and climate. Of all greenhouse gas emissions from the EU food system, food waste accounts for 16%.

During 2010-2022, greenhouse gas emissions from the waste sector[152] in the EU-27 decreased from 137 million tonnes to 110 million tonnes[153]. The reduction in greenhouse gas emissions during waste processing was caused by: 1) a decrease in the storage of biodegradable waste in landfills; 2) technical arrangement of landfills; 3) processing of waste into useful substances. Emissions from waste incineration (without energy generation) decreased by 13%. Waste recycling for energy purposes increased by 49%.

A number of regulatory acts have been adopted as legal support for waste management in the European Union: 1) Waste Framework Directive 2008/98/EC; 2) The European Green Deal COM(2019) 640 final); 3) EU Climate Law (Regulation (EU) 2021/1119); 4) Single-use Plastics Directive (EU) 2019/904) and others. These regulations defined strategic objectives, plans for specific measures, responsible executors, financing mechanisms, etc.

To provide information on environmental policy, information centres and training programs were created: 1) EU platform on food losses and food waste; 2) EU food loss and waste prevention hub; 3) European Environment Information and Observation Network (Eionet); 4) training project "European citizens' panel on food waste". These information resources have become: 1) sources of information on food waste and losses in the EU; 2) methodological materials for member states and businesses to address the environmental challenges they face. The educational project "European citizens' panel on food waste" disseminated best practices for preventing food waste in everyday life among households.

The Champions 12.3 coalition was created to coordinate the efforts of all stakeholders for the successful implementation of environmental waste policy in the EU. The coalition brought together high-level leaders: governments of EU member states, businesses, international organisations, scientific institutions, public environmental organisations, farmers' associations, etc. The coalition is working to ensure the implementation of UN Sustainable Development Goal 12.3 by 2030. This goal is closely related to the problem of food waste.

The problem of implementing best practices in waste management has several aspects: technological, legal, organisational, financial, and social. Modern technologies make it possible to recycle waste from the processing of horticultural products and obtain useful and commercially profitable products. Maximum waste recycling is a powerful step towards forming a circular economy, reducing the negative impact on the environment, and ensuring food security. On the agenda is the urgent organisational issue of sorting, accumulating and recycling waste. From a social point of view, the following are important: 1) consumer adaptation to upcycle food; 2) development of a mechanism for redistributing surplus food products between different segments of the population; 3) waste sorting in households.

[152] Landfills, waste incineration without energy recovery, biological recycling

[153] Preventing waste in Europe. Progress and challenges, with a focus on food waste. URL: Preventing waste in Europe - Publications Office of the EU

3.4. Harmonisation of EU and Ukrainian environmental recycling standards

Harmonisation of standards for ecological recycling is being implemented as a continuation of harmonisation in the context of the European integration process. In the Association Agreement between Ukraine and the European Union, these issues are addressed in Chapter 17 “Agriculture and Rural Development” and Chapter 6 “Environment” of the Section V “Economic and Sectoral Cooperation”. Harmonisation covers standards for production, packaging, labelling, waste management, etc.

In accordance with Article 405 of Chapter 17 “Agriculture and Rural Development”, the parties to the Association Agreement agreed to gradually approximate and harmonise EU standards, which are included in Annex XXXVIII to Chapter 17. In particular, Annex XXXVIII to Chapter 17 contains EU directives for the implementation of which no deadline has been set:

- Council Directive 2001/112/EC of 20 December 2001 relating to fruit juices and certain similar products intended for human consumption,
- Council Directive 2001/113/EC of 20 December 2001 relating to fruit jams, jellies and marmalades and sweetened chestnut purée intended for human consumption.

A comparison of Ukrainian standards[154] and Council Directive 2001/112/EC identified areas for their harmonisation. In particular, it was necessary to harmonise the following in the Ukrainian standards: 1) terminology; 2) list of permitted ingredients; 3) processing methods; 4) content of pulp or concentrated juice/puree in fruit nectars; 5) minimum content of soluble solids. These requirements were taken into account in the order of the Ministry of Agrarian Policy and Food dated 07/31/2023 No. 1450 “On approval of the Requirements for fruit juices and certain similar food products”[155].

The harmonisation of Council Directive 2001/113/EC with domestic regulations[156] took place, among other things, within the framework of the EU project "Support for the Implementation of Agricultural and Food Policy in Ukraine". To implement the EU directive into domestic legislation, employees of the Ministry of Agrarian Policy and Food, the State Service on Food Safety and Consumer Protection, specialised associations, manufacturers, importers, etc., were involved. As a result, the Ministry issued an order dated 02/14/2024 No. 391 “On approval of the Requirements for fruit jams, jellies, marmalades and sweetened chestnut puree”, which implemented the provisions of the EU directive into domestic legislation[157].

In March 2024, experts from UNIDO prepared Action plans for the green recovery and transformation of the Ukrainian food industry[158]**.** One of the sections of the Action Plan was dedicated to the processing of horticultural products.

In the context of the EU Green Deal, the Ukrainian food industry faces the following strategic objectives: 1) reducing carbon emissions; 2) reducing waste; 3) increasing waste recycling; 4) switching to renewable energy sources; 5) increasing energy efficiency; 6) saving water; 7) switching to eco-friendly packaging; 8) increasing energy independence to counter power outages; 8) introducing new technologies for freezing and storing frozen products, in particular, isochoric freezing; 9) phasing out the use of hydrofluorocarbons as refrigerants.

[154] DSTU 4283.1:2007 DSTU 4283.2:2007 Juices and juice products; 2) DSTU 7159:2010. Canned, reconstituted juices

[155] The order of the Ministry of Agrarian Policy and Food dated 07/31/2023 No. 1450 “On approval of the Requirements for fruit juices and certain similar food products”. URL: https://zakon.rada.gov.ua/laws/show/z1391-23#Text

[156] DSTU: 4900:2007 Jams. General technical conditions; 2) DSTU 4333:2018 Marmalade. General technical conditions; 3) DSTU 6094:2009 Fruit jellies. Technical conditions

[157] The order of the Ministry of Agrarian Policy and Food dated 02/14/2024 No. 391 “On approval of the Requirements for fruit jams, jellies, marmalades and sweetened chestnut puree”. URL: Про затвердження Вимог до фрукто... | від 14.02.2024 № 391

[158] Action plans for the green recovery and transformation of the Ukrainian food industry. URL: https://www.unido.org/sites/default/files/unido-publications/2025-01/Action-Plans-for-Green-Recovery-and-Transformation-of-Ukrainian-Food-Industries.pdf

Hydrofluorocarbon (HFC) belongs to the group of fluorinated greenhouse gases (F-gases). Regarding F-gases, the EU has adopted two legislative acts: the F-gas Regulation[159] and the MAC Directive[160]. In April 2022, the European Commission came out with a proposal to update the F-gas Regulation. This document was aligned with the European Green Deal, European Climate Law, and the EU's international obligations under the Montreal Protocol. In this context, Regulation (EU) 2024/573 of the European Parliament and of the Council of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014 was adopted[161].

3.5. Harmonisation of waste management standards between the EU and Ukraine

In accordance with Article 361 of Chapter 6 “Environment” of Section V “Economic and Sectoral Cooperation” of the Association Agreement between Ukraine and the EU, the parties to the Agreement agreed to cooperate, among other things, in addressing climate change and waste management.

In accordance with Article 363 of Chapter 6 “Environment” of Title V “Economic and Sectoral Cooperation” of the Association Agreement, Ukraine has undertaken to approximate its legislation to that of the EU in the field of environmental protection within the established deadlines in accordance with Annex XXX to Chapter 6.

In accordance with Annex XXX, Ukraine undertakes to harmonise its legislation with the provisions of Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives within the established deadlines (Table 3.5). After the adoption of the Law of Ukraine “On Waste Management” dated 20.06.2022 No. 2320-IX, the provisions of Directive No. 2008/98/EC were partially implemented.

Table 3.5 – Deadlines for implementing the provisions of Directive 2008/98/EC on waste

Provision	Implementation period[1], years
Adoption of national legislation and designation of the competent authority(ies)	3
Preparation of waste management plans in accordance with the five-step waste hierarchy and waste prevention programmes (Chapter V of Directive 2008/98/EC)	3
Establishing a full cost recovery mechanism in accordance with the polluter pays principle and the principle of extended producer responsibility (Article 14)	5
Establishing a permit system for establishments/undertakings carrying out waste disposal or recovery operations, with specific obligations regarding the management of hazardous waste (Chapter IV of Directive 2008/98/EC)	5
Introduction of a register of undertakings carrying out waste collection and transportation (Chapter IV of Directive 2008/98/EC)	5

[1] From the date of entry into force of the Association Agreement (01.09.2017)
Source: Association Agreement between the European Union and its Member States, of the one part, and Ukraine, of the other part. URL: EUR-Lex - 22014A0529(01) - EN - EUR-Lex

[159] Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006. URL: Regulation - 517/2014 - EN - EUR-Lex

[160] Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air conditioning systems in motor vehicles and amending Council Directive 70/156/EEC. URL: Directive - 2006/40 - EN - EUR-Lex

[161] Regulation (EU) 2024/573 of the European Parliament and of the Council of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014. URL: Regulation - EU - 2024/573 - EN - EUR-Lex

In accordance with Annex XXX, Ukraine undertakes to harmonize its legislation with the provisions of Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste within the established deadlines (Table 3.6). After the adoption of the Law of Ukraine "On Waste Management" dated 20.06.2022 No. 2320-IX, the provisions of Directive No. 1999/31/EC were partially implemented.

Table 3.6 – Deadlines for implementing the provisions of Directive 1999/31/EC

Provisions	Implementation period[1], years
Adoption of national legislation and designation of the competent authority(ies)	6
Classification of waste disposal sites (Article 4)	6
Preparation of a national strategy to reduce the amount of biodegradable municipal waste sent to landfills (Article 5)	6
Establishing a system of application and permit procedures, as well as waste acceptance procedures (Articles 5-7, 11, 12 and 14)	6
Establishing control and monitoring procedures during the operation and closure of landfills, as well as procedures for subsequent care after closure to ensure their neutralization (Articles 12 and 13)	6
Implementation of clean-up plans for existing landfills (Article 14)	6
Establishment of a cost calculation mechanism (Article 10)	6
Ensuring the necessary treatment of relevant waste before its disposal (sending to landfills) (Article 6)	6

[1] From the date of entry into force of the Association Agreement (01.09.2017)
Source: Association Agreement between the European Union and its Member States, of the one part, and Ukraine, of the other part. URL: EUR-Lex - 22014A0529(01) - EN - EUR-Lex

In accordance with Annex XXX, Ukraine has undertaken to harmonize its legislation with the provisions of Directive No. 2003/87/EC establishing a scheme for greenhouse gas emissions trading within the Community and amending Directive No. 96/61/EC, as amended by Directive No. 2004/101/EC, within the established deadlines. After the adoption of the Law of Ukraine "On the Principles of Monitoring, Reporting and Verification of Greenhouse Gas Emissions" dated 12.12.2019 No. 377-IX, the provisions of Directive No. 2003/87/EC were minimally implemented.

Table 3.7 – Deadlines for implementing the provisions of Directive 2003/87/EC

Provision	Implementation period[1], years
Adoption of national legislation and designation of the competent authority(ies)	2
Establishment of a system for identifying relevant facilities and determining greenhouse gases (Annexes I and II)	2
Development of a national plan for the distribution of quotas between factories (Article 9)	2
Introduction of a greenhouse gas emissions permit system and quotas to be sold at the national level between plants/industrial complexes in Ukraine (Articles 4 and 11-13)	2
Establish a system of monitoring, reporting, inspections and proper implementation, as well as public consultation procedures (Articles 9, 14-17, 19 and 21)	2

[1]From the date of entry into force of the Association Agreement (01.09.2017)

Source: Association Agreement between the European Union and its Member States, of the one part, and Ukraine, of the other part. URL: EUR-Lex - 22014A0529(01) - EN - EUR-Lex

In the implementation of the EU Farm to Fork Strategy, the European Commission has proposed amendments to certain directives on packaging and packaging waste. The proposal was sent to the European Parliament and the Council of the EU on 30.11.2022. The European Parliament and the Council then introduced a new regulation aimed at reducing, reusing and recycling packaging waste[162]. This regulation, known as the Packaging and Packaging Waste Regulation, amended Regulation (EU) 2019/1020 and Directive (EU) 2019/904.

In the EU, 40% of plastic and 50% of paper are used for packaging. 36% of municipal solid waste consists of packaging residues. The volume of packaging is constantly increasing. The level of reuse and recycling is low. This significantly hinders the formation of a low-carbon circular economy. During 2012-2020, the amount of packaging on the EU market increased, which, by its design, hindered recycling after use. It could not be separated into separate homogeneous parts that could be recycled using the same technology. Therefore, packaging must be designed and manufactured in such a way that it can be separated into homogeneous parts after use.

The Regulation on Packaging and Packaging Waste set the following objectives: 1) to reduce the amount of packaging in use relative to its volume and weight; 2) to reduce the amount of packaging used; 3) to abandon packaging where possible; 4) to increase the use of reusable packaging.

According to the new rules, all packaging, except lightweight wood, cork, textile, rubber, ceramic, porcelain and wax, must be recyclable.

According to the regulation, online retailers and other entrepreneurs are responsible for the disposal and recycling of packaging waste in accordance with the principles of extended producer responsibility.

The regulation set a goal of recycling 55% of all packaging by 2025, 60% by 2030, and 70% by 2035.

The packaging materials industry in Ukraine is quite well developed. Among the most powerful manufacturers are the following companies: 1) Vetropack Gostomel Glass Factory; 2) Rubizhne Cardboard and Package Mill; 3) Plast-Box; 4) Planet Plastic; 5) Technocom; 6) Kyiv Cardboard and Paper Mill. The interests of the industry are protected by the Club Packagers of Ukraine, which is a member of the World Packaging Organisation (WPO).

The industry is largely dependent on imported supplies. Domestic enterprises import many raw materials for the production of modern packaging materials.

In 2020, 80-85 kg of packaging materials were used per capita in Ukraine per year. The volumes of packaging materials and packaging waste were smaller than in Europe. However, their volumes were growing rapidly. Over the past 15 years, the production and consumption of packaging materials in Ukraine has increased by 3-3.5 times. According to the survey, 78% of packaging material manufacturers plan to switch to sustainable packaging production[163]. But at the same time, 62% of producers noted that they do not have the financial resources for this.

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[162] REGULATION (EU) 2025/40 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 December 2024 on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC. URL: Regulation - EU - 2025/40 - EN - EUR-Lex

[163] Action plans for the green recovery and transformation of the Ukrainian food industry. URL: https://www.unido.org/sites/default/files/unido-publications/2025-01/Action-Plans-for-Green-Recovery-and-Transformation-of-Ukrainian-Food-Industries.pdf

Domestic regulations on the use and recycling of packaging include: 1) Law of Ukraine “On Waste Management” dated 06/20/2022 No. 2320-ИХ; 2) Order of the Ministry of Economy and European Integration of Ukraine “On Approval of the Procedure for Collection, Sorting, Transportation, Recycling and Utilization of Used Packaging (Packaging)” dated 10/02/2001 No. 224.
Comparison of domestic regulations on the use and recycling of packaging with EU regulations indicates the need to take the following measures: 1) adoption of the Law on the Production, Use and Recycling of Packaging; 2) updating in the context of reducing the "carbon footprint" of the Law of Ukraine "On Waste Management" dated 06/20/2022 No. 2320-IX; Order of the Ministry of Economy and European Integration of Ukraine dated 10/02/2001 No. 224; standards GOST 13799-81 and GOST 23285-78.
The Law on the Production, Use and Recycling of Packaging should provide for: 1) a reduction in the production of packaging from fossil fuels; 2) a strategy to increase the share of packaging that is recycled; 3) measures to reduce packaging volumes; 4) the introduction of innovative packaging recycling methods.

3.6. Proposals and priorities for environmentally friendly recycling and waste management

1. Introduce a system for monitoring food waste generation along the entire life cycle chain of the processed product: cultivation of agricultural raw materials, processing, storage, transportation, sale, and final consumption by households. Actual data on the volume and dynamics of fruit waste generation, methods of waste management at all stages of the life cycle will make it possible to better plan measures to reduce the amount of waste, as well as its rational utilisation.
2. Among all possible measures to introduce environmental practices (regulatory, economic, voluntary, informational), it is feasible to give priority to regulatory and economic ones. This is evidenced by the experience of the EU. The first waste prevention programs relied mainly on “soft” political instruments: voluntary initiatives, information campaigns. But the specificity of environmental measures is that they do not increase the competitiveness of businesses. Environmental measures are actually a burden for entrepreneurs and households. Therefore, while maintaining “soft” political instruments, it is necessary to give priority to more stringent ones. In particular, these are regulatory measures (mandatory regulations, prohibitions, etc.) and economic measures (tax incentives, extended producer responsibility, etc).
3. In order to achieve synergies, it is recommended to integrate measures for the ecological management of waste with strategies for biodiversity and climate change. Climate change, biodiversity loss, accumulation of food waste are closely interrelated problems. Reducing food waste reduces greenhouse gas emissions and reduces pressure on ecosystems. Currently, measures to prevent food waste are not sufficiently integrated into biodiversity and climate strategies. This reduces the opportunities for synergies. Therefore, it is recommended to consider these three environmental problems in a complex manner.
4. To provide information and methodological support for environmental policy, it is important to create information platforms on the Internet dedicated to waste management issues. These information centres (portals) will become a source of best practices, regulatory documents, statistical data, scientific publications, etc., for interested parties

(government bodies, businesses, environmental organisations, households). Since the bulk of food waste is generated in households, it is important to supplement these information platforms with educational programs aimed directly at households.

5. To coordinate the efforts of various stakeholders, it is feasible, following the example of the EU, to create a broad coalition of representatives of government, business, environmental organisations, scientific institutions, and public associations to exchange information and experience, discuss current problems, draft regulations, and conduct training programs and educational campaigns.

4 INTRODUCTION AND DEVELOPMENT OF RENEWABLE ENERGY SOURCES IN AGRICULTURE, INCLUDING FRUIT AND BERRY GROWING

4.1 Current state and perspective of RES use in Ukraine and the EU

Energy is one of the most important resources. Two key indicators describe energy flows: total energy supply and final consumption. In general, the first one means all available energy for consumption by society and economy, including losses due to energy transformations, transmission, distribution, etc[164]. The second indicator describes the energy consumption at the so-called “farm/enterprise/household level”[165] .

Features of European energy supply and consumption

Total energy supply (TES) in the EU was quite stable until the energy crisis and further Russian invasion of Ukraine. During 2014-2019, the annual TES was 1400 Mtoe, decreasing on average by 6% in 2020-2023. There are two key trends:

- fossil fuels still play a key role in satisfying energy needs, supplying ⅔ of energy;
- there is a gradual growth in renewable energy sources – renewables and biofuels (RE)[166] due to the increase of wind, solar and biofuels, mainly: from 14.3% in 2014 to 20.7% in 2023 (Fig. 4.1).

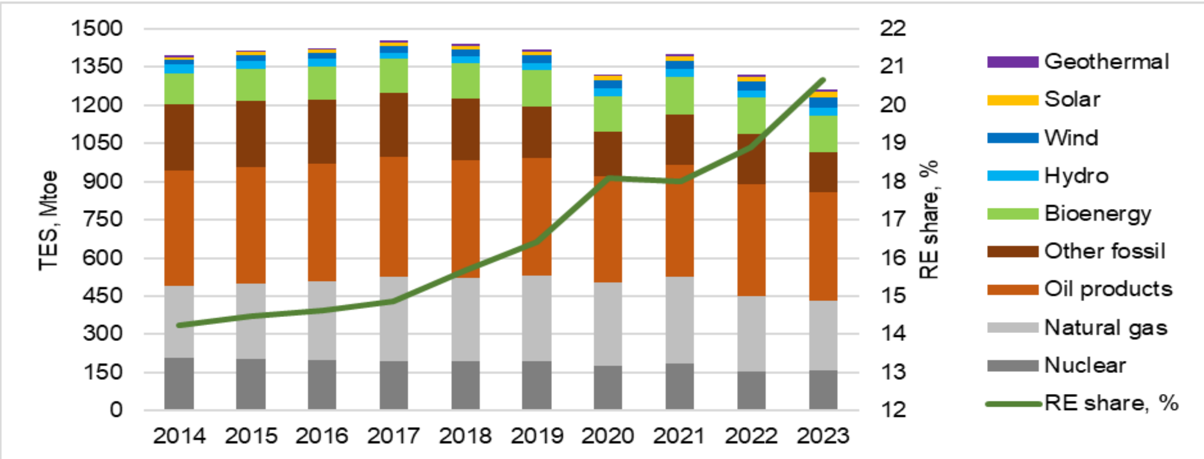

Figure 4.1 – Total energy supply and the RES share in the EU

Source: Eurostat

The highest RES share in TES is in Latvia, Sweden, Norway and Iceland, providing more than half of the energy supply (Annex 4).

Biofuels provide more than half of RES, supplying on average 137 Mtoe. All biofuels revealed the increasing trend during 2014-2023. Bioethanol and biodiesel revealed the highest growth (two-fold) among biofuels, supplying in 2023 3% and 11% of the total volume of biofuels, respectively. Therefore, the share of biodiesel has equalled the share of biogas. Feedstock for their production come mainly from agriculture. Also, agriculture supplies some part of the largest group of biofuels - solid biofuels (Fig. 4.2).

[164] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Total_energy_supply
[165] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Final_energy_consumption
[166] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Renewable_energy_sources

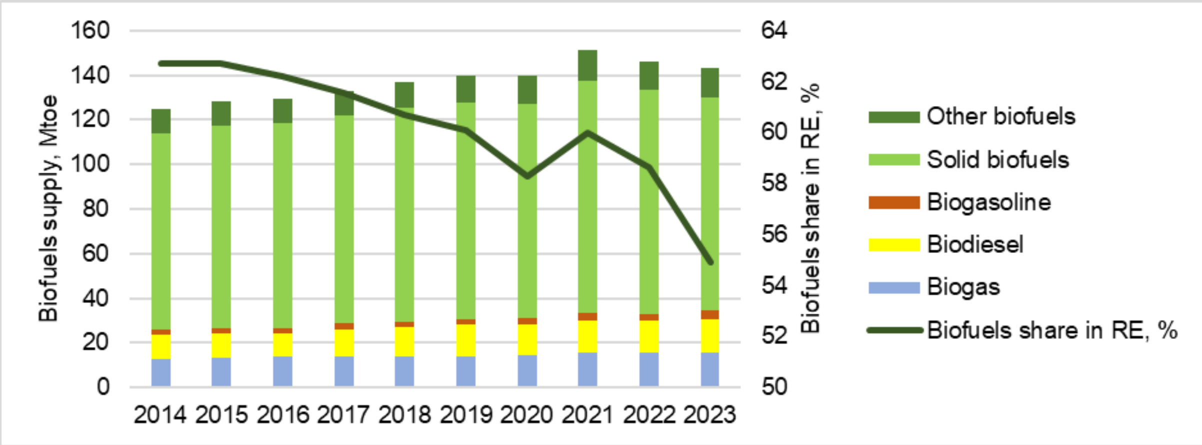

Figure 4.2 – Biofuels supply and share in RES in the EU

Source: Eurostat

The volume of biofuels is more than enough to provide energy self-sufficiency for agriculture and forestry (below – agriculture). The EU's annual ***final energy consumption*** (including oil and petroleum, electricity, natural gas, renewables and biofuels, and solid fossil fuels) by agriculture was 26.6 Mtoe during 2014-2023. In 2018-2021, the annual energy use by agriculture and forestry increased by 13.5% compared to 2014-2017. During 2022-2023, it fell by 6% compared to 2018-2021, but it was 7% higher than in 2014-2017 (Fig. 4.3).

