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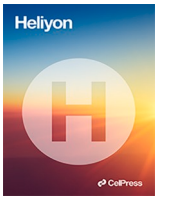

The 2022 Russia invasion on Ukraine: The biofuel energy security challenge on Ukraine and some related countries

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ABSTRACT

Europe, United States and other countries make moves to compensate for the loss of Ukraine's exports by diverting crops meant for biofuels into food production and to relax some of the biofuels mandates due to the challenges of 2022 Russian invasion on Ukraine (RIU). Ukraine as a leading exporter of cereals and oil crops in the world has suffered reduction in exports of grain products since the inception of the invasion. This work critically evaluates the immediate and remote potential effects of the RIU on Ukraine's biofuel capacity and potentials, energy strategies and policies, direct impacts of the war on Ukraine and Russia and other countries' biofuels policies were evaluated. Ukraine is found to be a very important big player on global biofuels energy security and policies. It was observed that there are more significant impacts of the war on Ukraine biofuel industry than that of Russia due to very low priority on the development of Liquid biofuels (LBs) in Russia. Recommendations based on the concepts of national energy security and independence were elucidated. Post invasion-strategies such as development of framework for management of post-war waste, ensuring strict adherence to EU biofuels sustainable directives, and implementation of Bioplus-project for Ukraine government were underpinned. This article provides useful information, guidelines and directives that would enable Ukraine government and other countries facing energy insecurity and political crises to restore energy independence and national economy.

1. Introduction

Over the years, Russian military has made several attempts of invasion on Ukraine. Dating back to 2014, Russian soldiers were able to trespass the Ukrainian territories following an uprising that brought about the replacement of the Russia-friendly Ukrainian president [1]. Several intervention efforts made to bring the fight to a halt in 2015 seemed not to work as the fight lingered. On February 24, 2022, Ukraine experienced a shocking invasion from Russia which is believed to be a continuation of Russia's preparation in October 2021 when they moved to its border with Ukraine with her troops and military equipment [2].

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The cause of the fight between Russia and Ukraine being a hard nut to crack, many researchers, social and political science analysts have found this topical issue to be complicated while some believed it could be a continuation of series of long-time loggerheads ranging from political sovereignty to military invasion. According to Congressional Research Service [3], the main cause of the fight between these two countries is not unconnected to the Ukrainian's government efforts to be integrated fully with the North Atlantic Treaty Organization (NATO) and European Union (EU). However, the eligibility of Ukraine's membership in the aforementioned organizations has always been challenged by the Russian government amongst other challenges including but not limited to Russian's occupation of Ukrainian's territories [2]. The Russian president and other Russian political figures maintain that Ukraine is under Russia' sphere of influence, hence view Ukraine's moves to join NATO or the EU as illegitimate [1]. Russia has equally sought to institutionalize a political entity inside Ukraine to influence domestic politics [4]. Additionally, Bukkvoll [5] has suggested the application of uprising as a way of war against unwanted regimes as well as western exploitation of Russia weakness for many years as major reasons for Russian behaviour. Meanwhile, Davies [6] has argued against the view that Russia's reaction was based on policy of destabilization and rather puts forward the motion that Russia's engagement has remained a perennial state of flux owing to contradictions in its policy centering on the combination of a complex set of competing security logics. Moreover, some researchers have underpinned the peculiar political and ethno-cultural order of Donetsk and Luhansk oblasts, legitimacy of crisis of interim government, destabilizing effects of the status quo created by victory of Euromaidan, proximity of Russian border, *trans*-border ethnic politics as well as the activities of Russian naturalist groups, etc as reasons for RIU [6].

Some researchers have observed and likewise suggested that the RIU will be beneficial to North America and Europe through trade diversion hence, Ahn et al. [7] extensively studied the ex-post counterfactual trade effects and region-specific global trade reallocation of the Russian invasion of Ukraine and opined that it will promote international grain and oil seed trade. Also, the invasion equally seems to have promoted the synchronization of grain, energy and fertilizer prices at the global level in both direction and size [8]. More so, Feng et al. [9] and Lin et al. [10] observed that RIU would result in an astronomical increase in agro product prices, decreasing trade volume and food insecurity from countries that export from Ukraine and Russia (e.g Egypt, Mongolia, Georgia, Azerbaijan and Turkey). Also, the authors are of opinion that some countries like USA and Canada might see the invasion as very beneficial while generally, the restrictions on upstream energy and fertilizer will promote the negative effects of food insecurity. Other countries such as India, Australia, France, Argentina and Germany might equally benefit likewise. Integral impacts reflect the conflict on food output trade prices and general welfare across sectors and countries.