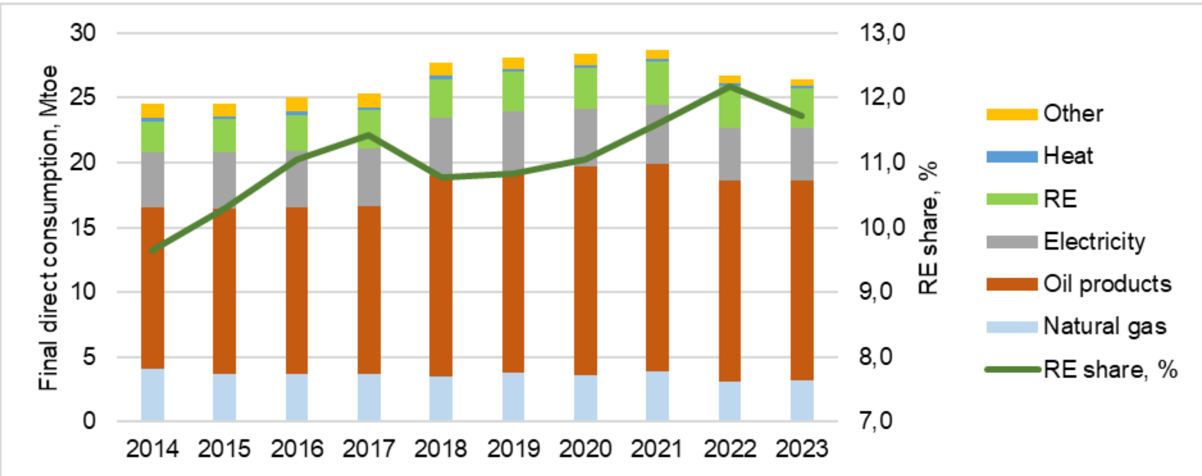

Figure 4.3 – Final energy consumption by agriculture in the EU

Source: Eurostat

Agriculture accounted for 2.9% of total direct energy use on average during 2014-2023, reaching the maximum in Latvia (4.7%), Poland (5.3%), and the Netherlands (8.5%).

The EU’s agriculture is still strongly dependent on fossil fuels, particularly petroleum products. During 2014-2023, the volume of petroleum use increased by 3 Mtoe, or 7,2 pp, representing 58,3% of final energy consumption by agriculture in 2023. Electricity and natural gas are the next important energy sources, with approx equal shares, covering ⅓ of final energy consumption in 2004 and decreasing to ¼ in 2023, mainly due to the natural gas shortage in

2022-2023. Against the background of these trends, the usage of renewables and biofuels in agriculture revealed a growing trend during 2014-2022 (except for a slight decline in 2023), supporting the EU effort for the mitigation of global climate change (Fig. 4.4).

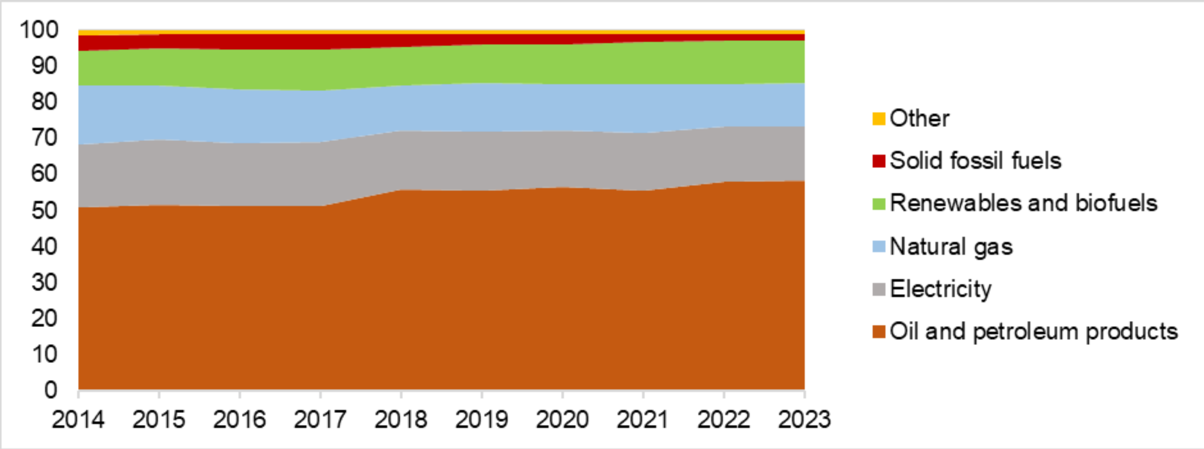

Figure 4.4 – Final energy consumption structure by EU agriculture, %

Source: Eurostat

Agriculture and rural areas are central to the European Green Deal. The new CAP for 2023-2027 aims to boost the previous CAP period efforts and to reach the ambitious targets of reducing GHG emissions, safeguarding natural resources (in particular, non-renewable energy sources), and enhancing biodiversity, which are supporting 2030 targets, including a minimum of 42.5% renewable energy target, which is more ambitious than target set in 2018 – 32%[167].

The previous renewable energy target – at least 22% for 2020 – has been successfully achieved: the actual share of RE in gross final energy consumption[168] was confirmed at 22.1%[169]. All European countries, except France, confirmed their targets. Some of them succeeded more than others, in particular, Sweden (60%) had by far the highest share among the EU Member States, ahead of Finland (44%) and Latvia (42%); at the opposite end of the scale, the lowest proportions of renewables were registered in Malta (11%), followed by Luxembourg (12%) and Belgium (13%)[170]. In 2023, the renewables share accounted for 24.5%, which is 2.5 times higher than in 2004 (9.6%). Among the countries with a low (less than 3%) starting position in renewables usage, the highest progress was noted in Malta and the Netherlands (15 pp), Ireland and Belgium (13 pp), and Luxembourg (11 pp). Among the countries with a high RE share in 2004 (more than 25%), the best gain was accounted for by Sweden (28 pp), Finland and Iceland (21 pp), Norway (17 pp), and Latvia (10 pp).

Agriculture contributed to achieving this target. During 2014-2020, the amount of RE, used for direct consumption in agriculture, increased by 32.5%, reaching 3,14 Mtoe in 2020 (total direct energy consumption by agriculture increased by 15%). As a result, the share of RE in

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[167] 2030 Targets. European Commission. https://commission.europa.eu/energy-climate-change-environment/overall-targets-and-reporting/2030-targets_en

[168] https://www.eea.europa.eu/help/glossary/eea-glossary/gross-final-energy-consumption

[169] Renewable energy targets. European Commission. https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en

[170] EU overachieves 2020 renewable energy target. Eurostat. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220119-1

total direct energy consumption by agriculture rose from 9.6% in 2014 to 11.0% in 2020. In 2021 and 2022, the RE growing trend continued, after which there was a slight reduction in 2023, compared to 2022, but it was still higher than during 2014-2021 (Fig. 4.3). Among the EU countries, the highest RE share (more than 25%) was achieved in Sweden, Austria, Czechia, and Finland (Annex 5).

Biofuels cover 91-95% of RE consumption by agriculture in EU. Among biofuels, the leading share takes by solid biofuels, decreasing year by year. Biogas takes second place with a quite stable share of approx 30%. Biodiesel is high increasing biofuel, starting with 3,5% in share in 2014 and reaching a share of 15% in 2023 (Fig. 4.5).

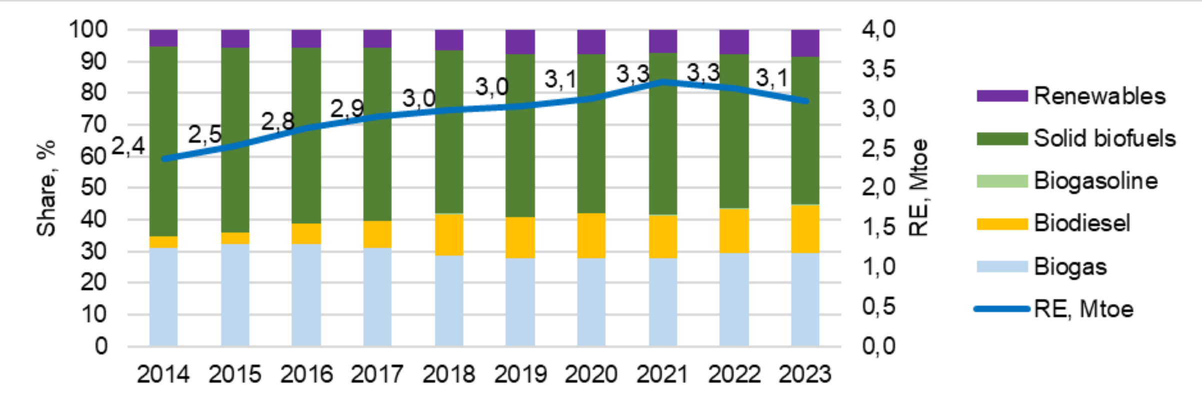

Figure 4.5 – RE consumption by agriculture in the EU

Source: Eurostat

Features of Ukrainian energy supply and consumption. Unlike European countries, Ukraine remains more dependent on fossil fuel supplies. The volume of TES in Ukraine is comparable to that in Poland and 2.5 times less than in France. However, renewables and biofuels provide a threefold smaller share than in the above-mentioned countries. Fossil fuels provide 70% of TES in Ukraine, followed by nuclear with a 25% share. Starting from 2015, the share of natural gas in TES decreased from approx. 35% to approx. 25%. The solid fossil fuels showed the same trend as natural gas. The increase in oil products supply covered some part of the decrease in the mentioned fossil fuels. Also, supply of renewables and biofuels increased by 2 Mtoe between 2014-2020, providing the twofold growth of RE share in TES: from 2,6% in 2014 to 5,6% in 2020 (Fig. 4.6)

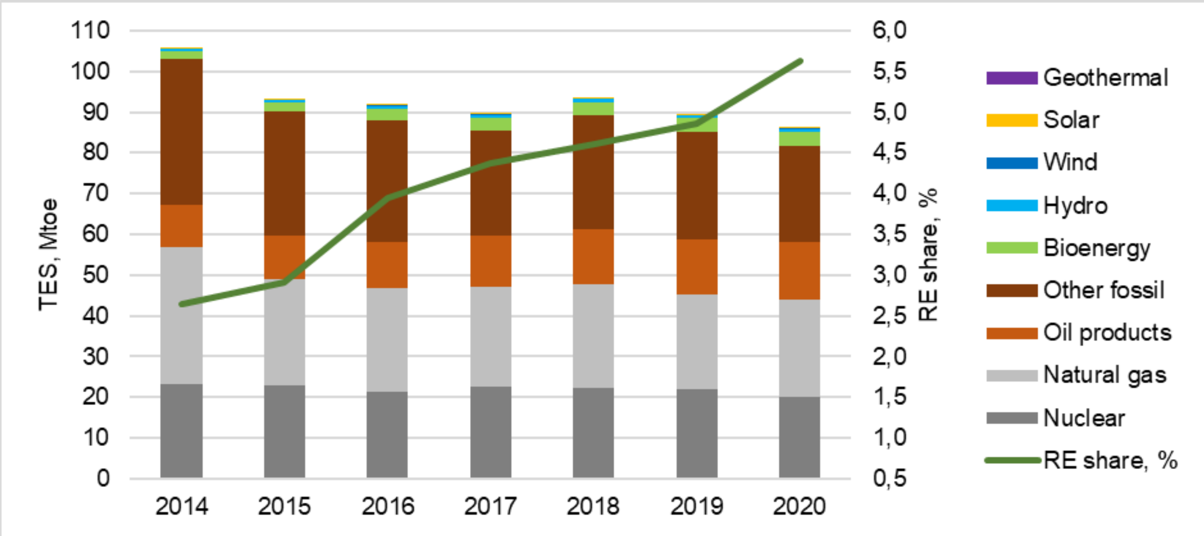

Figure 4.6 – Total energy supply and the RE share in Ukraine

Source: Eurostat

Concerning RE, Ukraine has some features that differ from other European countries. First, biofuels provide a bigger share of RES supply: 70-78%, depending on the year (Fig. 4.7). Second, hydro is the largest of non-combustible sources (compared to wind in Europe), followed by solar with 10% share. Wind source, which is the largest in Europe (approx. 15% of RE), is only the third one in Ukraine, covering approx. 5% of RE supply, due to lower wind potential in Ukraine than in Europe (Fig. 4.8).

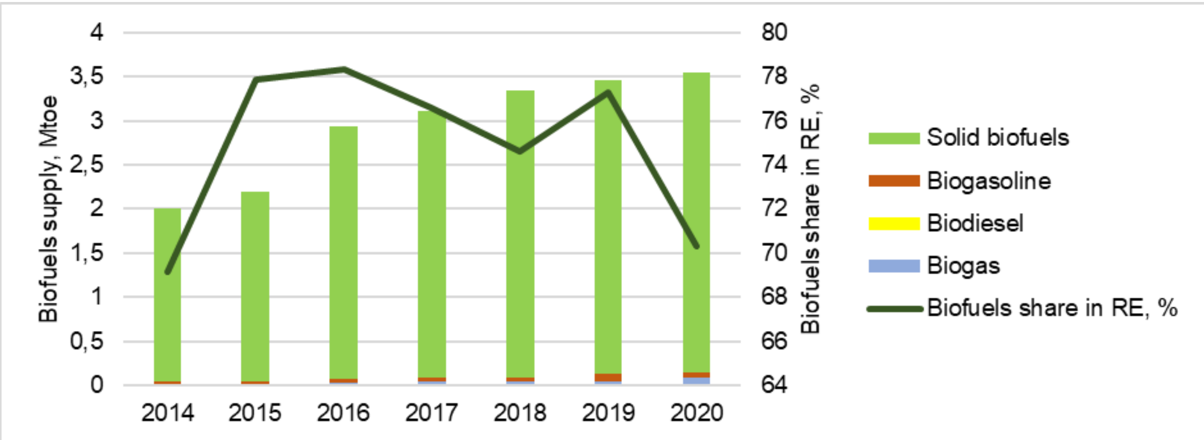

Figure 4.7 – Biofuels supply and share in RES in Ukraine

Source: Eurostat

The supply of biofuels in Ukraine is less diversified than in the EU. More than 95% of biofuels are solid, mainly from forestry and less from agriculture (sunflower and grain residues).

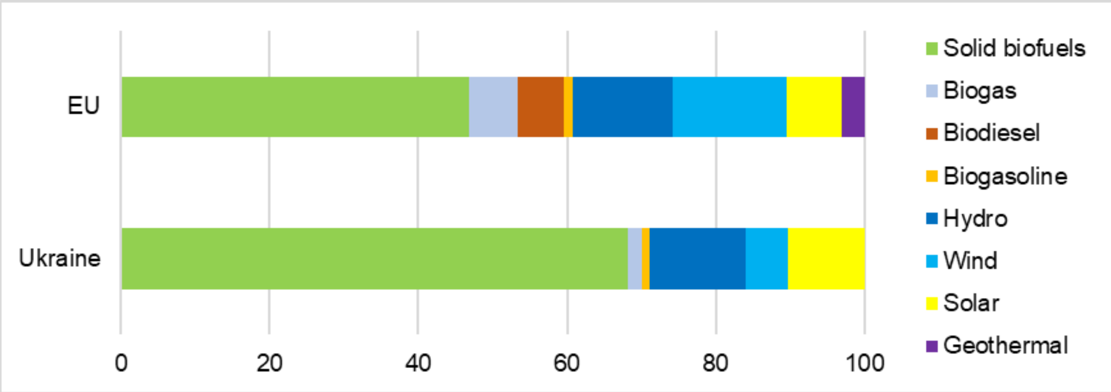

Figure 4.8 – RES structure in 2020: UA and EU comparison

Source: Eurostat

Ukrainian agriculture and forestry consume approx. 4% of total final energy, which is 1 pp higher than the EU average, but 1,5 pp less than the Polish figure. The final direct energy consumption by Ukrainian agriculture decreased during 2014-2020 from 2,0 Mtoe to 1,66 Mtoe (Fig. 4.9). Agriculture is highly dependent on fossil fuels. Renewables and biofuels account for a negligible share of direct energy consumption – approx. 2%, which is 5 times less than the average EU level, but still higher than in some countries like Portugal, Croatia, and Moldova (Annex 6).

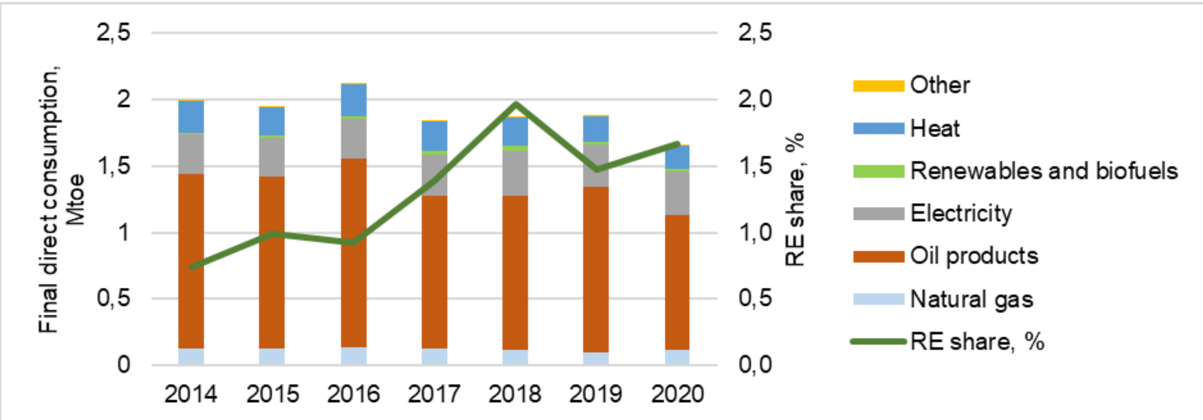

Figure 4.9 – Final direct energy consumption by agriculture in Ukraine

Source: Eurostat

Features and trends during the invasion of Ukraine. Due to the war in Ukraine, official energy data is limited, but some professional and expert organisations provide overviews on energy trends, including RE.

Unfortunately, during 2022, 94% (1.4 GW) of wind capacities were occupied, and 31% (2.0 GW) of solar generation was occupied or destroyed.

Despite the war, the Ukrainian energy system is developing, supporting net-zero emission goals: 312 MW of new renewables were installed in 2022, and 350 MW in 2023[171]. About 157 MW of new wind power capacity, 56 MW of SPP, and 23 MW of biomass worked within

[171] https://ua-energy.org/uk/posts/ukraina-protiahom-dvokh-rokiv-vvela-660-mvt-novykh-potuzhnostei-vde-minenerho

a feed-in-tariff in 2023. The capacity of biomass-operated TPPs/CHPs increased by 23.6 MW and reached 178 MW in 2023, including 110 MW operating on agricultural residues (sunflower husk). The installed capacity of biogas facilities has not changed during 2023 and accounts for 135 MW. Consequently, the total installed capacity of RES facilities for electricity generation reached 8.8 GW in 2023.

In 2023, the total volume of electricity production from biogas increased by 15% to 580 million kWh. The average utilisation rate of the installed electrical capacity of biogas plants is 49%. Of the total number, 20 installations did not produce electricity at all. Only 5 plants had indicators of installed capacity use at the level of 75-82%[172].

RE sources supplied 8 TWh (8.8% of total electricity supplied to the grid) of electricity within a feed-in tariff in 2023, an increase of 27% compared to 2022[173].

Biomethane. During 2022-2024, 7 biomethane plants were planned to start their activity with a total capacity of 111 million m³: two plants each are planned to be launched in Vinnytsia and Khmelnytskyi regions (with a total capacity of 94 million m³) and three plants in Kyiv, Dnipro and Chernihiv regions[174]. They mainly used manure (from pigs, cows, and poultry) as a raw material, adding crop residues or corn silage. At the end of 2024, two Ukrainian biogas plants supplied the first million cubic metres of biomethane to the Ukrainian gas underground storage[175].

4.2 RE options in horticulture

Modern horticulture is facing diverse challenges, and the most negatively affected ones come from climate change. An increase in the average annual temperature, prolonged heat waves lead to a number of negative effects, the main of which are a higher level of moisture evaporation, sunburn of plants and fruits. A decrease in the frequency of precipitation and an increase in its intensity lead to a decrease in moisture supply, damage to plantings, and intensive leaching of nutrients from the soil. An increase in the frequency and intensity of adverse weather and climatic phenomena (hail, thunderstorms, downpours, frosts) leads to a loss of plant productivity, excessive damage to fruits, etc. Some protective measures and preventive options are required to minimiie these negative effects. Some of these measures and options (e.g., irrigation) have become more available to farmers during the last decade due to renewables' wider sharing (PV panels, wind turbines, etc.). Nowadays, the general list of RE options, implemented in agriculture and, in particular, horticulture, includes a wide range of applications, providing various benefits (Table 4.1).

[172] https://saf.org.ua/en/news/1866/

[173] https://www.nerc.gov.ua/storage/app/sites/1/Docs/Byuleten_do_richnogo_zvitu/broshura_do_richnogo_zvitu_nkrekp-2023.pdf

[174] https://agrotimes.ua/opinion/u-agrariyiv-velyki-perspektyvy-u-vidnovlyuvalnij-energetyczi/

[175] https://ua-energy.org/uk/posts/ukrainski-vyrobnyky-zakachaly-do-merezhi-ta-psh-vzhe-1-mln-kub-m-biometanu

Table 4.1 – RE options for horticulture

Renewables type	Application	Benefit
Solar photovoltaic	Irrigation pumps, lightning, HVAC appliances	Modular, scalable. Excess electricity can be sold back to the grid
Wind	Irrigation pumps, lightning, HVAC appliances	Modular, scalable. Hybrid solar + wind systems overcome intermittency
Solar thermal	Water heating, space heating	Reduces natural gas usage
Anaerobic digestion	Electricity, heat, renewable natural gas	Produces biofertilizer. Reduces GHG emissions
Waste gasification / pyrolysis	Process heating, electricity generation	Generates bio-oil and syngas to replace fossil fuels
Waste incineration	Process heating, electricity generation	Reduces waste volume. Nutrient recovery from ash
Biodisiesel / Renewable diesel	Tractors, generators, boilers	50%+ reduction in lifecycle emissions vs diesel
Biethanol	Gasoline substitution	Substitutes for fossil fuels. Higher blends are used efficiently
Renewable natural gas	Heating, drying, electricity, curing	Cost-effective. Compatible with existing infrastructure

Source:[176]

Opportunities for RE uses in horticulture stipulated by the growing electricity consumption within the production processes, main of which are:

- irrigation and introducing fertilizer, which are applicable for both open-field and greenhouse technologies;
- heating, ventilation, air conditioning (HVAC), and lightning, which are more applicable for greenhouses;
- pest and disease control, supported by vehicles (diesel engine) in open-field horticulture and by stationary electrical solutions for greenhouses.

Solar photovoltaic. The use of solar stations for electricity production has become widespread, including in agriculture, due to the rapid development of technology and the reduction in the cost of solar panels.

Farmers, based on the characteristics of agricultural activities and the availability of power grids, can use solar stations in one of three available connection methods:

- Off-grid stations - as a rule, are used when the entity is remote from power grids and to ensure an uninterrupted electricity supply in case of their unreliability. The efficiency of off-grid solar stations is increased by using batteries to store energy during times of excess and consume it during the absence of an energy source.
- Grid stations - are practised when there is a connection to centralised power grids in order to save money when purchasing electricity from the grid and receive additional income from selling excess energy produced by solar stations through incentive mechanisms (e.g., green tariff, etc.).
- Hybrid stations - combine the capabilities of the above-described solar power stations. The presence of a hybrid inverter expands the options for using a solar power plant, allowing you to program energy storage and consumption modes.

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[176] Indurthi et al. Horticultural innovations elevating crop yields and agricultural sustainability for a flourishing future. Plant Cell Biotech. Mol. Biol., vol. 25, 2024, no. 1-2, pp. 22-44. DOI:10.56557/PCBMB/2024/v25i1-28560

Agrivoltaic systems (AVS) are the integration of solar power production as the most promising renewable energy sources and agricultural activities. AVS support the energy security, safeguarding the traditional agrarian activities within the same land plot. In this way, energy production within AVS provides additional income, which is often several times higher than the main one, for farmers, diversifying their activities.

AVS are growing option in horticulture due to the production features, in particular:

- long production life cycle;
- planting system;
- requirements for cover from hail and frost, and in some cases from excessive sun radiation.

Emerging AVS can be differentiated into three types:

- Static
- Full-sun tracking
- Agronomic tracking.

AVSs shade 10 to 55% of the land area with photovoltaic panels (with an average range of 30 to 40%). Shading impacts on crop yields range from positive to negative depending on crops, locations and used technology. Under low–moderate shading percentages (less than 30%), crops behave moderately well, productivity is maintained or only slightly affected (5% decline)[177]. In the case of some crops, like strawberries or other berries with lower light demand, even higher shading would be acceptable, while for apples, reduced light availability would result in lower bud and flower numbers and reduced function, lower amount of fruits, about one week later harvest, and complications in fruit colouring. On the other hand, apple varieties that are sensitively reacting toward excessively high solar radiation can be protected against sunburn by shading during the most intense midday hours, which is confirmed by the practical experience of the extremely hot 2025 season[178]. In addition to the shading effect, some investigations confirm other positive environmental effects of PV systems. In particular, they can help to save up to 50% of applied fungicides for apple production. Also, PV systems can save up to 30% of water used for irrigation due to the wetter microclimate and reduced evapotranspiration produced by AVS. Finally, AVS can serve as a protective factor, to some extent, against environmental risk factors, like heavy rainfall, hail, or wind.

The positive environmental effects of AVS can be reduced by the higher investment costs for AVS construction compared to a ground-mounted PV system. This is due to a need for special technology for higher-mounted design. This construction requires better planning and design, and high-cost land preparation. In general, AV systems are up to 80% more expensive per installed capacity than ground-mounted PV. But AVS can be constructed for combined uses for hail protection, and can save up to 60% of investment costs (up to 10% in the case of apple orchards).

[177] Magarelli, A.; Mazzeo, A.; Ferrara, G. Fruit Crop Species with Agrivoltaic Systems: A Critical Review. *Agronomy* **2024**, *14*, 722. https://doi.org/10.3390/agronomy14040722

[178] Pears thrive under solar panels: 'Results exceed expectations'. Fresh Plaza. URL: https://www.freshplaza.com/north-america/article/9761688/pears-thrive-under-solar-panels-results-exceed-expectations/

CAPEX for AVS ranges between 1500-2500 USD/kW[179] for US cases and 800-2000 USD/kW for the Ukrainian market (CAPEX for ground-mounted PV starts from 350 USD/kW depending on capacity, location, and others). In general, AVS are 1.5-3.5 times more expensive than ground-mounted PV, providing the same or a bit higher energy generation (Fig. 4.10).

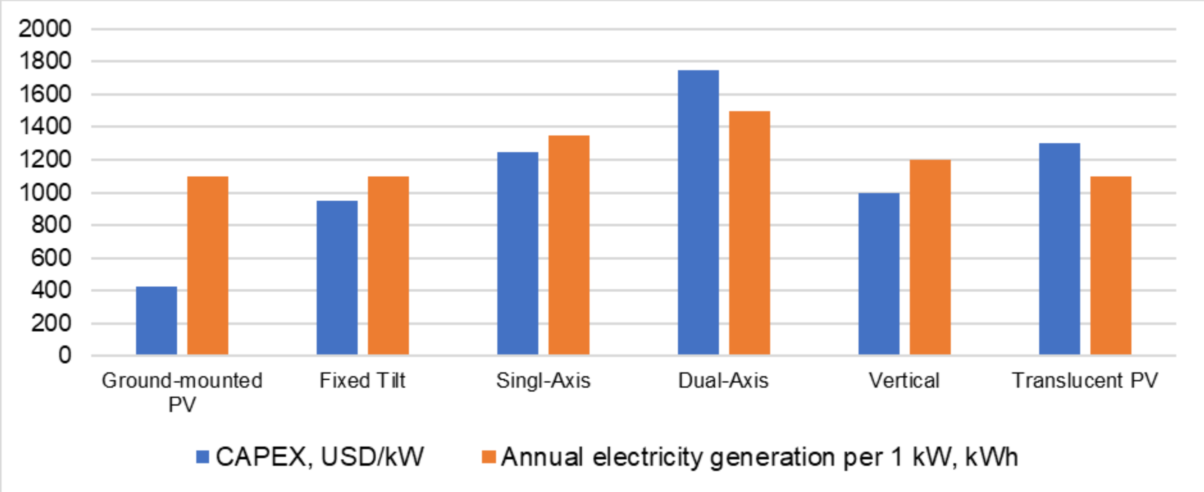

Figure 4.10 – Main characteristics of different AVS

Source: based on [180] [181]

Calculations indicate the possibility of installing agrivoltaic systems with a maximum capacity of 0.5-0.9 MW/ha of fruit and berry lands.[182]. This corresponds with the capacity of the biggest ground-mounted PV located in Ukraine (0,5-0,6 MW/ha)[183].

But in most cases, the loss of income from agrarian activity is compensated for by higher income from energy production. However, each potential agrivoltaic project must be evaluated separately, weighing the costs and benefits.

Wind. The use of wind turbines in fruit growing and horticulture can be economically justified, especially for those farms located in remote and mountainous areas, especially those located far from centralised power grids and characterised by high average wind speeds. The installation of turbines is necessarily preceded by an analysis of natural and soil conditions. The most important aspect is to assess the availability of wind flow, since turbines are most effective at a stable wind speed of 4-5 m/s, and the nominal power is achieved at wind speeds from 10-13 m/s to 20-25 m/s (Fig. 4.11). Also, taking into account the design features of wind turbines, their installation requires reliable fixation in the soil (significantly higher requirements compared to the installation of ground-based solar stations).

[179] Sollazzo, L., Mangherini, G., Diolaiti, V., & Vincenzi, D. (2025). A Comprehensive Review of Agrivoltaics: Multifaceted Developments and the Potential of Luminescent Solar Concentrators and Semi-Transparent Photovoltaics. Sustainability, 17(5), 2206. https://doi.org/10.3390/su17052206

[180] Agrovoltaics in the world and in Ukraine: are we ready for change? AgroPortal. https://agroportal.ua/blogs/agrovoltajika-u-sviti-ta-v-ukrajini-chi-gotovi-mi-do-zmin

[181] https://alteco.in.ua/ua/rishennia-alternatyvnoi-enerhetyky/soniachna-elektrostantsiia-500-kvt-dlia-pidpryiemstva

[182] Trommsdorff, M.; Hopf, M.; Hörnle, O.; Berwind, M.; Schindele, S.; Wydra, K. Can Synergies in Agriculture through an Integration of Solar Energy Reduce the Cost of Agrivoltaics? An Economic Analysis in Apple Farming. *Appl. Energy* 2023, *350*, 121619.

[183] Solar energy industry in Ukraine. TEPLA. https://tepla.com.ua/galuz-sonyachnoyi-energetiki-v-ukrayini/

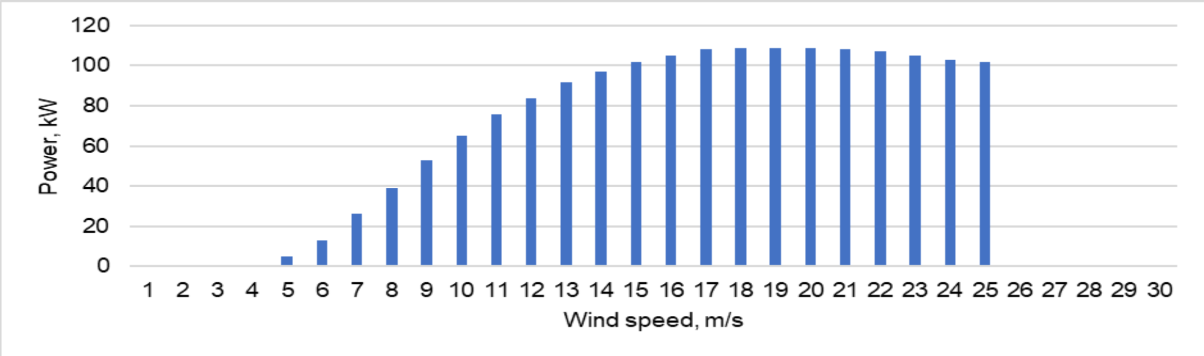

Figure 4.11 – Power generation of a 100 kW wind turbine

Source: https://www.thewindpower.net/turbine_en_484_vestas_v20-100.php

For agricultural purposes, wind turbines with a capacity of up to 100 kW are usually installed. The cost of such a wind turbine ranges between 50[184] -100[185] thousand EUR.

Wind turbines have certain challenges for their widespread use in the field of berry growing and gardening. Firstly, this is due to the need for large initial investments to install a wind turbine (turbine, related equipment, installation costs). Secondly, the instability of the wind flow limits the efficiency of energy generation by wind turbines. Thirdly, the need for specialized qualified service maintenance of the wind turbine. At the same time, wind turbines have significant advantages that are important from the perspective of agricultural activity. Firstly, their installation requires the smallest area of the earth's surface compared to other types of renewable energy, which saves valuable production resources in agricultural activity: for example, a 1 MW wind turbine occupies about 0.3-0.5 hectares, while a similar capacity of a solar power plant requires 2 hectares, and a small wind turbine - less than 0.1 hectares. Secondly, small wind farms (up to 150 kW) can be located 40 m from buildings. Together, these advantages allow placing small wind farms as close as possible to existing power grids in order to receive economic benefits from selling excess energy generated with minimal connection costs. Unlike solar power plants, a wind turbine is more efficient in the autumn-winter period, as well as in the evening hours, when solar power plants are unable to generate energy. In this regard, in practice, the most widespread use in agricultural enterprises has been the use of so-called hybrid systems - a combination of wind power plants and solar power plants with optional battery systems.

Solar thermal. This RE source is suitable for heat generation from solar energy, providing some benefits, including:

Economic:

- Cost savings - up to 60% less energy to heat water, up to 35% less energy for space heating

Environmental:

- No CO2 emissions during operation
- Reduced consumption of fossil fuels

[184] https://avante.com.ua/ua/catalog/vetrogenerator_setevoy_usw_56-100-01681/

[185] https://bts.net.ua/ua/alternative-energy-sources-and-generators/wind-power-generators/horizontal-wind-power-generators/v-trogenerator-dk-series-rx-100dk-100-kvt-gorizontalniy/?srsltid=AfmBOopNUhpcc3HtbWEycdv6BGqcE610k6xcgp1yiykGz5xv0t1p319D

Technical:

- Solar thermal systems can be integrated into existing systems
- Modern systems work efficiently even in winter[186].

Collected heat can be used in agriculture for space or water heating. Horticultural producers use water heating to provide a suitable water temperature for crops during irrigation with groundwater due to its low temperature. This is an effective solution for those farms that do not have special open water reservoirs used for temporary storage and heating of water to ambient temperature.

There are two widely used types of collectors - evacuated tube collectors and flat-plate collectors. The last one is more cost-effective, providing lower initial investment, lower maintenance, and repair costs. It is ideally suited for low-temperature systems to provide hot water and to support floor heating. Also, it is used in solar dryers to dry agricultural products like fruits, vegetables, and grains. This method is more efficient and less wasteful than traditional open sun drying, which can lead to quality loss and spoilage.

The rest of RE options, listed in Table 4.1., are described and discussed in the chapters below.

4.3 RE options for decarbonisation of horticultural production and processing

Horticultural activities are still highly dependent on fossil fuels despite RE development. This leads to high CO_2 emissions, which can and should be reduced due to the green pathway in Europe and Ukraine, in particular.

Fossil fuel consumption in horticulture (e.g., apple growing) represents nearly 50% of total energy use, including non-direct energy use (Fig. 4.12). Diesel vehicles are the most common in horticulture, generating up to 6% of the total CO_2 emissions from Ukrainian agriculture.

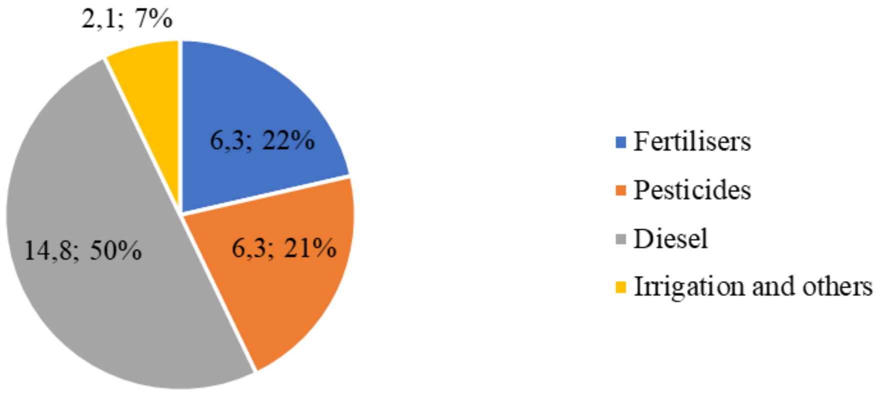

Figure 4.12 – Energy usage in an apple orchard, *GJ/ha; %*

Source: [187]

[186] Solar thermal heating. Vaillant. https://www.vaillant.com/home/advice-knowledge/how-different-technologies-work/solar-thermal-heating/

[187] Paris, B. et. al. Energy use in open-field agriculture in the EU: A critical review recommending energy efficiency measures and renewable energy sources adoption, *Renewable and Sustainable Energy Reviews*, Volume 158, 2022, 112098, https://doi.org/10.1016/j.rser.2022.112098.

Main directions of RE for decarbonisation

1. Substitution of fossil fuels
2. Decrease GHG emissions from mineral fertiliser consumption
3. Utilisation of organic waste
4. Use of electric vehicles

Replacement of fossil fuels: biodiesel. One of the most widespread in European, American and Asian countries technologies for decarbonization of diesel vehicles is biodiesel, blended with fossil diesel (FAME - Fatty Acid Methyl Ester). In 2023, the EU was the leading producer of biodiesel, reaching 13,1% of global output, followed by the USA with 8,3%, Brazil (6,1%) and Indonesia (5,8%)[188].

In the EU, 7% is the maximum content of FAME in biodiesel permitted by the Fuel Quality Directive for sale across the European countries. Most agricultural vehicles run with biodiesel without any technical changes. EU engine manufacturers have tested blends containing 5 to 10% biodiesel, 25 to 30% biodiesel, and 100% pure biodiesel, providing guarantees for each blend. Biodiesel use can reduce emissions by up to 90% compared to conventional diesel. In general, each ton of biodiesel can reduce the CO_2 emissions by 2,7 tonnes. EU biodiesel output uses up to ⅓ of total raw materials from Ukraine (rapeseeds and oils). Consequently, the Ukrainian agriculture and processing industry provides a huge gain to the European decarbonization efforts. At the same time, Ukraine does not use its available potential for decarbonising its agriculture and economy.

The Ukrainian biodiesel production is represented by almost 15 middle and large-scale biodiesel plants with a total production capacity of 300 thousand tonnes and appox. 50 small entities, locally distributed across the country, with 25 thousand tonnes of total capacity. Due to institutional and legislative gaps, most of these capacities have been underused during the last decade. In parallel, there were many cases of micro-production of biodiesel by farmers for their own purposes[189].

Equipment for the production of biodiesel in Ukraine is developed by such enterprises as Biodieseldnipro (Dnipro), Tan LLC (Chernihiv), UkrBioEnergy LLC (Kyiv), Ukrbudmash Plant (Poltava), etc. Biodiesel complexes of these manufacturers ensure that the produced fuel complies with the international standard EN 142214. The capacity of the smallest biodiesel device, such as BDD-50 manufactured by the Biodieseldnipro company, is 50 litres per hour. The price for the smallest Ukrainian equipment, manually operated, starts from 1 thousand euros[190]. The imported equipment, which is usually fully- or part-automated, is also used by the Ukrainian farmers to produce biodiesel. But the prices of foreign complexes start at 100 thousand euros and produce more than 1 ton of biodiesel per day[191]. Several successful cases are known, starting their activities in the early 2010s. In particular, farmer from the Lviv region started biodiesel production from rapeseeds in 2014, using Italian equipment[192].

188 Share of global biodiesel output by country, 2017-2023. IEA. https://www.iea.org/data-and-statistics/charts/share-of-global-biodiesel-output-by-country-2017-2023

189 Ukraine can replace 30% of diesel with its own biofuel. BRDO. https://brdo.com.ua/analytics/ukrayina-mozhe-zaminyty-30-dyzelyu-vlasnym-vyroblenym-biopalyvom/

190 https://flagma.ua/uk/obladnannia-dlia-vyrobnytstva-biodyzelia-o4141675.html

191 https://flagma.ua/uk/obladnannia-dlia-vyrobnytstva-biodyzelia-zavod-1-tden-avtomat-oliia-o16334979.html

192 The first biodiesel production plant has been put into operation in the Lviv region. ZAXID.NET. https://zaxid.net/na_lvivshhini_zapratsyuvav_pershiy_zavod_z_virobnitstva_biodizelya_n1308907

Other cases can be found in the different regions, sowing the oil crops[193]. The advantage of small equipment is its relatively low energy consumption (3-10 kW) and the ability to adjust the load of equipment (one processing cycle lasts from 2 to 6 hours). As a result, such complexes are quite successfully combined for the use of renewable energy sources, in particular, PV, adjusting the processing cycle to the period of optimal renewable energy generation with the lowest prices. It helps to provide better profitability of biodiesel production, despite the part-time working cycle. Such integrated systems can provide a significant share of the energy supply for biodiesel production from the solar system[194] or they can be developed further, based on deeper integration of solar, wind and bioenergy.

In wartime, farmers' interest in self-supply of energy, in particular, biodiesel, was increasing due to the scarcity of diesel supply and the high price of conventional diesel. In general, 1 ha of rapeseed can provide 1 ton of biodiesel. But in conditions where the price of conventional diesel on the market decrease to about 1000 euro per ton and the price of rapeseed reaches 500 euros per ton, biodiesel production loses any competitiveness (with a minimum yield of 2 t/ha, the farmer receives revenue from the sale of rapeseed seeds, which is equal to the revenue of biodiesel produced from this volume of seeds)[195]. The EU, as a key importer of Ukrainian rapeseeds and oil, provides state regulation on the biofuel market and financial incentives for biodiesel production, eliminates any stimulus for processing crop oils for biodiesel in Ukraine. So, renovation of biodiesel production in Ukraine requires significant steps for the Ukrainian law adjustments, which can offer a new lease of life for the available biodiesel plants and create stimulus for the development of new small and medium capacities[196].

Another direction of decarbonising orchard activity is ***replacing fossil fuel consumption with electric power usage***. In Ukraine, small and medium-sized (up to 50 ha) horticultural farm operates within one medium-powered tractor with 30-70 hp (e.g. UMZ-8244.2, MTZ-82), which covers most of the agricultural operations like plowing, mowing and spraying. Although such a tractor provides a certain versatility for the farm, when performing most operations in gardening, the available power is not used, which leads to excessive fuel consumption. In this regard, an electric tractor, having a sufficient power reserve, is more suitable for the needs of gardening, more effectively distributing the use of battery energy when performing agricultural operations of varying complexity.

Electric tractors provide 4-5 hours of operating time for heavy-duty tasks and 6-7 hours for moderate-duty tasks. For high-cost models, these periods are longer by 2-3 hours[197]. Electric tractors are generally 2-5 times as expensive as their competitors with internal combustion engines. But electric tractors have some advantages over conventional ones:

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193 Biodiesel: How to Make Tractor Fuel from Rapeseed on Your Farm. Agribusiness Today. https://agro-business.com.ua/agro/mekhanizatsiia-apk/item/18475-biodyzel-iak-vyrobliaty-traktorne-palne-z-ripaku-u-svoiemu-hospodarstvi.html

194 León, J.A.; Montero, G.; Coronado, M.A.; García, C.; Campbell, H.E.; Ayala, J.R.; Montes, D.; Sagaste, C.A. Renewable Energy Integration: Economic Assessment of Solar Energy to Produce Biodiesel at Supercritical Conditions. *Int. J. Photoenergy* **2018**, *2018*, 8769582.

195 Biodiesel from rapeseed: how to make it, pros, cons and price. LATIFUNDIST.COM. https://latifundist.com/cards/64-biodizel-z-ripaku-yak-vigotoviti-plyusi-minusi-ta-tsina-pitannya

196 Parkhomets M., Uniiat Л., Chornyi P., Chorna H., & Hradovyi В. (2023). Efficiency of production and processing of rapeseed for biodiesel in Ukraine. *Agricultural and Resource Economics: International Scientific E-Journal*, *9*(2), 245–275. https://doi.org/10.51599/are.2023.09.02.11

197 The Future of EV Tractors in Agriculture. Monarch. https://www.monarchtractor.com/blog/ev-tractors

Technical:

- instant torque delivery
- energy storage and short-term energy independence
- opportunity for integration with a renewable system (e.g. APV)

Economic:

- cost savings on fuel
- lower maintenance and operational costs

Social:

- lower noise pollution

Environmental:

- zero emissions (if electricity comes from renewable sources)
- healthier soil due to a renewable engine type
- more friendly to insects that provide pollination for gardens.

EV-tractors are most suitable for non-intensive agricultural activities, in particular, horticulture. The above-mentioned diesel tractors consume 5-8 litres of fuel per hour on average. Additionally, they need motor oils. Due to the features of the diesel tractor engine, it requires at least three types of maintenance, which enhances the EV-tractor's competitiveness. Our calculations, based on 1000 hours of tractor annual run time, confirm a minimum 4,5 thousand euros of savings annually in the case of purchasing electricity from the grid, and approximately. 6,0 thousand euros within the usage of renewable energy (e.g. PV). Even taking into account the need to replace the battery after 10 years, which costs 15-20 thousand euros, after 20 years, a diesel tractor could cost 151 thousand euros to own and operate, while an electric model might run 141 thousand euros within the grid electricity scenario and 117 thousand euros within the renewable electricity scenario. Other investigations and practices also confirm the high level of savings and the competitive advantage of EV-tractors[198].

The average Ukrainian apple farm with a 50 ha intensive orchard can provide investments for an EV-tractor, amounting to 90 thousand euros for purchasing a new tractor and 20 thousand euros for battery replacement after 10 years, with a 2-year discounted payment period. The intensive apple orchard provides 30-90% of profitability, ranging between 1-4 thousand euros per hectare[199].

Scenario of providing the EV-tractor, charging with renewable energy from the own farm sources or the renewable power grid, supports a net-zero emissions pathway. In the case of replacing the diesel tractor's annual run by the EV-tractor, it could eliminate the 13,53 tonnes of CO_2 per year or approx. 271 tonnes of CO_2 during the whole tractor's life cycle (20 years).

Successful foreign experience supports the opportunity of a self-sufficient renewable scenario of horticultural development, based on electric machines and equipment, charging with renewable energies. In particular, Forest Lodge Orchard (New Zealand) has been operating for several years without burning fossil fuels. They replaced all tractors and machinery (20 units together), hand equipment with electric ones. So, all agricultural activities are powered by renewable electricity. Forest Lodge uses nearly 100 MWh of power

[198] Electric Tractors: Sustainable Savings or Shocking Costs? APN NEWS. https://www.apnnews.com/electric-tractors-sustainable-savings-or-shocking-costs/

[199] Zhuk V.M., et al. (2022) Efficiency of growing promising apple varieties selected by the Institute of Horticulture of the NAAS in intensive gardens. Bulletin of Agrarian Science. №2 (827), PP. 34-41. https://doi.org/10.31073/agrovisnyk202202-05

a year to run everything from electric tractors to electric chainsaws, irrigation, and frost-fighting systems (frost-fighting wind system) on 6 ha of berry orchards. 80% of electric demand is covered with their own solar power station and battery storage, and the remaining 20% is coming from the renewable power grid. Their solar power station consists of a 150 kW land-grounded system (0,2 ha) and a 10 kW roof system, which together generate 200 MWh of energy annually. The uninterrupted operation of the stations is supported by a 300 kWh battery[200].

One of the most promising options for decarbonization of mineral fertiliser use in horticulture is ***green ammonia production***. Today's production of nitrogen fertilisers is energy-intensive due to the features of the process – steam methane reforming (SMR). Although SMR is the least carbon-intensive of the technologies available today, it nevertheless generates large amounts of CO_2. Around 2.6 tonnes of carbon dioxide equivalent (CO_2e) are produced per tonne of nitrogen-based fertilizer production (1.7 tonnes for phosphate-based fertilizer and 0,6 tonnes for potassium-based fertilizer). Nitrogen-based fertilizers, accounting for approx. 5% of global GHG emissions[201]. Ammonia is a key factor of EU decarbonization efforts, and can be used as an energy carrier with zero- or near-zero carbon footprint.

There are several known efforts to provide an economically viable technology for green ammonia production. One of them is a development of the Canadian technology company – FuelPositive, proposing a modern decision for farmers to produce nitrogen-based fertilizer in a renewable way.

FuelPositive developed two demonstration systems, one of which is operating in Canadian Manitoba in an open-field small farm. The system fits within three standard 6-metre containers, providing a modular and scalable decision for easy transportation. The system is simple for managing by customers staff (e.g. farmer) after online training. The company can also easily monitor the system operation process online, providing some optimization, management and maintenance.

The smaller system can provide 300 kg per day of green anhydrous ammonia (100 tonnes/year). It requires less than 500 liters of clean water per day and nearly 1 MW of renewable energy capacity (e.g., PV with battery storage) to provide a self-sufficient production (Table 4.2).

Table 4.2 – Green ammonia system specification

Indicators	System size type	
	Small	Average
Fertiliser production capacity, tonnes:		
- per day	0.3	1.5
- per year	100	500
Water consumption, m³:		
- per day	0.5	2.4
- per year	167	800
PV capacity with battery storage, MW	1	5
Ammonia System cost (CAPEX), million euro	0.7	3.4
Fertiliser production cost (OPEX), euro/ton	500	450

Source: summarised from [202]

[200] https://www.forestlodge.nz/electric-farming

[201] Understanding fertilizer emissions for carbon regulation. Carbon Chain. https://www.carbonchain.com/blog/understand-your-synthetic-fertilizer-emissions

[202] FuelPositive Business Model. FuelPositive. https://fuelpositive.com/business-model/

The European research university is testing smaller equipment for green fertilizer production in Africa. This equipment can produce 1.24 kg per day of liquid nitrogen fertilizer with 10% KNO3 using only solar energy, water, and air. It costs 70 thousand euros, making it the cheapest solution on the market. But the developers expect the price will come down considerably once it is being produced on a larger scale[203].

In Ukraine, there are available scientific developments and practical solutions for green hydrogen production, supporting innovative solutions for cooperation with fertiliser plant[204].

4.4 Prioritised approach and practices of agricultural circular economy and bioenergy production

Agriculture produces, besides the main food products, a huge volume of residues, which are often burned, discarded, or just left on the fields and orchards. Some of these residues (or some part of them) support the ecological sustainability of agricultural systems, benefiting the soil fertility, protecting the soil from water and wind erosion, etc. But these positive effects require additional efforts and costs, for example, for shredding of plant residues for better and faster decomposition. As a result, most of the agricultural residues are utilized in a non-environmental and non-beneficial way.

The modern alternative to the conventional agricultural model is a circular economy concept, which is based on the following principles: designing products to minimize waste and pollution; extending the lifecycle of products and materials through reuse, repair, re-manufacturing, and recycling, and regenerating natural systems. The valorisation of agricultural residues presents a unique nexus of environmental stewardship, economic opportunity, and rural development. By redirecting these materials into productive uses – ranging from biochemicals and biofuels to innovative materials like bioplastics and biocomposites – industries can simultaneously reduce their environmental footprint and create new value streams. Concerning agriculture, the circular economy concept means creating a closed-loop system with reintegrating the residues into the production of animal feed, bioproducts and materials or bioenergy[205].

Agricultural residues and, in particular, horticultural ones are an excellent source of biomass for bioenergy production through one of the available methods, producing solid, liquid, or gaseous fuels. All directions and types of circular usage of horticultural waste are described in Fig. 4.13.

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[203] Using plasma technology to feed the world. Eindhoven University of Technology. https://www.tue.nl/en/news-and-events/news-overview/01-01-1970-using-plasma-technology-to-feed-the-world

[204] Ukrainian developers are already ready to offer hydrogen projects to investors. https://ua-energy.org/uk/posts/ukrainski-rozrobnyky-vzhe-hotovi-proponuvaty-vodnevi-proekty-investoram

[205] Tofănică B.M., et. al. Circular economy solutions: exploring agricultural residues, Bul. Inst. Polit. Iasi, 70 (74), 4, Chem. Chem. Eng., pp. 33-48 (2024). https://www.researchgate.net/publication/387626900_Circular_economy_solutions_exploring_agricultural_residues

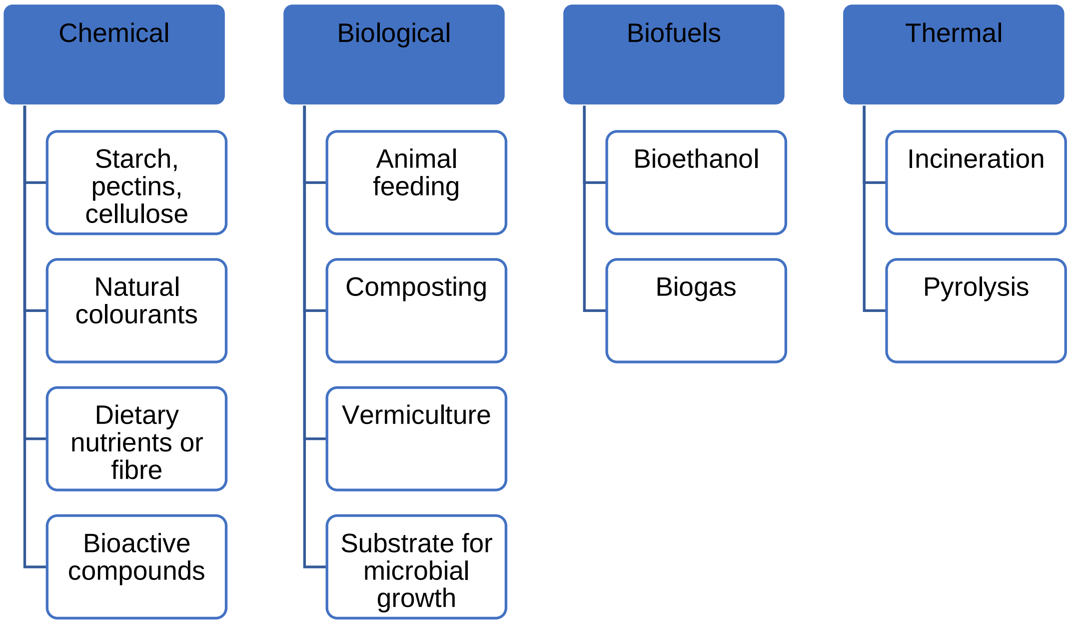

Figure 4.13 – Directions and types of circular usage of horticultural waste

Source: based on [206]

Solid fuels as a thermal option. Agriculture and, in particular, horticulture, generates a huge volume of solid biomass residues, which have a significant potential for renewable energy production.

Ash content varies from 1.52% weight on a dry basis in an apple to 5.39% weight on a dry basis in a walnut.

Walnut pruned biomass is least suitable for energy purposes due to the small volume of residues from a unit of orchard area and a high level of ash, which is suitable for industrial boiler usage, but not for individual ones. From these points, apple pruned biomass has the best characteristics among the investigated crops for energy usage (Fig. 4.14).

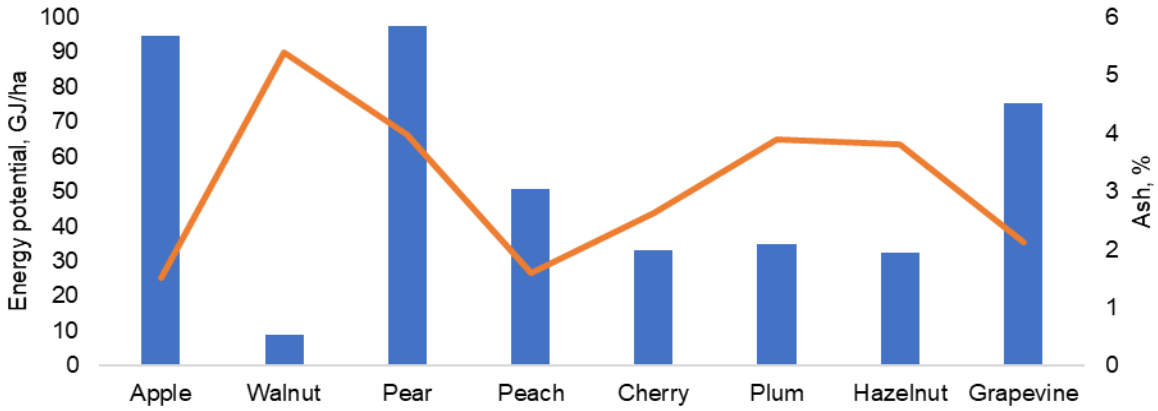

Figure 4.14 – Energy potential of pruned biomass and ash percentage for the selected horticultural crops within the intensive management system

Source: [207]

[206] Lobo, M. G., & Dorta, E. (2019). *Utilization and Management of Horticultural Waste. Postharvest Technology of Perishable Horticultural Commodities, 639–666.* doi:10.1016/b978-0-12-813276-0.00019-5

The calculated energy potential is based on the maximum amount of pruned biomass. In practice, these numbers are lower due to conditions, particularly plant age, management system, geographical location, etc. So, the Ukrainian orchard experience reveals that pruned biomass volume varies between 25% and 75% compared to the maximum level.

According to the widely used method of harvesting the pruned biomass in the Ukrainian orchards (removal of pruned biomass to the edge of the garden), the cheapest technology of biomass preparation for energy usage is the further manual loading of biomass for shredding and transportation for storing (technology A – Table 4.3). This technology requires significant manual work, increasing total operating costs. The alternative option (technology B) uses only two working units, but requires higher-cost equipment for the mechanisation of all processes. In general, taking into account biomass losses during technological operations of the current chain, an average of 1.2 tons of wood chips with a moisture content of 25% is obtained from 1 hectare of orchard[208]. Due to lower working requirements and faster processing, technology B provides 30%-higher efficiency of processing the available biomass for energy production.

Table 4.3 – Key economic characteristics of technology for wood chip production from pruned biomass

Indicators	Technology	
	A. Tractor-mounted disc shredder	B. Trailer-mounted shredder with hopper
Biomass production and transportation cost (OPEX), UAH:		
- per ton	110	766
- per ha	2200	1532
Equipment cost (APEX), thousand UAH	145[209]	850[210]
Energy costs, UAH/GJ[211]	109.54	76.28

Source: calculated based on [212]

Wood chips produced by both technologies can be burned in industrial boilers directly by farmers, local authorities, or other businesses. The economic feasibility of using wood chips as fuel is determined by the logistics costs of delivering fuel from the place of production (storage) to the place of use. This is due to the low bulk weight of wood chips and the large cargo volume.

The price of wood chips varies depending on geographical location, wood types, quality characteristics, etc. Horticultural wood chips are classified as non-high-quality raw material for solid fuel due to the specific features of harvesting: high percentage of tree bark; it can contain dry and rotten wood; a small percentage of soil; high moisture (35-55%). Considering these features, the price of horticultural wood chips is lower than the average market price for wood chips, but still competitive, compared with other feedstock like straw or

[207] Bilandzija, N. et al. Energy potential of fruit tree pruned biomass in Croatia. *Spanish Journal of Agricultural Research*, (2012) 10(2), 292-298

[208] A project to process wood for energy production has been launched in Zaporizhia region. https://propozitsiya.com/ua/u-zaporizkiy-oblasti-zapustyly-proekt-pererobky-derevyny-dlya-otrymannya-energiyi

[209] https://arpal-izmelchitel.com.ua/ua/p710294589-scheporez-izmelchitel-vetok.html?source=merchant_center&utm_source=google&utm_medium=cpc&utm_term=&utm_campaign=merchant&utm_content=&gad_source=1&gclid=Cj0KCQjw2N2_BhCAARIsAK4pEkU6Q1lFjDS0sPPRB7KyZ7Swbof6HiMkr68G_AOYsebV7SkTBGKuCasaAg1TEALw_wcB

[210] https://www.technikboerse.at/view/neumaschine/mulchgeraet-haeckselgeraet/6725024/berti-picker-c-140.html?dp_ref=lp_cat_org

[211] 1 kcal = 4.184 kJ

[212] https://uabio.org/wp-content/uploads/2023/12/6.-ZHelyezna-T.-A.-Zagotivlya-ta-postachannya-dlya-energetychnyh-potreb-biomasy-vid-obrizky-ta-vydalennya-sadiv-i-vynogradnykiv.pdf

other agricultural crop residues. Despite this, horticultural wood chips are a competitive source of energy self-sufficiency due to low production costs: 110 UAH per GJ compared to 164 UAH per GJ of market price for wood chips, providing minimum 33% cost savings within technology A or 53% within technology B (approx. 2000 UAH per ton of wood chips with 30-35% moisture, excluding logistics cost[213]).

They can also be used as raw materials for pellets or briquettes production, supporting a higher value-added chain. In general, the production process of briquets and pellets from wood chips is similar, consisting of milling and pressing stages as the key ones. The first stage of briquetting and pelleting is milling the raw materials (e.g., wood chips) into the sawdust with the 2-5 mm fraction. The second stage is compressing the sawdust under high pressure and, in some cases, under heating up to 250-350 ºC. Within the compressing, lignin is released from the wood, binding the raw materials into briquettes or pellets. Briquettes production requires a lower level of moisture, but less energy, and pellets are vice versa (Table 4.4).

Table 4.4 – Technical requirements for briquette and pellet production

Indicators	Solid fuel type	
	Briquettes	pellets
Moisture, %	5-12 (8)	10-12
Energy consumption, kWh/t	60	90

Source: [214]

The average area of apple orchards in the agricultural enterprises is approx. 50 ha[215], providing 100-200 tons of wood residues annually. The low volume of residues limits the economic feasibility of these projects. Most of the available equipment in the Ukrainian market requires 10-15 times larger residues for full-time load of equipment[216].

Raspberry residues are also good raw materials for the production of solid fuels. Several successful experiences from different Ukrainian regions support this statement. As an example, in 2015, in the Ternopil region (village Losyatyn), the local berries cooperative started briquette production, using raspberry residues as a main raw material[217]. Another practical case of solid fuel production from strawberry residues is located in northern Ukraine (Chernigiv region, Nizhyn). Unlike the case described above, here the farm cuts raspberries with a silage harvester and sends the raw materials for the production of briquettes[218].

Walnut residues provide equal energy potential as oak wood, and processed walnut residues by briquettes have a twofold higher potential than wood (see annex C). There are some practical cases of processing walnut residues for pellets or briquettes[219]. However, they are challenged due to the absence of small-scale equipment technically capable of

213 https://flagma.ua/uk/products/q=%D1%82%D1%80%D1%96%D1%81%D0%BA%D0%B0/

214 https://www.ameliart.vn.ua/

215 Poperechna O. Current state of horticulture in Vinnytsia region. https://secbiomass.com/wp-content/uploads/2019/12/fruit-projects-up-running.pdf

216 https://www.ameliart.vn.ua/

217 They have a monopoly on themselves. How a cooperative in the Ternopil region heats houses with "raspberries". https://epravda.com.ua/publications/2017/02/1/619225/

218 Fuel briquettes are made from the cut mass of raspberries. AGROTIMES. https://agrotimes.ua/ovochi-sad/zi-skoshenoyi-masy-malyny-vygotovlyayut-palyvni-brykety/

219 Waste into profit: a unique technology for processing walnut shells into pellets. AGROPORTAL. https://agroportal.ua/publishing/idei-dlya-biznesa/vidhodi-v-pributok-unikalna-tehnologiya-pererobki-gorihovoji-shkaralupi-na-peleti

processing walnut shells. Due to the low lignin level of walnut shells, this equipment requires higher power capacity for harder pressing or an additional component for better bonding.

Biogas. Biogas production can be an effective, sustainable solution for waste disposal, both in the cultivation of horticultural products and in their processing.

The technological process of soil cultivation in gardens involves ***regular mowing of the grass cover***. The grass must be mowed 6-8 times a year, when it reaches a height of 15 cm (about every 3 weeks). The volume of green mass is on average 2-5 t/ha depending on the type of cover crops, weather conditions, etc. Traditionally, mowed grass remains in the rows or is worked into the soil to a shallow depth to improve tree nutrition with organic fertilisers. In addition, chopped grass is used to mulch the trunk areas, which has become particularly relevant in the context of climate change, namely, a reduction in the frequency of precipitation and an increase in natural moisture evaporation. An alternative solution may be the production of biogas from mowed grass. This will provide the farm with additional income in the form of biogas, which can be either sold or used for various energy purposes of the farm, depending on the needs (electricity, heat). At the same time, in addition to energy, the farm will receive 750 kg of high-quality organic fertilisers from each ton of green mass to maintain the balance of organic matter in the soil.

Grass demonstrates the best biogas yield - 240-250 m³ per ton with a methane content of 70% (for comparison, corn silage 220 m3). Grass is so cheap to produce that the payback of biogas plants can be compared with the payback of waste plants. The cost price of grass is 2-3 euros per 1 ton. To provide a biogas plant with 1 MW of electrical power, 50 tons of grass per day are needed[220].

Unlike corn silage, when using grass, there is no need to build silos for 1 year. A storage for 4 months is enough.

Stations for processing grass into biogas are structurally no different from stations for corn silage. The most suitable technology for them is the high-load reactor technology. The disadvantage of the application is the duration of the production cycle. The process of obtaining biogas lasts up to two months. The raw material must be carefully crushed.

The processing of fruit and berry products is accompanied by the formation of a significant amount of waste, which is also an excellent raw material for ***biogas production***: fruit and vegetable pulp, as well as cleaning waste, substandard fruits, vegetables and expired products. The main advantage of biogas production is that processing plants provide a year-round supply of raw materials. In the presence of seasonality, fruit and vegetable pulp must be ensiled to ensure the operation of the biogas plant all year round.

Until recently, most biogas plants in Ukraine used sugar[221] and dairy[222] waste as raw materials. In 2025, several fruit processing plants announced their intentions to produce biogas. In particular, Lvivsky Sad LLC announced plans to install a biogas plant that will use waste from fruit processing and other organic residues to produce biogas. The produced gas will be used to generate electricity and heat, which will significantly reduce the company's dependence on traditional energy sources. The construction of the biogas plant is planned to

[220] Biogas plants on perennial grasses. ZORG BIOGAS. https://zorg-biogas.com/uk/otraslevye-resheniya/slon-trava

[221] TOP-6 biogas producers in Ukraine named. AGRAVERY. https://agravery.com/uk/posts/show/nazvano-top-6-virobnikiv-biogazu-v-ukraini

[222] Biogas production from dairy industry waste launched in Ukraine. Infagro. https://infagro.com.ua/ua/2023/03/29/v-ukrayini-zapustili-virobnitstvo-biogazu-z-vidhodiv-molochnoyi-promislovosti/

be completed within the next two years. In addition, in the event of successful implementation of the project, the company is considering the possibility of expanding the plant's capacity[223].

Interjuice Bukovina also announced its intention to complete the construction of a new fruit processing plant by the end of 2025, which will process 1,500 tons of raw materials per day. Fruit raw materials are planned to be purchased from farms in the Chernivtsi region and neighbouring regions, which should be a significant support for local agricultural producers. The main products are concentrated apple juice, as well as juices from local berries: raspberries, cherries, sweet cherries, and plums. In addition to juice production, the plant will produce biogas obtained during fruit processing. This energy-efficient solution will allow using the resulting gas for heating local buildings, which will have a positive impact on the environment and energy saving of the community[224].

The pomace from fruit and grape processing has sufficient energy value for biogas production, which is comparable to waste from potato starch production or brewing products and three times higher than the dregs of the alcohol industry (Figure 4.15).

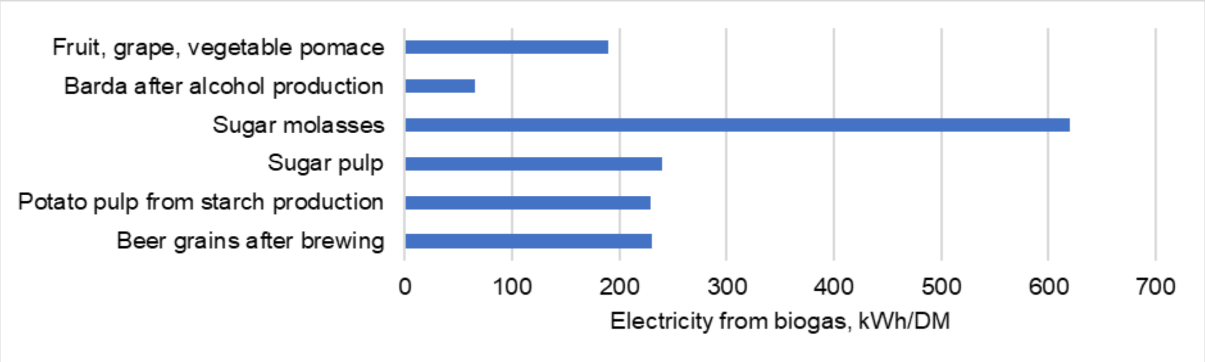

Figure 4.15 – Biogas (electricity capacity) energy potential of different raw materials from the processing industry

Source: [225]

Equipment for micro and small biogas production is available in Ukraine[226]. However, the cost of such investment projects (<100kW) starts from 5 thousand euros/kW, which is twice as much as for large-capacity projects (>10 MW). Considering the high initial investment costs, even with the possibility of obtaining a green tariff, the simple payback period is 12-17 years, which reduces the attractiveness of such projects[227]. However, in wartime conditions, the value of maintaining energy independence for enterprises becomes one of the decisive factors for investments in biogas production. In addition, demand for Ukrainian biomethane from the EU is growing, which stimulates producers to increase domestic production (biogas production and purification to 98-99% methane) and exports[228].

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[223] The owner of Lvivsky Sad LLC spoke about plans to build a biogas plant. GADERIA. https://gaderia.com.ua/vlasnyk-tov-lvivskyj-sad-rozpoviv-pro-plany-budivnycztva-biogazovoyi-ustanovky/

[224] A juice and biogas plant will be built in Bukovina. AGROREVIEW. https://agroreview.com/content/roslyny/bukovyni-zbuduyut-zavod-vyrobnycztva-sokiv/

[225] Biogas from by-products of the food and processing industry – AgroBiogas. AgroBiogas. https://agrobiogas.com.ua/biogas-from-by-products-of-food-and-processing-industry/

[226] Small Biogas Stations – AgroBiogas. AgroBiogas. https://agrobiogas.com.ua/low-power-biogas-stations/

[227] Trypolska, G., Kyryziuk, S., Krupin, V., Wąs, A., & Podolets, R. (2022). Economic Feasibility of Agricultural Biogas Production by Farms in Ukraine. *Energies*, *15*(1), 87. https://doi.org/10.3390/en15010087

[228] Biomethane production in Ukraine: how much was sold abroad and what are its prospects in the future. https://suspilne.media/chernihiv/969965-virobnictvo-biometanu-v-ukraini-skilki-prodali-za-kordon-ta-aki-jogo-perspektivi-u-majbutnomu/

4.5 Recommendations and priorities of RE consumption and RE technology in agriculture and horticulture

Globally, agriculture, forestry, fisheries and aquaculture consume 15% of total energy use, overcoming 9000 TJ and increasing by more than 12% during the second decade of 21 century. The share of renewable energy used in the agriculture, forestry and fisheries sectors increased from 10.8% in 2011 to 15.4% in 2021. These trends will be continued due to stable population growth and fast renewable technology development[229].

The most promising sources of renewable energy for the next few decades are solar, wind, biomass, and energy storage[230]. Agriculture has better opportunities than other economic sectors for harnessing these renewable energy sources due to the availability of huge land spaces, buildings and a stable surplus of waste and biomass. By harnessing renewable energy sources farmers can significantly reduce operating costs, lessen their environmental impact, create more resilient business models, and provide a sustainable way of future growth[231].

Due to modern renewable technology development, the main priorities of RE consumption in agriculture during the next decade will be based on:

- integrated use of available production resources for agricultural (food and feed) and energy purposes;
- efficient utilization of waste heat based on a heat recovery system;
- replacement of fossil fuel use by wider provision of electric tractors and machinery, including autonomous ones;
- smart water management and solar-power irrigation systems;
- utilization of organic waste for energy production;
- replacement of mineral fertilizer by green ammonia and low-carbon fertilizers.

Faster renewable development in Ukrainian agriculture faces difficulties due to:

- small-scale of farms and production opportunities for the implementation of renewable options;
- spatial distribution of farms and resources;
- scarcity of investment capital;
- high level of the main activity risks due to the war.

Some of these difficulties can be overcome by the implementation of strategies and options listed below.

Diversified use of agricultural raw materials for food (feed) and energy purposes. In conditions of high volatility of prices for agricultural raw materials and energy resources, an important problem arises in ensuring the stability of cash receipts and profitability of agricultural producers.

[229] Renewables in agriculture. Renewables 2024. Global status report. Renewables in energy demand. REN21. https://www.ren21.net/gsr-2024/modules/energy_demand/04_renewables_in_agriculture/

[230] The Future of Farming: Integrating Renewable Energy into Agricultural Practices. https://www.linkedin.com/pulse/future-farming-integrating-renewable-energy-agricultural-g1j4e

[231] Driving the Future of Farming with Renewable Agricultural Technology. Agritech future. https://www.agritechfuture.com/smart-farming/driving-the-future-of-farming-with-renewable-agricultural-technology/

Raw material markets, like agricultural products, depend on the volume of supply, which is influenced by many factors that direct producers cannot influence: market and economic, weather and climatic, institutional and political, etc. Unfavorable market conditions can make the supply of produced products to the market unprofitable for farmers. Long-term storage of produced products in order to wait for a more favorable situation is not an acceptable strategy for all farmers due to the lack of storage capacity, the high cost of storing products, etc. In such conditions, the possibility of diversified use of produced products can ensure the desired profitability of agricultural activities, reducing farmers' dependence on unfavourable market conditions in agricultural raw materials markets. The use of agricultural raw materials for purposes other than the main ones - food and feed - supports a diversified strategy of agricultural production. One of such diversification options is the energy use of agricultural raw materials. The production of liquid biofuels and biogas from agricultural raw materials is a fairly common practice of diversifying agricultural activities. For example, "Gals-agro", which is engaged in the production of crop and livestock products and additionally horticulture, is developing energy projects. As a result, the company has the opportunity to regulate the production volumes of the main product - corn grain, and the harvesting of corn silage for the purposes of biogas production. The enterprise grows universal corn hybrids, which have equally high silage and grain yields. In the event of unpredictable weather and climate conditions or predicted unfavourable price conditions on the grain market, the company is able to regulate the production of agricultural raw materials, directing most of them for biogas production. The company also has capacities for the production of bioethanol from grain, which allows for additional diversification of production chains[232]. From May 1, 2025, a mandatory share (5%) of ethanol in gasoline in Ukraine has been standardised, which creates conditions for increasing demand for ethyl alcohol and will stimulate the development of bioenergy projects.

Wider development of diversified feedstock usage requires some policy measures, in particular:

Legislative:

- standardisation of the mandatory proportion of biodiesel in diesel in Ukraine

Organisational:

- support scientific activities for the selection of appropriate crop hybrids, suitable for food and energy usage

Fiscal:

- renovation of the state program for crop selection due to the new request from the renewables direction.

Cooperation of agricultural producers for the reliable supply of raw materials and scaling up energy production.

Most energy projects require agricultural producers to have a stable, and most importantly, planned supply of raw materials, which is due to technological processes of equipment operation, the shutdown of which either leads to a significant increase in costs or is practically impossible. On the other hand, the above analysis shows that virtually all energy

[232] Serhiy Kravchuk: Corn yields can be increased dozens of times. KURKUL. https://kurkul.com/spetsproekty/1410-sergiy-kravchuk-pributkovist-kukurudzi-mojna-zbilshiti-v-desyatki-raziv

projects depend on economies of scale, where relative investment and operating costs decrease as capacity increases. Therefore, for medium and small agricultural farms, the implementation of energy projects may be complicated or unprofitable due to the reasons described above. To overcome these challenges, farmers can unite / cooperate. To unite the efforts of farmers in the development of energy projects, several prerequisites must be met:

- local concentration of production capacities to minimise costs for transportation of agricultural raw materials;
- consistency of the production profile of farms with the goals of energy projects (for example, livestock farms with a large amount of waste, and crop farms capable of providing a high-quality raw material structure in biogas production projects).

In Ukraine, there were the first attempts at energy cooperative development, including those that joined agricultural producers, local authorities, and non-profit organisations. But they are not developing or widespread. To support cooperative development in renewable energy, some measures are needed at the national and local levels:

Organizational:

- develop training courses and facilitate experts to provide wide expertise for energy cooperatives;
- disseminate successful experience and training visits for local authorities and interested persons;
- promoting the establishment of special “energy zones” in regions with high potential for renewables development;
- compliance of the Ukrainian legislation regarding energy cooperatives with European legislation on energy communities.

Fiscal:

- develop and implement new financial schemes to supportthe collective initiative in renewable energy [233].

Integration of renewable energy sources in modern agricultural technologies. Agriculture, especially horticulture, is increasingly relying on irrigation systems amid climate change. To comply with agricultural technology requirements, it is not recommended to irrigate with water directly extracted from groundwater, but rather with water that has been brought to ambient temperature. As a rule, farmers use open or closed reservoirs (natural, artificial) for these purposes, which are filled with water as needed and from which water is taken for irrigation. Integration of renewable energy sources into existing irrigation systems allows for reducing operating costs, reducing dependence on external energy supply, and reducing negative impact on the environment (due to emission reduction). Potential points for integrating renewable energy sources into existing irrigation systems:

- use of PV panels or hybrid systems to power pumping equipment for extracting groundwater resources[234].

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[233] Energy cooperatives: energy independence for communities / Martynyuk A.M., Sakalyuk D.S., Maryuk O.V., Kholodova N.V., // Public organization "Ecoclub". https://ua.boell.org/sites/default/files/2019-11/Енергетичні-кооперативи_енергонезалежність-для-громад.pdf

[234] Gabrovska-Evstatieva, K.; Evstatiev, B.; Trifonov, D.; Mihailov, N. Autonomous powering of an orchard irrigation system and fruit storage. In Proceedings of the 47th International Symposium, Actual Tasks on Agricultural Engineering, Opatija, Croatia, 5–7 March 2019; pp. 203–211, ISSN 1848-4425.

- integration of mini-hydroelectric power plants (micro hydropower system, MHP) into irrigation water supply channels for electricity generation[235].

The mentioned options should be integrated into the national irrigation policy, in particular, into the Long-term plan of irrigation development of Ukraine until 2050 and the Plan of measures to implement the long-term plan for the development of the irrigation complex of Ukraine until 2030[236].

Implementation of comprehensive solutions based on the integration of RES, IoT and AI. In the context of climate change and increasing availability of advanced agricultural technologies, it is becoming increasingly obvious that traditional agriculture is a thing of the past, and new forms and methods of agricultural activity are replacing it. Rapidly changing conditions (weather and climate, market, financial and economic, etc.) of agricultural activity increase the demand for the development of forecasting and modelling systems based on large data sets of available information. The use of various sensors and smart systems allows you to track changes in weather and climate, as well as soil conditions. The combination of diverse information flows based on the use of IoT allows you to plan and implement agricultural activities more effectively. Renewable energy sources provide deep penetration of these technologies even into the most remote areas that are deprived of access to centralised energy supply networks. AI has made it possible to plan the optimal use of RES to maintain the operability of advanced technologies: coordinating the schedules of accumulation and use of RE in agricultural activities. Smart irrigation systems powered by renewable energy and controlled by IoT sensors reduce the use of natural resources, primarily water, and energy consumption, which ensures a reduction in greenhouse gas emissions. AI-based analytics further optimise these operations to ensure that resources are used only when and where necessary, in accordance with peak demand and taking into account the available RE. Renewable energy in agriculture has enormous environmental benefits. For example, irrigation systems powered by RES, controlled by AI-based systems, have obvious advantages in reducing dependence on fossil fuels. The high accuracy of such systems of activity contributes to increasing the productivity of agricultural activities while reducing pressure on the environment, and therefore supports the course towards achieving global climate goals[237].

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https://www.researchgate.net/publication/332383223_AUTONOMOUS_POWERING_OF_AN_ORCHARD_IRRIGATION_SYSTEM_AND_FRUIT_STORAGE

[235] Agricultural Hydropower Generation. COLORADO STATE UNIVERSITY. Extension. https://extension.colostate.edu/topic-areas/natural-resources/6-708-agricultural-hydropower-generation-farm/

[236] https://zakon.rada.gov.ua/laws/show/280-2025-%D1%80#Text

[237] Morkūnas, M.; Wang, Y.; Wei, J. Role of AI and IoT in Advancing Renewable Energy Use in Agriculture. *Energies* 2024, *17*, 5984. https://doi.org/10.3390/en17235984

5 Digitalisation in crop production in Ukraine, particularly in fruit and berry growing

5.1 Analysis of the regulatory environment for digitalisation in Ukrainian agriculture

The digitalisation of agriculture in Ukraine is part of a broader state policy of digital transformation of the economy. There is currently no specialised regulatory act that comprehensively regulates the digital transformation of agriculture – norms regarding the digitalisation of agriculture are contained in general and sectoral strategic documents, laws and other regulatory acts.

5.1.1 General and special strategic documents

Strategic documents on the development of Ukraine's economy that contain provisions on the digitalisation of agriculture

Strategy for the development of innovation for the period up to 2030[238] (Order of the Cabinet of Ministers of Ukraine No. 526-r of 10 July 2019). The agricultural sector is identified as a key driver of economic growth with high potential for modernisation through digital technologies. The strategy provides for the introduction of innovations such as process automation, modern technologies (IoT, sensors, satellite imaging) and "Agriculture 4.0" to increase productivity and environmental sustainability.

The National Economic Strategy 2030 (NES 2030)[239] identifies the development of the digital economy as one of the drivers of Ukraine's economic growth. The strategic goal for the development of the digital economy is to transform the resource sectors of the economy into highly productive, intelligent and competitive ones. The strategy sets the task of increasing fixed Internet coverage and household connectivity in commercially unattractive rural areas. Digitalisation is recognised as a key driver of growth, including for the agricultural sector, through the dissemination of digital skills and access to technology for SMEs. There are also plans to digitise phytosanitary documents and integrate them into the international system for the exchange of such documents, digitise licensing procedures and administrative services in the field of land relations, introduce digital product traceability systems, and provide electronic public services using software tools and information and communication systems.

Strategic documents relating to the digitisation of the economy and containing provisions on the digitisation of agriculture

The Concept for the Development of Ukraine's Digital Economy and Society for 2018–2020[240] (the document has the status of "in force") provides for measures to introduce incentives for the digitalisation of the economy, public and social spheres, and also identifies critical areas and projects for digitalisation, measures to stimulate the domestic market for the production, use and consumption of digital technologies. The concept focuses on overcoming the digital divide through the development of digital infrastructure, especially in

[238] Strategy for the Development of Innovation for the Period until 2030. Resolution of the Cabinet of Ministers of Ukraine No. 526-r of 10 July 2019. https://zakon.rada.gov.ua/laws/show/526-2019-%D1%80#Text

[239] Resolution of the Cabinet of Ministers of Ukraine No. 179 of 3 March 2021 "On Approval of the National Economic Strategy until 2030". https://zakon.rada.gov.ua/laws/show/179-2021-%D0%BF#Text

[240] On approval of the Concept for the Development of the Digital Economy and Society of Ukraine for 2018-2020 and approval of the action plan for its implementation. Order of the Cabinet of Ministers of Ukraine No. 67-r of 17 January 2018. https://zakon.rada.gov.ua/laws/show/67-2018-%D1%80#Text

rural areas. In the context of the agricultural sector, it envisages the introduction of digital farming — a fundamentally new management strategy based on the use of digital technologies — and a new stage in the development of the agricultural sector, linked to the use of geographic information systems, global positioning, on-board computers and smart equipment, as well as management and executive processes capable of differentiating between methods of cultivation, fertilisation, chemical soil improvement and plant protection. Agriculture is not listed among the critical areas of digitalisation, but ecology and environmental protection are among the latter. The main directions of digitalisation in the field of ecology and environmental protection are, in particular, "smart" energy consumption, increasing the efficiency of energy production and supply; "smart" use of terrestrial and aquatic ecosystems and prevention of biodiversity loss. The priority initiatives include the creation of a national system for independent environmental monitoring and assessment of the state of natural ecosystems and the atmosphere; the creation of electronic registers of natural resources to provide information to state institutions and citizens during discussions and decision-making on the management of natural resource use, early warning, rapid response and recovery in the event of emergencies; the creation of an analytical system integrated into the European onlineShared Ecology Infrastructure System, to analyse short- and long-term trends in biodiversity, environmental pollution, weather conditions and ecosystem development, as well as to plan measures to prevent harmful changes.

The action plan for the implementation of the Concept provided for the development of a draft act of the Cabinet of Ministers of Ukraine on intensifying the development of digital agriculture and the digitalisation of the agricultural sector (the draft act was submitted to the Cabinet of Ministers of Ukraine for consideration in 2018).

The Strategy for Digital Development of Innovative Activities in Ukraine (WINWIN) until 2030[241] to ensure sustainable development and economic breakthrough identifies key industries that are the basis for innovation development, including AgroTech - technologies for agriculture and the food industry. An industry-specific strategy for AgroTech has been developed, identifying key trends in the global AgroTech market, including:

- Sustainable agriculture: precision farming technologies and the creation of new-generation farms (indoor and vertical farms) that can operate in cities, contribute to the transformation of the agricultural sector towards deep automation, and enhance its sustainability and environmental friendliness.
- Digital twins and generative AI: active use of digital twins and AI by agricultural producers to make informed decisions about planting and crop management, optimise resource use and increase yields with less impact on the environment.
- Agricultural biotechnology: adaptation to the challenges of climate change necessitates the development of sustainable crop varieties that are suitable for adverse climatic conditions and adapted to marginal lands and new urban farms.

Key types of AgroTech technologies have been identified, including:

- Automated equipment and robots:

[241] On approval of the Strategy for Digital Development of Innovative Activity in Ukraine for the period until 2030 and approval of the operational plan of measures for its implementation in 2025-2027. Order of the Cabinet of Ministers of Ukraine dated 31 December 2024 No. 1351-r. https://zakon.rada.gov.ua/laws/show/1351-2024-%D1%80#Text

- Autonomous tractors and robotic harvesters equipped with GPS navigation, sensors and AI, capable of independently tilling the soil, sowing crops and harvesting.
    - Autonomous irrigation and watering systems for agricultural crops that analyse soil conditions for the uniform application of seeds, fertilisers and pesticides.
    - Weeding robots equipped with cameras and machine learning algorithms are capable of finding weeds and mechanically removing them with precise application of herbicides.
- Drones:
    - Tracking livestock numbers and identifying pastures.
    - Creating 3D soil maps, which can be used to analyse soil quality and field conditions, as well as to determine the most effective sowing patterns.
    - Fertiliser application and pesticide treatment for safer and more efficient field cultivation.
    - Monitoring the entire irrigation network to identify any problems in real time.
- Precision farming:
    - Satellite technologies for real-time area analysis, topography and crop yield assessment.
    - Weather stations and soil moisture sensors to forecast precipitation and fertiliser requirements.
    - GPS monitoring systems and fuel control sensors to optimise resource management.
    - AI, Big Data and IoT-based software for timely and accurate detection of pests and diseases in crops.
- Trade:
    - E-commerce platforms based on AI, blockchain and Big Data technologies to increase the transparency of the agricultural market and find partners and suppliers.
    - Software and platforms for land bank management (sale, purchase, audit of own and unoccupied land plots).
    - Platforms for convenient transactions by agricultural market participants using mobile devices.

Among the key opportunities for promoting the development of the AgroTech sector is the creation of state grant programmes to support SMEs and start-ups in the industry, as well as ensuring transparent conditions for obtaining them. It is also proposed to introduce training and retraining programmes for specialists in the field of AgroFoodTech in cooperation with higher education institutions, private training centres and vocational education institutions.

The strategy identifies priority areas for technology development, including:

- Automated and robotic harvesting systems: robotic systems and equipment equipped with AI, GPS, cameras, sensors and IoT to automate the process of harvesting agricultural products.
- Introduction of technologies for adaptation to climate change: sensor technologies and satellite imagery for monitoring crop conditions, automated irrigation systems, crop rotation and adaptive crops that are resistant to climatic conditions.
- Vertical farming: a method of growing crops in vertically stacked layers using artificial lighting and a controlled environment.
- Precision farming: the use of advanced technologies, data and analytics to optimise and control crop cultivation processes.

Strategic documents related to the development of agriculture and rural areas that contain provisions on the digitalisation of agriculture

The Strategy for the Development of Agriculture and Rural Areas in Ukraine for the Period until 2030[242] focuses on digital transformation as a tool for improving the sustainability of the agricultural sector. It is noted that, in addition to monitoring fields and crops, the digitalisation of agriculture can help optimise the use of fertilisers, seeds and pesticides, thereby reducing the use of chemicals in agriculture. The tasks for the digitalisation of agriculture are formulated in the Strategy in two areas: (1) digitalisation of agriculture (includes tasks for the introduction of digital technologies for precision farming, automation, creation of knowledge banks and ensuring traceability of agricultural products); (2) digital agricultural advisory services that address the challenge of facilitating access to digital agriculture for small producers in order to increase farm productivity and optimise the use of chemicals (individual consultations for farmers can be complemented by digital services offering onlinetraining and advice on farming practices, access to finance and market trends).

5.1.2 General and specific regulations relating to digitalisation in agriculture.

The Law of Ukraine "On Electronic Commerce"[243] establishes a framework for electronic transactions, which also applies to trade in agricultural products (e-commerce of agricultural products), with an emphasis on harmonisation with the EU. In general, Ukrainian legislation in the field of electronic commerce also includes the Laws of Ukraine "On Consumer Protection"[244], "On Advertising"[245], "On Electronic Documents and Electronic Document Management"[246], "On the Protection of Information in Information and Communication Systems"[247], "On Telecommunications"[248], "On Electronic Identification and Electronic Trust Services"[249], "On Payment Services"[250], "On Financial Services and Financial Companies"[251], "On the Protection of Personal Data"[252].

The Law of Ukraine "On National Geospatial Data Infrastructure"[253] defines the legal and organisational basis for the creation, functioning and development of the national geospatial data infrastructure. Ukraine is creating a national geospatial data infrastructure in accordance with the principles of the EU Directive on the establishment of a spatial information infrastructure in the European Community. The national geoportal provides convenient search and free access for users to publicly available geospatial data sets (from 24 February 2022

[242] Strategy for the development of agriculture and rural areas in Ukraine for the period up to 2030. Order of the Cabinet of Ministers of Ukraine No. 1163-r of 15 November 2024. https://zakon.rada.gov.ua/laws/show/1163-2024-%D1%80#Text

[243] Law of Ukraine "On Electronic Commerce" dated 13 April 2020 No. 554-IX. Current version dated 01.01.2024. https://zakon.rada.gov.ua/laws/main/675-19#Text

[244] https://zakon.rada.gov.ua/laws/show/1023-12#Text

[245] https://zakon.rada.gov.ua/laws/show/270/96-%D0%B2%D1%80#Text

[246] https://zakon.rada.gov.ua/laws/show/851-15#Text

[247] https://zakon.rada.gov.ua/laws/show/80/94-%D0%B2%D1%80#Text

[248] https://zakon.rada.gov.ua/laws/show/1280-15#Text

[249] https://zakon.rada.gov.ua/laws/show/2155-19#Text

[250] https://zakon.rada.gov.ua/laws/show/1591-20#Text

[251] https://zakon.rada.gov.ua/laws/show/1953-20#Text

[252] https://zakon.rada.gov.ua/laws/show/2297-17#Text

[253] Law of Ukraine "On National Geospatial Data Infrastructure" dated 13 April 2020 No. 554-IX. https://zakon.rada.gov.ua/laws/main/554-20#Text

until the end of martial law, access to the public part of the system is restricted). Geospatial data includes land plots and cadastral zoning (formed land plots and their parts, land areas, agricultural land areas, cadastral zones and quarters). In December 2023, the software for the national geoportal was adopted and put into trial operation. In 2024-2025, the development, administration and design of a comprehensive information protection system and the creation of effective functionalities for working with geospatial data will be ensured.

The Law of Ukraine "On the Information and Communication System "State Agrarian Register"[254] came into force in January 2025. This law is key to the digitalisation of the agricultural sector. It regulates the creation of a unified electronic system for the collection, accumulation, integration, storage and processing of data on agricultural producers. The register serves as a "single electronic window" for interaction with state bodies, expands the circle of users (including water user organisations) and ensures monitoring of the targeted use of state support. The law is integrated with other systems, promoting transparency and traceability of products.

The Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding the Organisational Principles of Support in the Agricultural Sector" dated 3 November 2025, No. 4619-IX[255] provides for the creation of a modern, transparent and fair system of support for farmers in Ukraine that will meet European Union standards.

The implementation of the Law will allow:

- create a Paying Agency – an independent state institution that will administer support for farmers. This is a guarantee of transparency, honesty and the fight against corruption;
- introduce an Integrated Administration and Control System (IACS), which will allow the use of funds to be monitored through digital technologies and satellite monitoring – a European standard for digitalisation and transparency;
- introduce a sustainable development data system (FSDN). This is a European tool that will show the real state of farms – economic, social and environmental – on an annual basis;
- introduce European-level controls – automated checks, documentary audits, on-site inspections – in line with EU requirements.

The Law of Ukraine "On Agricultural Receipts"[256] (with the Register of Agricultural Receipts, approved by the Order of the Cabinet of Ministers No. 665 of 17 August 2013[257]) ensures the transparency of the agricultural market through an electronic register, protects the rights of participants and promotes the digitisation of financial instruments in agriculture.

5.1.3 Regulatory acts relating to the digitisation of education, including agricultural education

The Concept for the Development of Digital Competencies[258] contains the conceptual foundations for the formation of state policy in the field of developing the digital skills and

[254] Law of Ukraine "On the Information and Communication System "State Agrarian Register" No. 3980-IX, 19 September 2024. https://zakon.rada.gov.ua/laws/show/3980-20

[255] Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding the Organisational Principles of Support in the Agricultural Sector", 3 November 2025, No. 4619-IX https://zakon.rada.gov.ua/laws/show/4619-20#Text

[256] https://zakon.rada.gov.ua/laws/main/5479-17#Text

[257] https://zakon.rada.gov.ua/laws/show/665-2013-%D0%BF#n8

[258] On the approval of the Concept for the Development of Digital Competencies and the approval of the action plan for its implementation. ORDER OF THE CABINET OF MINISTERS OF UKRAINE dated 3 March 2021 No. 167-r. https://zakon.rada.gov.ua/laws/show/167-2021-%D1%80#Text

digital competencies of Ukrainian citizens. The implementation of this Concept is planned for the period up to 2025. Digital competence is defined in the Concept as a dynamic combination of knowledge, skills, abilities, ways of thinking, views, and other personal qualities in the field of information and communication and digital technologies, which determines a person's ability to successfully socialise, conduct professional and/or further educational activities using such technologies. In accordance with this concept, the Ministry of Digital Transformation of Ukraine has developed a digital competence framework[259], which can be used to create training programmes, educational resources, and more detailed digital competence frameworks for various professional groups in different sectors of the economy, including agriculture. Currently, there is no separate approved digital competence framework for agriculture in Ukraine. Agricultural producers can develop their skills using the digital competence framework for entrepreneurs in Ukraine, which defines the areas of digital knowledge and skills necessary for the confident use of digital technologies in professional activities, including data analysis, information management and communication[260] . A digital competence framework for teachers and academic staff has also been developed[261], designed to develop digital education in schools, including in rural areas, and in higher education institutions, including agricultural ones.

5.2 Introduction of digital technologies in the agribusiness management system

State Agricultural Register

On 12 August 2022, the State Agricultural Register (DAR) began operating in Ukraine. It is an automated electronic system created with the technical assistance of the European Union for the effective and transparent distribution and administration of all types of support for Ukrainian farmers.

The DAR works similarly to the registers of agricultural producers that exist in all EU member states. Agricultural producers registered with the DAR will be able to apply for state subsidies, targeted subsidised loan programmes, loans and technical assistance from the European Union and other international donors.

DAR is a state information and communication system for all agricultural producers, regardless of their size and organisational and legal form. Since its launch in 2022, as of 20 August 2025, DAR has implemented more than 50 support programmes worth over UAH 8 billion, integrated seven state registers and connected 35 banks for online verification of borrowers under the "5-7-9% Loans" programme. As of 20 August 2025, approximately 200,000 users were registered in the system, with 20.9 million hectares of land and 7.5 million land plots accounted for[262].

[259] Description of the digital competence framework for Ukrainian citizens DigCompUA for Citizens 2.1. Ministry of Digital Transformation of Ukraine. 2021. https://thedigital.gov.ua/storage/uploads/files/news_post/2021/3/mintsifra-oprilyudnyue-ramku-tsifrovoi-kompetentnosti-dlya-gromadyan/%D0%9E%D0%A0%20%D0%A6%D0%9A.pdf

[260] Description of the digital competence framework for entrepreneurs in Ukraine. Based on DigCompUA, DigComp 2.1 and EntreComp EU. 2021. Ministry of Digital Transformation of Ukraine. https://osvita.diia.gov.ua/uploads/0/2904-2605_co_ramka_pidpriemca_11_2021_compressed.pdf

[261] Conceptual and reference framework for digital competence of teaching and research staff. https://osvita.diia.gov.ua/uploads/0/2900-2629_frame_pedagogical.pdf

[262] https://me.gov.ua/News/Detail/46f453f7-3a3a-4dc0-aa57-e2f29ef18ead?lang=uk-UA&title=NoviMozhlivostiDerzhavnogoAgrarnogoRestru-ZapratsiuvavScheOdinFunktsionalDliaSilgospvirobnikiv

DAR is developing as a modular system: new services and registers are being integrated gradually, creating a foundation for the implementation of European digital tools. One such element is the State Register of Agricultural Producers.

Integrated Administration and Control System

The EU's Common Agricultural Policy requires EU Member States to establish and use an Integrated Administration and Control System (IACS) to manage, monitor and control payments under the Common Agricultural Policy[263] . It is planned that IACS in Ukraine will become a subsystem of DAR. IACS in EU countries consists of an animal identification and registration system, a land parcel database (LPIS) and modules for geomonitoring and control of payment compliance. It is expected that IACS will start operating in Ukraine on 1 January 2027.

5.3 Training in digital technologies in agriculture

Introduction of AKIS

The Agricultural Knowledge and Innovation System (AKIS) is a legally established component of the EU's Common Agricultural Policy (CAP) and requires each Member State to develop a national plan. For Ukraine, its development is aligned with the National Strategy for the Development of Agriculture and Rural Areas until 2030, which sets priorities for competitiveness, innovation, digitalisation and effective knowledge sharing.

In Ukraine, the national AKIS web portal, which will provide farmers, advisors and researchers with personalised access to professional knowledge and a discussion platform, is being created with the support of the EU-funded project "Institutional and Policy Reform of Small-Scale Agriculture in Ukraine" (EU4SmallFarms)[264]. It is expected that AKIS will be integrated with DAR. It is also planned to create eight regional AKIS hubs as centres for knowledge exchange, development of cooperation between farmers, scientists, advisors and businesses, and introduction of European practices and technologies into domestic production.

Projects of the Ministry of Digital Transformation of Ukraine

The Ministry of Digital Transformation of Ukraine coordinates digitalisation processes in Ukraine, including the digitalisation of agriculture. The following projects of the Ministry of Digital Transformation of Ukraine provide support to SMEs and the development of digital skills among the rural population:

- Дія.Освіта: a portal with online courses, including courses on digital literacy.
- Дія. Business: a portal to support SMEs, including components for starting a business (Дія. Business Start), business development (Дія. Business Development), and export (Action. Business Export), assistance to women in starting and developing a business (Action. Business Women), assistance to veterans in starting and developing a business (Action. Business Veterans).

[263] Regulation (EU) No 1306/2013 of the European Parliament and of the Council of 17 December 2013 on the financing, management and monitoring of the common agricultural policy and repealing Council Regulations (EEC) No 352/78, (EC) No 165/94, (EC) No 2799/98, (EC) No 814/2000, (EC) No 1290/2005 and (EC) No 485/2008. http://data.europa.eu/eli/reg/2013/1306/oj

[264] https://me.gov.ua/News/Detail/d1d62c5c-98e8-4f64-8aa0-8a63065d1d24?lang=uk-UA&title=MinekonomikiTaPartneriObgovoriliVprovadzhenniaSistemiSilskogospodarskikhZnanTaInnovatsii-akis-

The Ministry of Digital Transformation of Ukraine calculates the Digital Transformation Index of Ukraine's regions[265]. Among other things, the Digital Transformation Index of Ukraine's regions takes into account the level of digital skills and digital infrastructure in Ukraine's regions – indicators that indirectly assess the ability of small and medium-sized agricultural producers and households to use digital technologies. According to the results of the 2024 study, the average Digital Transformation Index score in Ukraine was 0.651 out of a possible 1. One of the highest values is the sub-index "Internet Development" (0.686), and the lowest value is the sub-index "Digital Education" (0.406), which indicates the need to develop digital skills among the population.

Office for Entrepreneurship and Export Development

In September 2023, the State Agency "Office for Entrepreneurship and Export Development" was designated as the National Contact Point (NCP) within the Digital Europe Programme. The Agency provides information on the European Union's digital policy and the opportunities available under the Programme. The Digital Europe Programme (DIGITAL) is an EU funding programme aimed at introducing digital technologies for businesses, citizens and public administrations. The total budget for the programme is €7.5 billion until 2027, €6 billion of which is allocated to funding areas of the programme that are available to Ukraine, including the development of digital skills and the use of digital technologies in the economy and society.

Higher education institutions

Higher education institutions in Ukraine have introduced master's programmes in precision farming. In particular, the National University of Life and Environmental Sciences of Ukraine (NULES) offers a course titled "Precision Farming System" at the Department of Agriculture and Herbology[266]. Sumy Agrarian University has a master's programme in Precision Farming Systems[267] at the Faculty of Engineering and Technology. Students at Uman National University study precision farming technologies at the O.I. Zinchenko Department of Plant Growing.[268] Vinnytsia National Agrarian University teaches the subject "Precision Farming" at the Faculty of Agronomy, Horticulture and Plant Protection[269].

Agricultural business

Some agricultural companies conduct their own training in digital technologies for their employees, with the involvement of students from agricultural higher education institutions. Service companies also periodically conduct training for their clients on the use of new products.

With the support of agribusiness and international organisations, educational agricultural platforms are being created. For example, with the support of USAID, the Ukrainian Agribusiness Club has created the AgroKebetyPRO training platform[270] — an online portal

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265 Digital Transformation Index of Ukrainian Regions. Results for 2024. Ministry of Digital Transformation of Ukraine. 2024. Action. Digital Community. URL: https://backend.hromada.gov.ua/storage/uploads/files/research/indeks-cifrovoyi-transformaciyi-regioniv-ukrayini-pidsumki-2024-roku/%D0%86%D0%9D%D0%94%D0%95%D0%9A%D0%A1%202024%202%201.pdf

266 https://nubip.edu.ua/sites/default/files/u427/robocha_programa_sistema_tochnogo_zemlerobstva_2024_0.pdf

267 https://snau.edu.ua/pro-universitet/struktura-universitetu/viddil-jakosti-osviti-licenzuvannja-ta-akreditacii/zabezpechennja-jakosti-osviti/katalog-osvitnih-program/

268 https://crops.udau.edu.ua/ua/novini/tehnologii-tochnogo-zemlerobstva.html

269 https://socrates.vsau.org/b04213/html/cards/getfile.php/35029.pdf

270 https://courses.agrokebety.com/

that provides free access to online training courses and all the necessary materials for distance learning for students, teachers and specialists in the agricultural sector, including courses on smart technologies.

5.4 The use of digital technologies in crop production processes, including for the purpose of adapting to climate change and making products more environmentally friendly

In the absence of official statistics on the use of digital technologies in Ukrainian agriculture, research conducted by the Aggeek information agency in 2024 and 2025 was used to obtain information on the state of digital technology use in crop production processes. The first study in Ukraine on the use of digital technologies in crop production in Ukrainian agricultural companies, "Digital Agro Ukraine," was launched by Aggeek[271] in 2024. Then the study covered 50 innovative agricultural companies of various sizes (from micro, small and medium to large agricultural holdings) and 2,800 participants in the Agrotech market in Ukraine. The study identified the most popular digital technologies used by at least 50% of the innovative enterprises surveyed, including: the use of autopilots, precise fertiliser application during sowing, telematics (monitoring fuel levels and refuelling, tracking location), production planning in Excel, application of plant protection products from drones, monitoring (satellite images, plant development indices), online document flow when selling products, etc. Fig. 5.1 presents the results of a survey of innovative companies on the use of digital technologies in crop production processes.

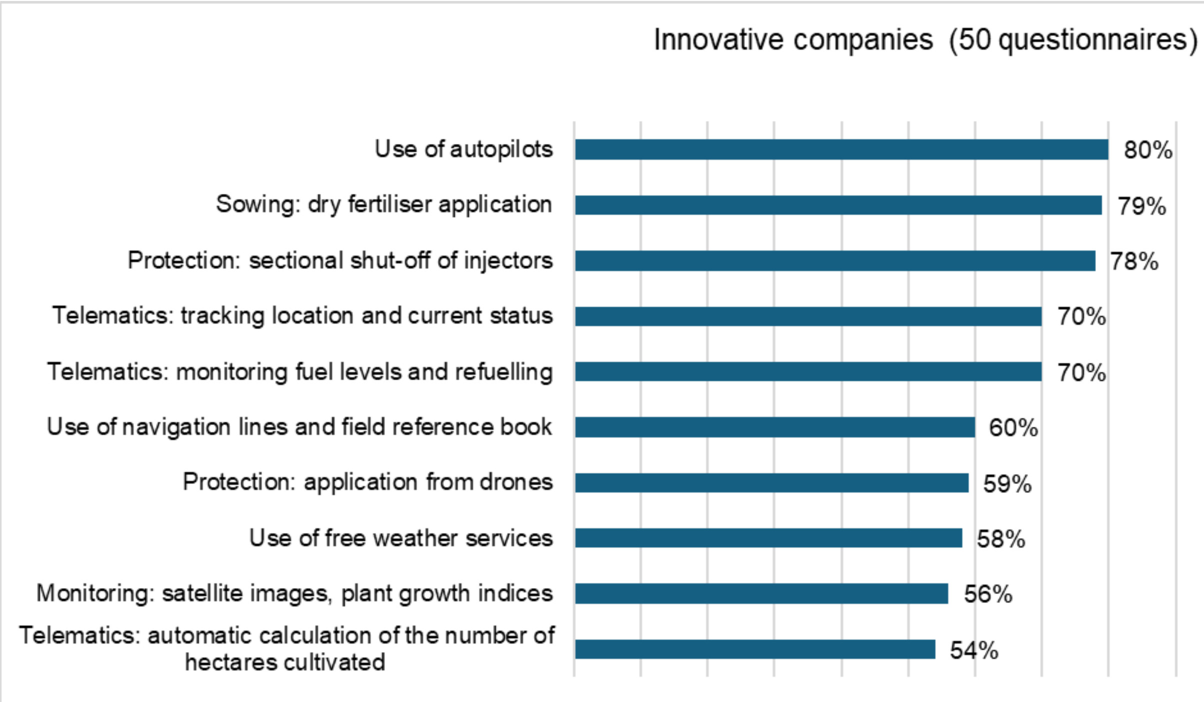

Figure 5.1 – Use of digital technologies in crop production processes in innovative companies in Ukraine, according to the results of a survey of innovative companies in the Aggeek study "Digital Agro Ukraine 2024".

Source: https://www.aggeekaggency.com/digitalagro

[271] Digital Agriculture in Ukraine 2024. Research. URL: https://www.aggeekaggency.com/digitalagro

According to data from 2024, 80% of innovative agricultural companies indicated in the questionnaires that they use autopilots, 79% use digital technologies for applying dry fertilisers during sowing, 78% use digital technologies for sectional shutdown of nozzles in plant protection measures, 59% use drones to apply plant protection products, 70% use telematics, 58% use free weather services, and 56% use satellite images and plant development indices based on them. Fig. 5.2 shows the results of an online survey of participants in the Ukrainian agricultural market regarding the use of digital technologies in their enterprises. According to the survey results, the most popular digital technologies are navigation (autopilots, course indicators), plant development monitoring (satellite images, applications) and weather monitoring, which are used in 60%, 40% and 24% of farms, respectively.

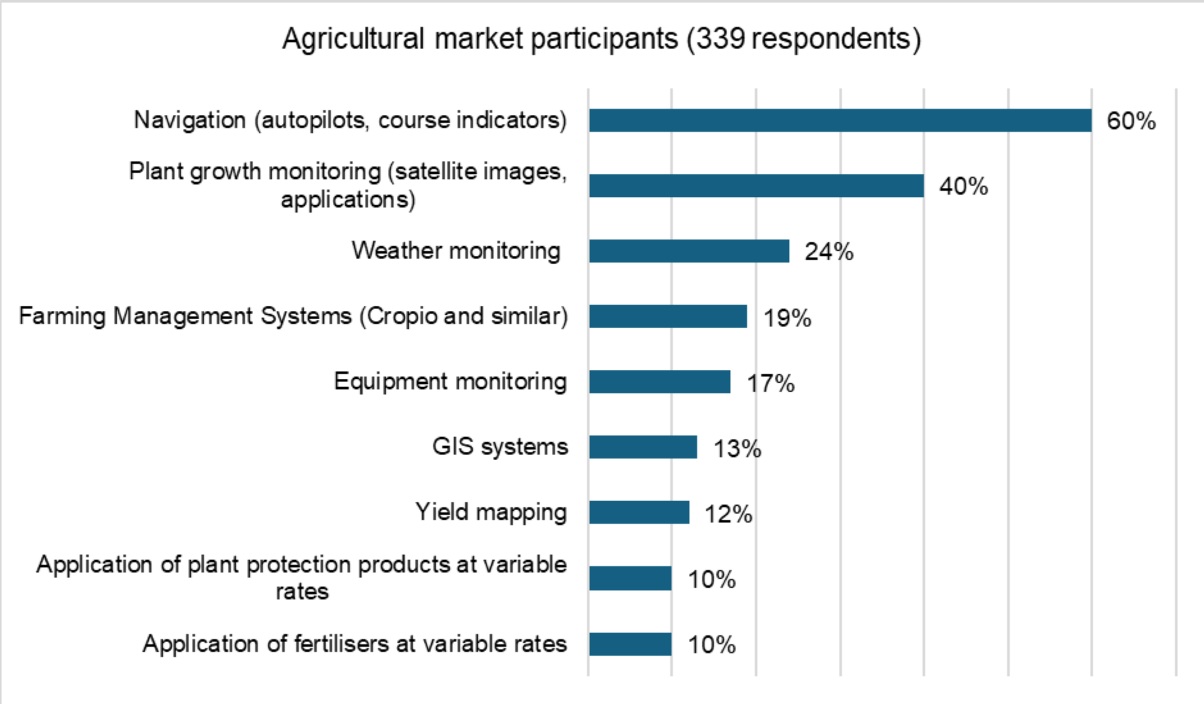

Figure 5.2 – Respondents' answers regarding the use of digital technologies in crop production processes on their farms, based on the results of an online survey of agricultural market participants in the Aggeek study "Digital Agro Ukraine 2024".

Source: https://www.aggeekaggency.com/digitalagro

Digital platforms are used in Ukraine for remote monitoring of agricultural land. In particular, Syngenta's Cropwise system monitors 25% of Ukraine's agricultural land. Cropwise is a leader in the application of FMS (Farming Management System) systems by small and medium-sized agricultural enterprises in Ukraine, which focus on field operations – monitoring weather conditions, crop development, harvesting, and monitoring equipment. Digital technologies are used for harvest logistics in Ukraine, including hopper sensors in combine harvesters, planning and monitoring of grain truck routes, electronic waybills (a permanent document number for shipment) for grain truck drivers, electronic queues at elevators, and AI for logistics planning. When selling crops, 52% of innovative companies use electronic contracts and electronic signatures, and 10% use electronic exchanges. The study "Digital Agro Ukraine 2025"[272] covered 54 agricultural companies with land use areas ranging from 80 to 500,000 hectares, which filled out questionnaires for agricultural companies, and 2,200 participants in online surveys (agricultural market participants). The total area of land cultivated by the agricultural companies that participated in the study is 2 million 168 thousand hectares, which is about 10% of the total land bank cultivated in Ukraine in 2025. A separate block of the study focused on regenerative farming technologies that reduce CO2 emissions and increase soil fertility. Figure 5.3 shows respondents' answers regarding the use of carbon emission reduction technologies on their farms.

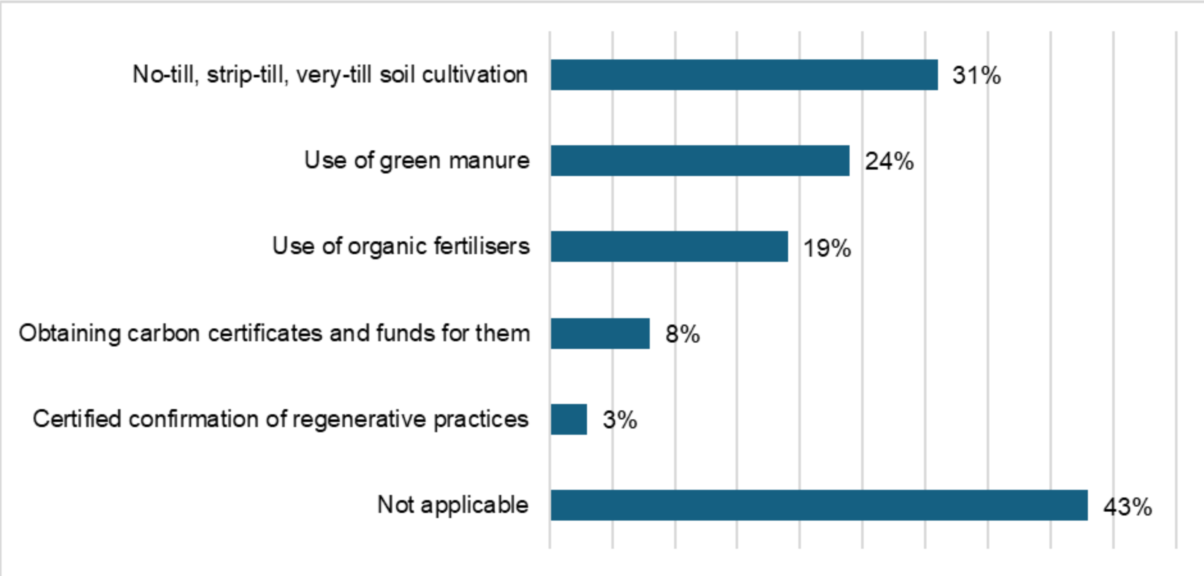

Figure 5.3 – Respondents' answers regarding the use of technologies to combat carbon emissions from Aggeek's anonymous survey "Digital Agro Ukraine 2025".

Source: https://www.aggeekaggency.com/digitalagro 2025

The study also showed (based on questionnaires from agricultural companies) that 31% of them have a carbon certificate and 22% have a regenerative practices certificate. These are mainly companies with a land bank of 1,000 to 500,000 hectares.

5.5 Use of digital technologies for agribusiness management

ERP systems (Enterprise Resource Planning) are used to manage innovative agricultural companies in Ukraine. This software integrates and automates key business processes such as finance, human resources, production, procurement and sales, providing a single database and a complete picture of the company's activities. ERP provides company management with operational reporting and analytical data for strategic decision-making. It allows you to optimise work, increase efficiency and make informed management decisions based on up-to-date analytics.

[272] Digital Agriculture in Ukraine 2025. Research. https://www.aggeekaggency.com/digitalagro2025

Aggeek's "Digital Agriculture 2025" study showed that innovative agricultural companies most often use 1C – BAS ERP (70% of companies), but the share of users of this system is gradually decreasing, and agricultural companies (mainly large ones) are beginning to prefer Microsoft Dynamics 365 (33%), SAP ERP (9%), ERP IT Enterprise (4%), and Oracle ERP (2%) systems (Fig. 5.4).

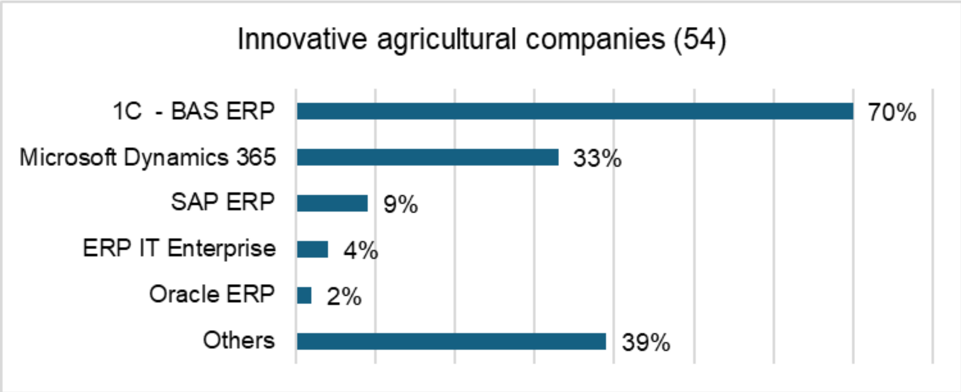

Figure 5.4 – Use of ERP systems in innovative companies in Ukraine according to the results of a survey of innovative companies in the Aggeek study "Digital Agriculture of Ukraine 2025".

Source: https://www.aggeekaggency.com/digitalagro2025

Innovative companies in Ukraine also use BI (Business Intelligence) systems, which automatically select and process data, convert it into a single format for analysis, and present information in the form of understandable dashboards, graphs, and reports, which facilitates analysis for consumers. Data visualisation supports the adjustment of operational goals and strategy development, and helps to identify risks, trends and patterns. The leaders in the use of BI systems in Ukrainian agricultural companies are Microsoft Power BI (43% of innovative agricultural companies) and Farming OS (32%) (Fig. 5.5).

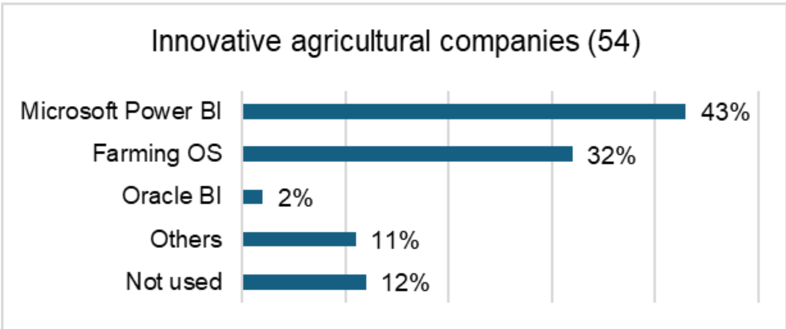

Figure 5.5 – Use of BI systems in innovative agricultural companies in Ukraine according to the results of a survey of innovative companies in the Aggeek study "Digital Agriculture of Ukraine 2025".

Source: https://www.aggeekaggency.com/digitalagro2025

The majority (74%) of innovative companies use Microsoft Excel for production planning and budgeting, while a significant proportion (40%) use 1C – BAS EPR, and 30% plan in a paper journal (Fig. 5.6).

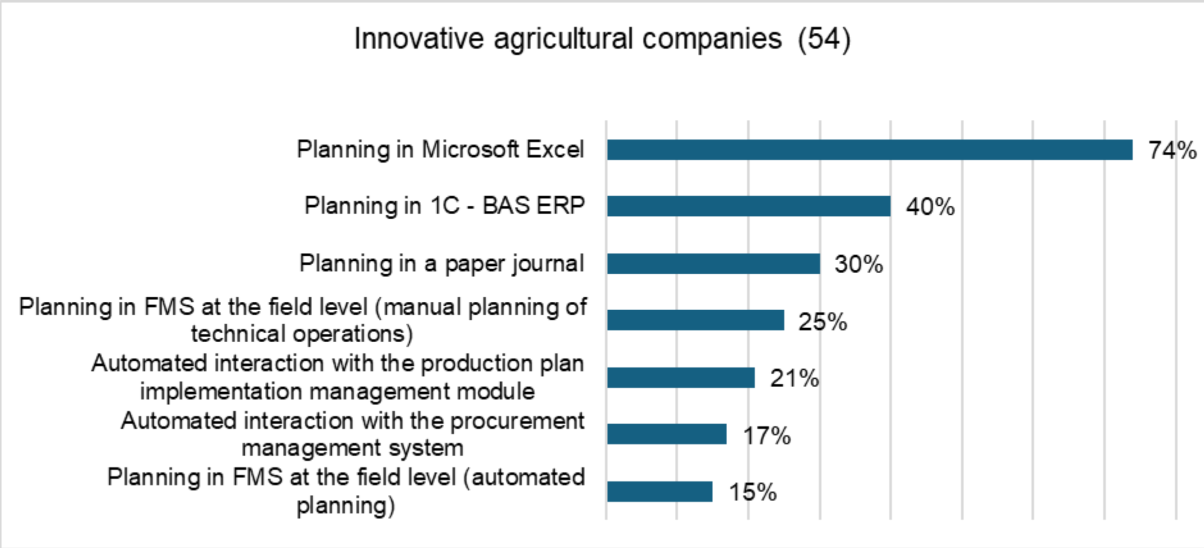

Figure 5.6 – Use of digital technologies in production planning and budgeting in innovative agricultural companies in Ukraine, based on the results of a survey of innovative companies in the Aggeek study "Digital Agriculture of Ukraine 2025".

Source: https://www.aggeekaggency.com/digitalagro2025

5.6 Use of digital technologies in climate-oriented fruit and berry growing practices

Key digital technologies in climate-oriented practices for growing raspberries and garden strawberries

The cultivation of berries, fruits and nuts in Ukraine faces challenges posed by climate change: droughts, frosts, soil erosion and increased CO_2 emissions. In particular, according to market experts' estimates, in 2025, due to spring frosts, producers lost 20%–30% of raspberries and 40%–59% of garden strawberries, depending on the variety of berries[273]. Therefore, climate-oriented practices for growing raspberries and strawberries in greenhouses (tunnels) are becoming more widespread. It should be noted that growing raspberries in tunnels is much more difficult than growing strawberries. The most popular solution for protecting raspberries from rain is lightweight plastic tunnels, known as farmer tunnels, or Haygroye elite tunnels. Sometimes raspberries are grown in heated Farmer plastic greenhouses, which significantly speeds up ripening and extends the harvesting period[274]. Due to the high labour intensity of growing berries in greenhouses, producers are increasingly moving towards the digitalisation and robotisation of production processes[275]. Although most innovations are used in large and medium-sized agricultural enterprises, small farms are also implementing simpler tools.

Climate-oriented practices for growing raspberries and garden strawberries focus on precision agriculture, which minimises the cost of fertilisers, water and pesticides. Precision agriculture is seen as a set of tools from which producers choose those they need. Table 5.1

[273] Results of the berry and fruit season in Ukraine: 2025 – a year of poor harvests and record prices. Seeds. 4 November 2025. URL: https://www.seeds.org.ua/pidsumki-sezonu-yagid-ta-fruktiv-v-ukraini-2025-rik-nevrozhayu-i-rekordnix-cin/

[274] Growing raspberries indoors. AGRONOM. 20 December 2009. URL: https://www.agronom.com.ua/vyroshhuvannya-malyny-v-zakrytomu-grunti/

[275] A farm in Cherkasy region grows 5 British raspberry varieties in tunnel greenhouses. SuperAgronom.com. 3 July 2025. URL: https://superagronom.com/news/20997-gospodarstvo-na-cherkaschini-viroschuye-5-britanskih-sortiv-malini-v-tunelnih-teplitsyah

presents the main precision agriculture tools adapted for growing raspberries and strawberries in Ukraine, including those developed in Ukraine.

Table 5.1 – Main precision farming tools adapted for growing raspberries and strawberries in Ukraine

Technology	Description	Application in raspberry and strawberry cultivation	Advantages	Examples in Ukraine
Drones and satellite monitoring	UAVs and satellite images for scanning plantations	UAVs help to conduct high-precision monitoring of growth, detection of diseases or nutrient deficiencies. Satellite images and NDVI indices[276] are used to assess plant condition and identify areas of stress.	Savings of up to 20% on fertilisers, 15% less use of chemical mixtures, 10% increase in yield[277,278].	Geosys App platform[279] with Ukrainian interface (free for Ukrainian farmers). Cropwise (Syngenta) - a platform for remote monitoring of agricultural land.
IoT sensors	Humidity, temperature and pH sensors integrated with cloud platforms.	Automatic irrigation in tunnels, microclimate control for remontant varieties.	Water savings of up to 40%[280], reduction of grey mould.	Small farms use drip systems or sprinklers, and control is carried out by a controller with humidity sensors to save water. Smart Irrigation Systems optimise water consumption based on weather forecasts and soil moisture. MyAgriLab agronomist portal[281].
AI and machine learning	Modelling climate risks.	Analysis of historical climate data and forecasting of risks of frost, heat or pests.	Support for decisions on planting, watering or protecting crops.	Ukrainian startup Agrieye is a platform for small farms based on AI and big data technologies. The system receives data from drones and satellites. Ukrainian startup AGRO BI from HOROS.TECH is a business intelligence platform that uses AI, satellite imagery, weather models, and telematics data to support decision-making.

[276] NDVI is a normalised differential vegetation index that quantitatively assesses the photosynthetically active biomass of plants. It shows how healthy the plants are.
[277] https://landlord.ua/news/innovatsiyi-v-agrosektori-5-korisnih-startapiv
[278] Analysts have revealed what autonomous and robotic technologies to expect in the agricultural sector in 2026. SuperAgronom.com. 10 November 2025. URL: https://superagronom.com/news/21642-analitiki-rozpovili-yaki-avtonomni-ta-robotizovani-tehnologiyi-ochikuvati-v-agrosektori-u-2026-rotsi
[279] New digital platform Geosys. AgriLab. 9 June 2022. URL: https://www.agrilab.ua/nova-tsyfrova-platforma-geosys/
[280] Choudhary, Anita & Dadarwal, Pinki (2025). Smart Irrigation Technologies for Water-Efficient Horticulture Crops. The Agriculture Magazine. https://www.researchgate.net/publication/391977587_Smart_Irrigation_Technologies_for_Water-Efficient_Horticulture_Crops/stats
[281] https://www.agrilab.ua/services/portal-agronoma/

Key digital technologies in climate-oriented apple growing practices

Digital microclimate monitoring systems

Apple orchards are increasingly using agrometeorological stations and sensor networks (IoT) to monitor temperature, soil moisture, precipitation, and solar radiation.

The Ukrainian-developed AgroControl meteorological station, platform and mobile application[282], and the Ukrainian independent weather service MeteoFarm[283], which provides farmers with information about weather conditions in specific fields across the country, offer solutions for automated data collection and frost risk forecasting. This allows farmers to make decisions about irrigation or activating frost protection systems.

Satellite and drone technologies

The use of *Sentinel* satellite images (Copernicus programme)[284] and drones makes it possible to monitor the condition of trees using the NDVI and NDWI indices[285] and to identify moisture deficits or plant damage.

Climate risk modelling

Artificial intelligence algorithms analyse long-term data on weather, soil and the phenological phases of apple trees. This makes it possible to predict the risks of spring frosts, pests or diseases. In Ukraine, a commercial platform (Bayer) for agricultural data and modelling, Climate FieldView[286], which is widespread in Europe and the United States, offers its services. It collects field data and meteorological information and provides risk/yield maps[287]. Climate AI — ClimateLens[288] (an AI platform for the agricultural sector) is also widespread worldwide, using AI to convert climate and weather data into operational business insights (forecasts of frost/drought risks, optimal sowing dates, and climate risk scenarios).

Digital irrigation management

Smart irrigation systems are integrated with moisture sensors, weather forecasts, and analytical platforms. For example, apple orchards in Ukraine (Renet Simirenko) use the iMetos automatic soil moisture station and the CROPWAT computer program[289]. In an orchard in the village of Lysets, Dunayevetsky district, Khmelnytsky region, where apple and pear trees are grown, a sprinkler system integrated with a weather station is used, which has increased yields by 22%[290].

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282 https://agrocontrol.net/

283 https://latifundist.com/kompanii/1148-meteo-farm

284 https://sentinels.copernicus.eu/copernicus

285 Normalised Difference Water Index. URL: https://eos.com/make-an-analysis/ndwi/

286 https://www.climatefieldview.com.ua/about

287 https://climate.com/en-us.html

288 https://climate.ai/solutions-products/climatelens-overview

289 Shatkovskyi, A., & Minza, F. (2019). DRIP IRRIGATION REGIME AND WATER CONSUMPTION OF APPLE TREES, DEPENDING ON THE METHODS OF IRRIGATION SCHEDULING. Land Reclamation and Water Management, (1), 28 - 35. https://doi.org/10.31073/mivg201901-165

290 Sustainable Agriculture in Central Ukraine: Transforming Villages through Berry Farming and GIS Technology. Farmonaut. URL: https://farmonaut.com/europe/sustainable-agriculture-in-ukraine-5-ways-berry-farming-transforms-villages

Digital technologies in nut cultivation

According to the Ukrainian Nut Association, the area of industrial nut orchards in Ukraine is 14.1 thousand hectares (2025). The majority of these are hazelnut orchards (7,900 hectares), followed by walnut orchards (approximately 6,100 hectares) and almond orchards (approximately 0.15 hectares)[291]. Although the area of commercial nut orchards is constantly increasing, this growth is due to hazelnut orchards. According to the Ukrainian Nut Association, 95% of the nut orchards newly established in recent years are hazelnut orchards. Most of the walnuts in Ukraine are grown on household farms, in protective and forest belts, and in roadside plantings, where digital technologies are generally not used.

Digital technologies are widespread in industrial walnut orchards. The company Ukrainian Walnut[292], which planted a walnut orchard in the Vinnytsia region in 2016 (100,000 Chandler American walnut trees), has fully automated orchard management, including micro-irrigation and fertigation technologies combined with soil moisture sensors.

5.7 Priorities and recommendations for the development of digitalisation in Ukrainian agriculture

Priorities

The priorities for digitalisation in Ukrainian agriculture are set out in the following strategic documents:

The National Economic Strategy 2030 (NES 2030)[293] defines *the strategic goal* for the development of the digital economy as the transformation of resource-based sectors of the economy into highly productive, intelligent and competitive ones. *The priority tasks* are to increase fixed Internet coverage and household connectivity in commercially unattractive rural areas and to promote digital skills and access to technology for SMEs.

The Concept for the Development of the Digital Economy and Society of Ukraine for 2018–2020[294] (document has the status of "in force") focuses on overcoming the digital divide through the development of digital infrastructure, especially in rural areas. In the context of the agricultural sector, *the priority task* is defined as the introduction of digital farming.

The AgroTech sectoral strategy, developed as part of Ukraine's Digital Innovation Development Strategy (WINWIN) until 2030,[295] sets out *the* following *priorities* for the development of digital technologies for crop production:

– automated and robotic harvesting systems: robotic systems and equipment equipped with AI, GPS, cameras, sensors and IoT to automate the process of harvesting agricultural products;

[291] Let's create a nut foresight together. Ukrainian Nut Association. 15 January 2025. URL: https://www.ukr-nuts.com.ua/news/let's-create-a-nut-foresight-together

[292] https://ukrainianwalnut.com/

[293] Resolution of the Cabinet of Ministers of Ukraine No. 179 of 3 March 2021 "On Approval of the National Economic Strategy until 2030". https://zakon.rada.gov.ua/laws/show/179-2021-%D0%BF#Text

[294] On approval of the Concept for the Development of the Digital Economy and Society of Ukraine for 2018-2020 and approval of the action plan for its implementation. Order of the Cabinet of Ministers of Ukraine No. 67-r of 17 January 2018. https://zakon.rada.gov.ua/laws/show/67-2018-%D1%80#Text

[295] On approval of the Strategy for Digital Development of Innovative Activity in Ukraine for the period until 2030 and approval of the operational plan of measures for its implementation in 2025-2027. Order of the Cabinet of Ministers of Ukraine dated 31 December 2024 No. 1351-r. https://zakon.rada.gov.ua/laws/show/1351-2024-%D1%80#Text

– introduction of technologies for adaptation to climate change: sensor technologies and satellite imagery for monitoring crop conditions, automated irrigation systems;
– vertical farming: a method of growing crops in vertically stacked layers using artificial lighting and a controlled environment;
– precision farming: the use of advanced technologies, data and analytics to optimise and control crop cultivation processes.

In the Strategy for the Development of Agriculture and Rural Areas in Ukraine for the period up to 2030[296], *the tasks* for the digitalisation of agriculture are formulated in two directions: (1) digitalisation of agriculture (includes tasks for the introduction of digital technologies for precision farming, automation, creation of knowledge banks and ensuring traceability of agricultural products); (2) digital agricultural advisory services that address the task of facilitating access to digital agriculture for small producers in order to increase the productivity of farms and optimise the use of chemicals.

Thus, based on an analysis of Ukraine's strategic documents, *the* following *priorities for the development of digitalisation in crop production, including fruit and berry growing*, can be identified:

– increasing fixed Internet coverage and connectivity for households in rural areas;
– spreading digital skills and access to technology for SMEs;
– introducing technologies to adapt to climate change: sensor technologies and satellite imagery to monitor the condition of crops and plantations, automated irrigation systems;
– precision farming: using advanced technologies, data and analytics to optimise and control crop cultivation processes.

Barriers to development

A barrier to the spread of digital technologies in rural areas is the digital divide in fibre-optic network coverage. According to the Accounting Chamber of Ukraine, as of November 2022[297], one-third of villages and settlements in Ukraine did not have fibre-optic network coverage. This barrier is to be overcome by the Draft Law on Amendments to Certain Laws of Ukraine on the Regulation of Certain Issues in the Field of Electronic Communications (No. 12094[298]), adopted on 4 November 2025, which, as of 16 November 2025, was awaiting the President's signature. The new law should ensure that Ukrainians have equal access to fast mobile internet, regardless of where they live or travel. It sets mandatory connection speed indicators that mobile operators will have to maintain. This should guarantee stable internet in villages. The law will accelerate the development of the network in rural areas. This will be possible after the moratorium on inspections is lifted, which previously hindered the installation of new base stations.

The digitisation of SPS procedures and the implementation of relevant EU legislation in the field of sanitary and phytosanitary control, which is the most complex part of adapting Ukraine's agricultural trade to the regulatory requirements of EU markets, face barriers. The

[296] Strategy for the Development of Agriculture and Rural Areas in Ukraine for the Period until 2030. Resolution of the Cabinet of Ministers of Ukraine No. 1163-r of 15 November 2024. https://zakon.rada.gov.ua/laws/show/1163-2024-%D1%80#Text
[297] https://rp.gov.ua/PressCenter/News/?id=1464
[298] Draft Law on Amendments to Certain Laws of Ukraine Regarding the Regulation of Certain Issues in the Field of Electronic Communications. 4 November 2025. No. 12094. https://itd.rada.gov.ua/billinfo/Bills/Card/44975

acceleration of these processes, including the introduction of electronic applications and the issuance of SPS certificates, would be facilitated by the accelerated implementation in Ukraine of the EU's TRACES information system[299], which is part of EU legislation in the field of sanitary and phytosanitary control. Electronic information exchange with the TRACES online platform is already being implemented in Ukraine. The website of the State Service of Ukraine for Food Safety and Consumer Protection contains a list of certificate forms that have already been adapted and integrated into the TRACES system, but they only apply to products of animal origin.

A barrier is the closed nature of small and medium-sized agricultural producers, who represent the majority of the market, to the introduction of digital technologies, as highlighted in the AgroTech Strategy.

The barriers to the development of AgroTech in Ukraine include:

- Lack of technological skills: a lack of employees with the relevant skills to work with technologies and capable of configuring and controlling them.
- Limited access to financing: SMEs' lack of awareness of the opportunities and ways to obtain financing hinders their move towards digitalisation.
- Outdated legislation: a lack of regulation of the use of technologies by agricultural producers.

A study conducted in 2021 by the Ukrainian Agribusiness Club (UAC) on behalf of the Embassy of the Kingdom of the Netherlands in Kyiv and the Netherlands Enterprise Agency[300] aimed to identify market opportunities in Ukraine for Dutch companies offering precision farming products and services. Although it was mainly focused on large agricultural enterprises, it also identified barriers to the application of digital technologies in farms with an area of less than 1,000 hectares.

The key findings of the UACB study on the category of agricultural producers with less than 1,000 hectares of land use are as follows:

- 85% do not have electronic field maps. At the same time, farmers who have created these maps digitise more than 90% of their land;
- Only 1/10 use satellite images/NDVI, and no more than 20% use their own weather stations and soil moisture sensors;
- These companies do not implement complex farm management systems — the implementation of such a system requires both financial costs and a pre-formed geoinformation base (at least) for their own company.

The UACB study identified barriers to the implementation of precision farming in farms that cultivate up to 1,000 hectares of agricultural land:

- difficult access to financing for the purchase of more expensive equipment;
- problems with the comprehensive and consistent use of precision farming technologies.

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[299] https://food.ec.europa.eu/horizontal-topics/traces_en

[300] https://www.agroberichtenbuitenland.nl/binaries/agroberichtenbuitenland/documenten/publicaties/2021/11/5/ukraine-precision-farming-study/Precision%2Bfarming%2BUkraine.pdf

5.8 Recommendations

To scale up the use of digital technologies in crop production in Ukraine, particularly in small and medium-sized farms growing fruit, berries and nuts, it is recommended to:

- Accelerate the implementation of EU requirements for food traceability, as defined by Regulation (EC) No 178/2002[301], by accelerating the introduction of electronic information exchange with the TRACES online platform and extending the exchange to crop production.
- Promote the use of blockchain-based platforms in fruit and berry growing in order to prove the use of organic or chemical-free practices, access to premium markets in the EU, compliance with product safety and certification standards, and strengthen consumer confidence. Examples of blockchain-based platforms: UNISOT's AgriOnChain[302] - a traceability platform with digital twins that tracks from seed to product; AgriOpenData[303] - a blockchain-based platform for farmers and agronomists to track the use of fertilisers and herbicides; FoodTraze[304] - blockchain tracing for fruit and vegetables from farmers to end consumers. Because of traceability platforms, producers can digitise their activities, avoid data loss and achieve transparency throughout the food chain - from farm to fork.
- Accelerate the development of a regulatory framework for the use of technologies in the agro-industrial sector, with a focus on autonomous equipment and precision farming technologies.
- Provide agricultural producers with grant programmes to support the implementation of precision farming technologies. Ensure access to information on opportunities and ways to obtain grants and preferential loans for the implementation of precision farming technologies.
- Encourage the creation of small producer cooperatives or clusters to address the challenges of financing expensive equipment and sharing access to costly technologies and expertise. Enable the issuance of preferential loans to agricultural production cooperatives.
- Expand Internet coverage and create digital maps of soils and agroclimatic zones with access for market participants.

To scale up training in precision farming technologies for farmers, farm specialists and students, it is recommended that:

- Agricultural universities should create courses for training in precision farming technologies with the issuance of appropriate certificates in cooperation with agribusiness and local authorities. An example is the Precision Farming Centre at Sumy Agricultural University[305], which conducts training courses for farmers, students and agricultural college students.
- Introduce the study of the basics of agricultural knowledge and innovation AKIS into master's programmes at agricultural universities, including training courses for advisors. The implementation of AKIS with the support of the EU-funded project "Institutional and

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[301] https://eur-lex.europa.eu/eli/reg/2002/178/oj/eng

[302] https://unisot.com/agrionchain/

[303] https://www.ezlab.it/en/featured/agriopendata/

[304] https://www.foodtraze.com/en/blockchain-food-producer-traceability

[305] https://itf.snau.edu.ua/mizhnarodna-spivpracya/tochne-zemlerobstvo

Policy Reform of Small-Scale Agriculture in Ukraine" (EU4SmallFarms) will provide farmers, advisors and researchers with personalised access to professional knowledge and a discussion platform.

- Develop the advisory services system in Ukraine towards scaling up the provision of services offering online training and advice on the use of digital technologies in farming practices, supporting access to finance for the implementation of digital technologies, and providing information on products and price trends in the precision farming market. This task is defined in the Strategy for the Development of Agriculture and Rural Areas in Ukraine for the period up to 2030.
- Expand the participation of teachers and students of agricultural universities, scientists from the National Academy of Agrarian Sciences, and advisors in the FAO e-Agriculture platform[306] – a global community of practitioners where people from around the world exchange information, ideas and resources related to the use of information and communication technologies (ICT) for sustainable agriculture and rural development.

[306] https://www.fao.org/family-farming/detail/en/c/296654/

6 ANNEXES

ANNEX 1

Impact of GAEC systems on water resources

GAEC 1 (Maintaining permanent pasture in Natura 2000 areas) – prevents the ploughing up of sensitive land that conserves moisture and biodiversity;

GAEC 2 (Protection of wetlands and peatlands) – reduces landscape drying, preserves natural water reservoirs;

GAEC 3 (Prohibition of stubble burning) – reduces soil degradation and moisture loss, improves organic matter;

GAEC 4 (Buffer strips along water bodies) – reduces the entry of fertilisers and pesticides into rivers and lakes;

GAEC 5 (Tillage management to reduce erosion) – prevents the washing away of fertile soil and the pollution of water with silt;

GAEC 6 (Minimum soil cover during sensitive periods) – protects against drying out, erosion and loss of organic matter;

GAEC 7 (Crop rotation or diversification) – maintains soil fertility and reduces water stress for monocultures;

GAEC 8 (Preservation of landscape features (agroforestry, strips, hedges)) – retains moisture, reduces erosion and serves as a natural filter;

GAEC 9 (Prohibition of conversion of permanent pastures in Natura 2000) – preserves natural ecosystems as stabilisers of the water regime.

Impact on water resources of the SMR system

SMR 1 (Nitrates Directive 91/676/EEC) regulates restrictions on the use of nitrogen fertilisers in "vulnerable areas" – protects groundwater and surface water from nitrate pollution;

SMR 2 (Water Framework Directive 2000/60/EC) regulates the maintenance of the "good status" of water bodies, including water abstraction control – it limits excessive irrigation and encourages efficient water use;

SMR 3 (Birds Directive 2009/147/EC) regulates the protection of wild bird habitats – indirectly preserving natural landscapes and wetlands;

SMR 4 (Habitats Directive 92/43/EEC) regulates the conservation of natural habitats – protects soils and aquatic ecosystems in Natura 2000;

SMR 5 (Animal Health Regulation (EU) 2016/429) on compliance with animal husbandry standards – indirectly regulates manure to prevent water pollution.

Regulatory and legal framework for irrigation and water resource management in Ukraine

Key documents	
Title and key points of the document	***Comments***
Ukraine's Water Strategy for the Period until 2030 It provides for: prevention of nitrate pollution of water; ensuring the introduction of technologies and management methods in agricultural production aimed at reducing the level of pollution of water bodies; increasing the area under irrigation and drainage to 500,000 hectares; reducing the share of arable land to 47% by 2030; ensuring a reduction in water intensity of GDP through further ecological and economic optimisation of water prices; using treated wastewater for irrigation; introducing a monitoring system for groundwater extraction, etc.	It contains quite reasonable tasks to ensure water conservation and the development of water-saving irrigation, but even the only two indicators that can be attributed to those reflecting the implementation of the set large-scale tasks have not yet been achieved (1: the share or lack of information on land where wastewater is used for irrigation should be at least 0.5% in 2025; 2: a register of areas vulnerable to nitrate accumulation should be created in 2024, and a plan of measures to reduce nitrate pollution of surface and groundwater from agricultural sources should be approved in 2025).
Irrigation and drainage strategy in Ukraine for the period up to 2030 and plan for its implementation States: the restoration of irrigation and drainage is a key tool for the development of the agricultural sector and the growth of Ukraine's export potential, minimising the impact of climate on the socio-economic development of regions. Notes that water resources, the capacity of main and distribution channels, etc., were sufficient to irrigate at least 1.5-1.8 million hectares of available (at that time) land (with 0.5-0.6 million hectares actually irrigated at that time). The main problems that need to be solved (and the corresponding tasks) are recognised as follows: the need to increase the level of utilisation of the existing irrigation potential; the settlement of issues that determine the conditions and possibilities for the sustainable functioning of irrigation systems on the basis of decentralisation by involving water users in their management and operation (in particular, in the formation of tariffs for water supply and drainage services); increasing funding for measures to modernise and reconstruct existing infrastructure and expand irrigated areas; regulating the mechanisms for using on-farm systems.	The Strategy focuses primarily on the functioning of irrigation infrastructure, as opposed to the development of mechanisms for conserving water resources and their economic use for irrigation purposes. The Action Plan for the implementation of the Strategy does not pay sufficient attention to promoting sustainable water use.
Water Code of Ukraine Defines the main elements of river basin management plans, the procedure for their approval and the powers of basin councils; defines the components of state water monitoring and the powers to implement it; Establishes the procedure for state control over the use, protection and reproduction of water resources; establishes the right of citizens and their associations, other public formations to participate in the implementation of measures for the use and protection of water and the reproduction of water resources. Defines the standard for the volume of water use for agricultural purposes (more than 5 m^3 per day) as special water use, for which a permit is required (no permit is required for lower daily extraction).	
Code of Ukraine on Subsurface Resources Establishes that agricultural producers have the right to extract groundwater for all their needs (including irrigation) without obtaining special permits, but within the limits of 300 m^3 per day from each water intake.	The volumes of groundwater extraction without special permits seem excessive, and the number of permissible water intakes is not specified.
The Land Code of Ukraine	It grants the right to transfer water bodies into

Establishes that land occupied by hydraulic engineering and other water management structures and canals, as well as land allocated for their right-of-way, may be owned by the state, municipalities or private individuals. By decision of the executive authorities or local self-government bodies, enclosed natural water bodies (with a total area of up to 3 hectares) may be transferred to citizens or legal entities free of charge, and lakes, reservoirs and other water bodies may be transferred on lease terms, in particular for the placement and maintenance of hydraulic structures.	ownership (or lease) free of charge for their further use at the discretion of the owners (lessees), which makes abuse in the process of water use possible.
Law of Ukraine "On Environmental Protection" Regulates the general and special use of water resources.	
Law of Ukraine "On Environmental Impact Assessment" Establishes that in the case of construction of engineering infrastructure facilities of land reclamation systems subject to environmental impact assessment, the results of the environmental impact assessment must be attached to the project documentation for the construction of such facilities, and projects of state-targeted and inter-state land reclamation programmes are subject to strategic environmental assessment.	
Law of Ukraine "On Land Reclamation" Establishes: the obligation of agricultural users of irrigation systems to comply with certain environmental irrigation standards.	It is primarily aimed at regulating property rights to land reclamation systems and the procedure for their operation.
Law of Ukraine "On Water Drainage and Wastewater Treatment" Establishes: the powers of the central executive body that formulates and implements state policy in the field of housing and communal services, regarding the approval of the procedure for the reuse of treated wastewater, subject to compliance with the standards for maximum permissible concentrations of pollutants; requirements for wastewater treatment and the obligations of economic entities engaged in water drainage.	
Law of Ukraine "On Water User Organisations and the Promotion of Hydrotechnical Land Reclamation" Establishes: membership in such an organisation requires the applicant to also indicate the approximate amount of water needed to irrigate their land; the obligation of members of the organisation to pay contributions in the amounts determined by the decisions of the general meeting and to pay for the services of the organisation; the obligation of the organisation to keep records of the water delivered to the water user and not to exceed the water abstraction limits; the components of the water tariff (all costs of maintaining the organisation's reclamation network; costs of abstraction, delivery of water to the water user and its drainage; costs of maintaining the organisation).	It keep unresolved the matter of reimbursement of the cost of water supplied to members of such an organisation for irrigation and the establishment of the dependence of this cost on water consumption volumes. The provisions of the law imply that, provided that water is used in volumes that do not require a special permit, only the services of the organisation and the maintenance of the irrigation network and water supply to users are paid for, which is unjustified given the rapid increase in water scarcity.
Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for Developing a River Basin Management Plan" Adopted in accordance with European approaches (in particular, the WFD). Defines the mechanism for developing a river basin management plan. The strategic environmental goal for all river basin districts is to achieve/maintain "good" ecological and chemical status of surface and groundwater bodies. It provides for a strategic environmental assessment of RBMP projects and public discussion of the RBMP project and the strategic environmental assessment report, as well as the publication of relevant information. The structure of the RBMP project has been defined (including its economic analysis, which in particular includes a forecast of water demand in key	

sectors and water tariffs as an instrument of economic control).	
CMU Resolution "On Standards for Environmentally Safe Irrigation, Drainage, Irrigation Management and Water Drainage" Establishes maximum permissible levels of quality for irrigation water and irrigated soils.	Does not establish standards or even an approach to determining them with regard to maximum volumes of irrigation water use.
Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for the Use of Funds Provided in the State Budget for the Provision of State Support to Agricultural Producers Using Reclaimed Land and Water User Organisations" The current version provides for budget subsidies to agricultural producers for the reconstruction/construction of land reclamation systems and to water user organisations for the restoration of pumping stations.	It does not provide for financial incentives for the implementation of water-saving practices and principles of greening water use (the previous version of this resolution removed the reference to the allocation of budget subsidies for the reconstruction/construction of land reclamation systems "using sprinkler or drip irrigation").
CMU Resolution "On Approval of the Long-Term Development Plan for the Irrigation Complex of Ukraine until 2050" Contains strategic guidelines for the development of irrigation and a plan of measures for their implementation; adopted with the aim of harmonising domestic water management with relevant European standards (in particular, with the WFD).	The principles for setting tariffs for irrigation water supply set out in the plan refer only to reimbursement of the cost of water suppliers' services, but do not mention payment for the cost of water itself. In addition, although the plan repeatedly refers to the advisability of growing drought-resistant crops, the example given of the increase in the yield of a number of them, namely those that are very moisture-loving (maize, soya, etc.), completely negates the principle of selecting crops according to their specific water consumption. The publication of information on best practices for water conservation (recognised as one of the key indicators for the achievement of Goal 2 – "Adaptation of agriculture to climate change") is important, but not sufficient to encourage farmers to engage in large-scale water conservation (especially as late as 2027-2028).
Procedure for the reuse of treated wastewater and wastewater sludge, subject to compliance with maximum permissible concentrations of pollutants Establishes the possibility of using wastewater for irrigation, provided that the maximum permissible concentrations of pollutants in such water are complied with. It is stipulated that the use of wastewater is prohibited for the irrigation of berry and vegetable crops that are consumed raw, as well as medicinal herbs or plants. The mandatory nature of the disinfection stage in the technological process of treating wastewater used for irrigation is recognised.	

ANNEX 3

Provisions of Ukrainian legislation that meet the requirements of the EU GAEC for the period 2023-2027.

GAEC, Ukraine-EU conformity assessment*	Relevant provisions of Ukrainian legislation
Climate and environment: climate change mitigation and adaptation	
GAEC 1. Maintenance of permanent pastures. – *Not compliant*.	Law of Ukraine "On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period until 2030" of 2019 No. 2697 – to increase the share of hayfields and pastures in the territory to 15.8%. An increase in the share is envisaged; in 2020, it was 12.5%.
GAEC 2. Protection of wetlands and peatlands. – *Largely compliant*.	Order of the Cabinet of Ministers of Ukraine "On Approval of Ukraine's Updated Nationally Determined Contribution to the Paris Agreement" No. 868 of 2021. In the Analytical Review of the Nationally Determined Contribution: it is necessary to ban peat extraction and restore drained and degraded wetlands within the forest fund; prohibit peat extraction on lands where it has not been extracted before, and restore degraded wetlands in areas where peat extraction has taken place. Resolution of the Cabinet of Ministers of Ukraine "On the Procedure for Granting Wetlands the Status of Wetlands of International Importance" No. 1287 of 2002. Decree of the Cabinet of Ministers of Ukraine "On Approval of the Concept of the National Target Programme for Land Use and Protection" dated 2022 No. 70: to preserve natural wetlands. Decree of the Cabinet of Ministers of Ukraine "On Approval of the Strategy for the Formation and Implementation of State Policy in the Field of Climate Change for the Period until 2035 and Approval of the Operational Plan of Measures for its Implementation in 2024-2026" dated 2024 No. 483: ensure the conservation and further sustainable use of peatland resources. However, it provides for the use of drained peatlands for agriculture using methods that minimise the loss of organic matter in peat and the fertility of peat soils.
GAEC 3. Prohibition of stubble burning on arable land. – *Compliant.*	Law of Ukraine "On the Animal World" of 2001 No. 2894, Article 39, and Law of Ukraine "On the Plant World" of 1999 No. 591, Article 27 – Burning of dry vegetation or its remains is permitted only in cases of economic necessity with the permission of the territorial bodies of the specially authorised central executive body for ecology and natural resources, subject to the relevant conditions.
Climate and environment: water	
GAEC 4. Establishment of protective strips along watercourses. – *Compliant*.	Land Code of Ukraine of 2001 No. 2768: Art. 60 – Coastal protective strips shall be established along rivers, seas and around lakes, reservoirs and other water bodies in order to protect surface water bodies from pollution and littering and to preserve their water content. The location and width of coastal protection strips and the procedure for their establishment are regulated; Article 61 – coastal protection strips are nature conservation areas with restricted economic activity. Water Code of Ukraine of 1995 No. 213: Article 89 – restrictions on economic activity in coastal protection zones.
Climate and environment: soil (protection and quality)	
GAEC 5. Managing tillage, reducing the risk of soil degradation and erosion. – *Less compliant*.	Law of Ukraine "On Land Protection" of 2003 No. 962: Article 47 prohibits ploughing slopes with a gradient of more than 7 degrees (except for areas for grassing, afforestation and soil protection measures). On slopes with a gradient of 3 to 7 degrees, the cultivation of row crops, black fallow, etc., is restricted. Law of Ukraine "On Land Management" No. 858 of 2003. Order of the Cabinet of Ministers of Ukraine "On Approval of the Concept of the National Target Programme for Land Use and Protection" of 2022 No. 70. Order of the Cabinet of Ministers of Ukraine "On Approval of the Strategy for Environmental Safety and Adaptation to Climate Change for the Period until 2030" of 2021 No. 1363: ensuring the application of sustainable land management practices while preserving and increasing soil organic matter; among the expected results is to contribute to achieving a neutral level of land degradation. Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for Monitoring Land and Soil" dated 2024 No. 848. Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for Land Conservation" dated 2022 No. 35. Order of the Ministry of Agrarian Policy and Food of Ukraine "On Approval of Rules for Ensuring Soil Fertility and the Use of Certain Agrochemicals" dated 2021 No. 382.

GAEC 6. Minimum soil cover during the most sensitive periods. *– Not applicable.*	The Land Code of Ukraine No. 2768 of 2001 does not use the terms "cover crops" or "plant cover"; "soil cover" (fertile soil layer) is used only in the provision on its removal.
GAEC 7. Crop rotation on arable land. *– Less compliant*.	Land Code of Ukraine No. 2768 of 2001; Article 111, Part 5 – information on restrictions on land use is specified in land management projects that provide ecological and economic justification for crop rotation and land improvement. (That is, only a mention of crop rotation remains, and the regulatory mechanism is not standardised. Part 4 has been removed from Article 22 – agricultural land plots for commercial agricultural production are used in accordance with land management projects approved in the established manner, which provide an ecological and economic justification for crop rotation and land improvement and provide for land protection measures). Resolution of the Cabinet of Ministers of Ukraine "On Approval of Standards for the Optimal Ratio of Crops in Crop Rotations in Various Natural and Agricultural Regions" of 2010 No. 164
Climate and environment: biodiversity and landscape	
GAEC 8. Maintaining non-productive functions to enhance biodiversity. *– Not applicable.*	Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Rules for the Maintenance and Preservation of Field Protection Forest Strips Located on Agricultural Land" dated 2020 No. 650: implementation of a set of measures to ensure the performance of agroforestry improvement functions. The term "fallow land" is not used in the Land Code of Ukraine No. 2768 of 2001. Article 22 states that agricultural land includes arable land, perennial plantations, hayfields, pastures, and fallow land.
GAEC 9. Prohibition on conversion or ploughing up of grassland in Natura 2000 areas. *– Not applicable.*	Law of Ukraine "On Ukraine's accession to the 1979 Convention on the Conservation of European Wildlife and Natural Habitats" of 1996 No. 436/96. Draft Law on Emerald Network Areas of 2020 No. 4461 was included in the agenda for 2025.

***** The authors have assessed the compliance of the provisions of Ukrainian regulatory and legal acts with EU GAEC standards.

Source: compiled from: Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013. https://eur-lex.europa.eu/eli/reg/2021/2115/oj#ntr1-L_2021435EN.01014601-E0001 Regulation (EU) 2024/1468 of the European Parliament and of the Council of 14 May 2024 amending Regulations (EU) 2021/2115 and (EU) 2021/2116 as regards good agricultural and environmental condition standards, schemes for climate, environment and animal welfare, amendment of the CAP Strategic Plans, review of the CAP Strategic Plans and exemptions from controls and penalties. https://eur-lex.europa.eu/eli/reg/2024/1468/oj/eng ; based on the current regulatory and legal acts of Ukraine.

Renewables and biofuels share in total energy supply (TES), %

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Malta	2,4	3,3	4,1	5,7	6,6	6,6	8,2	8,0	8,1	8,7
Netherlands	4,9	5,1	5,2	5,6	6,3	7,5	9,7	11,1	13,3	14,5
Belgium	6,6	7,2	7,2	7,5	8,0	8,1	9,8	9,3	10,5	11,6
Luxembourg	5,0	5,6	6,0	7,1	7,6	8,2	11,7	11,3	12,5	14,2
Cyprus	6,8	7,6	7,4	7,9	10,3	10,6	12,7	13,2	13,3	13,7
Ireland	8,0	8,6	8,1	9,8	10,8	11,9	13,5	11,9	13,5	15,1
Poland	9,3	9,6	8,9	8,7	11,3	12,1	12,6	12,0	13,0	14,5
Czechia	10,2	10,5	10,7	10,5	10,6	11,6	12,7	12,9	13,0	13,8
Hungary	12,1	12,1	11,9	11,2	10,6	10,7	11,4	11,9	13,0	13,9
France	9,5	9,7	10,7	10,5	11,4	11,8	13,0	13,0	14,1	15,3
Slovakia	11,1	12,9	13,2	12,5	11,8	12,9	13,1	13,1	13,0	12,5
Bulgaria	10,5	11,2	11,2	10,4	13,7	13,4	14,5	15,3	14,2	14,8
North Macedonia	13,1	15,7	14,4	13,0	14,9	11,9	13,8	14,1	13,3	14,8
Serbia	15,1	13,1	13,1	12,1	13,1	13,3	15,7	17,2	15,5	18,0
Greece	10,8	12,2	11,9	12,5	13,8	14,1	16,7	18,4	17,7	20,0
Germany	12,1	12,9	12,8	13,6	14,3	15,2	16,8	16,2	17,9	20,0
Spain	15,8	14,3	14,6	13,2	14,5	15,1	17,3	17,1	16,9	20,0
EU	14,3	14,5	14,6	14,9	15,7	16,4	18,1	18,0	18,9	20,7
Slovenia	19,2	17,3	17,6	16,2	17,1	17,3	18,9	19,3	16,6	20,6
Romania	19,5	18,9	19,7	18,2	18,0	18,2	18,6	18,7	19,0	20,5
Italy	18,1	17,2	17,2	18,5	19,1	19,5	20,9	19,9	19,4	21,1
Lithuania	18,3	20,0	20,2	20,7	20,6	20,7	21,8	23,8	25,5	27,8
Estonia	15,5	19,5	16,7	18,4	20,5	24,3	29,5	28,9	27,5	33,3
Moldova	24,8	25,4	26,2	27,4	26,4	23,6	22,9	22,1	21,6	23,1
Croatia	25,1	23,5	23,9	21,9	25,7	24,9	26,6	29,2	26,7	28,0
Portugal	28,1	24,7	27,8	23,4	26,9	27,0	30,5	31,8	30,8	34,7
Montenegro	32,9	29,8	33,5	25,6	32,8	28,8	29,5	33,1	29,0	34,5
Austria	31,2	30,4	30,9	30,5	30,2	30,8	32,8	32,1	32,6	36,7
Finland	30,5	32,8	32,0	35,1	35,3	36,6	37,7	41,0	40,4	40,7
Denmark	28,4	30,3	30,8	34,0	33,8	36,7	39,5	42,6	44,4	46,9
Albania	27,2	34,3	42,0	27,3	43,2	31,7	33,8	45,8	41,2	50,2
Latvia	37,1	36,0	38,0	43,9	40,1	40,5	42,0	42,3	44,8	46,5
Sweden	38,1	44,2	41,0	42,7	40,3	43,8	50,8	51,2	52,6	52,9
Norway	47,3	53,9	50,9	49,3	48,5	47,9	54,7	54,7	57,5	56,9
Iceland	89,0	88,3	87,2	88,5	88,8	88,8	89,6	88,8	88,3	89,1
Ukraine	2,6	2,9	3,9	4,4	4,6	4,9	5,6	n.a.	n.a.	n.a.

Source: Eurostat

ANNEX 5

Renewables and biofuels share in final direct energy consumption by agriculture, %

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Ireland	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Norway	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0
Moldova	1,6	1,2	1,4	1,1	1,0	0,9	1,2	0,8	0,8	0,9
Portugal	1,4%	1,3	0,9	0,7	1,2	1,4	1,4	1,4	0,7	0,7
Croatia	1,9	1,9	1,9	1,8	1,6	1,5	1,5	0,7	0,9	0,9
Ukraine	**0,7**	**1,0**	**0,9**	**1,4**	**2,0**	**1,5**	**1,7**	н.д.	н.д.	н.д.
Romania	1,5	1,7	1,2	1,3	1,0	1,6	1,9	1,3	1,8	1,4
Italy	1,4	1,9	1,9	1,9	1,8	2,0	1,9	2,5	2,5	2,5
Spain	2,8	2,9	2,8	2,8	2,9	2,7	2,6	2,6	2,8	3,0
Bulgaria	3,6	6,0	9,6	4,4	2,6	2,6	3,0	5,3	5,1	5,7
Slovenia	5,2	3,8	4,2	3,6	3,6	2,9	3,0	3,9	4,0	3,5
Estonia	4,5	3,1	4,0	4,0	4,2	3,4	4,4	6,2	5,3	1,7
Malta	0,9	1,1	0,0	0,0	4,4	3,4	4,6	3,4	2,9	3,9
Belgium	6,5	6,7	6,0	5,4	5,2	4,4%	4,9	4,0	4,3	3,6
Luxembourg	10,2	10,0	11,0	13,6	16,5	9,6	5,6	1,3	8,0	0,9
Hungary	7,4	7,5	7,6	8,5	8,7	8,2	7,2	7,3	9,6	10,3
Cyprus	7,1	5,2	5,6	5,5	5,6	6,8	7,2	7,0	6,9	7,2
France	3,9	4,1	6,2	7,6	8,5	8,7	8,8	9,1	9,4	10,4
Denmark	8,5	8,6	8,8	9,0	9,2	9,3	9,2	10,1	9,8	10,0
Serbia	4,8	4,6	2,9	4,8	5,8	6,9	9,7	10,8	10,2	10,9
Netherlands	4,4	5,2	5,5	6,1	7,0	8,6	9,8	10,5	13,6	10,2
Greece	11,6	12,1	11,4	10,3	12,1	11,7	10,2	9,1	11,0	11,4
Iceland	13,8	14,8	13,9	13,9	13,4	13,1	10,3	9,6	8,7	8,7
EU	**9,6**	**10,3**	**11,1**	**11,4**	**10,8**	**10,8**	**11,0**	**11,6**	**12,2%**	**11,7**
Montenegro	0,0	0,0	0,0	0,0	8,6	11,7	11,9	12,4	10,4	10,9
Poland	13,7	14,8	14,7	13,3	12,9	12,5	12,6	15,1	14,3	12,2
Lithuania	11,5	11,1	11,2	13,5	14,0	13,6	15,1	14,7	14,1	15,2
Latvia	9,5	11,2	11,7	16,1	13,8	17,6	15,9	11,2	11,2	18,0
Albania	14,8	16,6	16,0	15,8	16,1	12,8	16,1	15,6	17,4	15,3
Finland	23,5	20,4	22,1	21,7	22,3	21,0	19,3	23,1	23,3	23,8
Slovakia	4,6	24,3	22,9	24,0	22,8	17,3	19,8	20,7	17,8	17,3
Czechia	19,8	20,4	22,9	21,9	21,6	21,0	21,2	23,9	25,0	25,2
Germany	40,2	45,3	46,5	51,2	23,1	21,5	22,8	22,6	22,4	22,1
North Macedonia	26,1	22,9	22,4	23,6	23,3	22,6	25,2	23,5	24,4	22,9
Austria	33,4	33,9	33,7	34,6	32,8	31,1	30,4	32,7	32,0	32,2
Sweden	23,8	24,9	27,8	33,0	34,1	35,9	37,1	35,3	39,2	36,4

Source: Eurostat

Main heating characteristics of selected solid fuels

Solid fuel	kcal/kg	Ash content, %
Wood briquettes, soft wood	450	0.5
Wood briquettes, oak, ash, hardwood	4900	0.5-1.0
Vine briquettes	3350	1
Briquettes from corn cobs, stalks	3800	3
Walnut shell briquettes	60	0.5
Wood chips wet(40-50%)	240	2
Dry firewood (humidity 10%)	3850	1.5
Dry firewood (humidity 25%)	2600	2
Freshly cut wood (humidity 50-60%)	1700	3

Source: [307]

[307] https://bioekoprom.com.ua/ua/novini/teplotvornaya_sposobnost_toplivnyih_briketov_i_nekotoryih_vidov_topliva/