Notwithstanding, many researchers have called for urgent attention from policy makers from the West and Russia on the management of the attendant consequent instability centering on competitive influence-seeking in the post Soviet space [11]. In view of the above, Zhou et al. [12] has recommended that international organizations should balance the global security demand of energy and

Fig. 1. Map of Ukraine with Russia and neighbouring countries [23].

food between big countries and small countries with more attention paid to some small African and Asian countries to mitigate the risk. Hassan et al. [13] considered among other impacts, the effects of the RIU on some sustainable development goals (SDGs). They concluded that SDG 12 (responsible consumption and production) would suffer implementation realization. They have suggested much attention on sustainable ecological food system through immediate and long term reform and policies. Also, Jaglap et al., [14] investigated on the implication of Russian-Ukraine war on the global food supply chain using preferred reporting items for system reviews and meta-analyses (PRISMA) approach. They provided solutions and strategies to ameliorate supply chain effects which include: alternative food raw materials, suppliers and supply chain partners supported by innovative technologies. Nasir et al. [15] concentrated only on the impact of RIU on global food crops and concluded that global food security for low income countries is in a serious danger with sustainable development goals not being feasibly achievable.

Obviously, following the fight, Ukraine has suffered several attacks from Russian military troops. These attacks have touched several sectors of the Ukrainian government. This attack did not only target sectors of the Ukrainian government and economy but also wasted lives. According to Human Rights Watch [16], in the first eleven days of the fight, more than 450 civilians lost their lives to it. Buildings were not left out as schools, worship places, shops, living houses and public buildings were destroyed. Infrastructures were damaged and this affected the people's access to certain essential services like electricity and water. Human Right Watch noted that as at March 7, at least 14 healthcare facilities were badly damaged. This will in no small way affect healthcare delivery during the period of the fight, consequently leading to more casualties. It is also worthy of note that Ukraine suffered series of cyber-attacks on her computer network in January 2022. According to European Parliamentary Research Service [17], Russian attack on Ukraine came in different dimensions. These are disinformation, economic pressure, and attack on energy and cyber attacks which seems to be prominent as evidenced by the Ukrainian's government website massively attacked [18].

Ukraine is the second largest country in Europe with an area of over 600,000 km^2 (70 % is agricultural) and a population of 45.5 million. It is located at 49° 0′0″N, 32° 0′ 0″ E. Fig. 1 shows the map of Europe containing the clear positions of Russia and Ukraine. Russia and Ukraine are key players in the energy, food, and fertilizers markets. Russia is the world's largest exporter of wheat, the second largest exporter of sunflower oil, and fertilizers. Similarly, Ukraine is the largest exporter of sunflower oil, the fourth largest exporter of maize, and the fifth largest exporter of wheat [19]. Therefore, the disrupted agricultural production in Ukraine, which is likely to continue even in the post invasion era, and the serious extensive international sanctions imposed on Russia, limiting the country's trades, will in no doubt affect both food and fuel markets. In addition to the petroleum price increase, the Ukraine war has affected significantly negatively the biofuel feedstock supply chain and, consequently, adversely affected biofuels production [20]. Ukraine has 61.46mtoe, 10.33mtoe and 17 % fuel energy consumption, fuel energy consumption in transport and fuel energy in transport share respectively. About 115 biofuel shares in transport fuels are 41ktoe with fuel mix of gasoline, diesel and bio-ethanol. IEA reports that 2 % of the global oil demand is made up of biofuels. EU has an estimated biofuels consumption of 36 million metric tonnes in 2030 against 14.8 and 2.0 in 2010 and 2004 respectively [21]. Also, EU has about 1440 million gallons of bioethanol production against 8620 million gallons for USA and 900 million gallons for China [22].

In USA, the major source of bioethanol is corn, in Brazil sugar cane is the major source of bioethanol but in Europe, wheat and barley which are starchy grains are the major sources of bioethanol [24]. Globally, biofuel mandate has become a serious policy and out of 52 countries; EU has the bulk of biofuel mandate with Renewable Energy Directive (RED) - 10 % renewable writer by 2020 across the entire member countries with 7 % from biofuels. Beside EU, U.S, China and Brazil have biofuel mandates. Brazil had 15–20 % range between 2020 and 2022, India had 20 % ethanol for 2017 but shaky implementation and US was moving towards 36 billion gallon biofuels target by 2022. EU has established sufficient robust policies with properly focused targets and monitoring frameworks on advanced biofuel application to decarbonise European transport by 2030 [25,26]. Efforts to realize the 2030 targets must be immediate to overcome the challenges, sustain the green deal and sustainable development goals (SDGs). In 2014, EU signed an agreement with Ukraine for an increase in the share of bioethanol to 5.75 % with an expected amount of bioethanol production of 320 thousand tons.

Global biofuels energy employment rose from 2.4 million jobs in 2012 to 3.06 million jobs in 2017 [27]. Ukraine and Russia combined is responsible for about 75 % of world's sunflower oil exports and over 26 % of wheat exports. Since the Russia-Ukraine war began, there are strong speculations that many European countries have started adjusting to their biofuel mandate. Reports have it that due to the RIU, Finland has temporarily reduced its 2022 and 2023 biofuel mandates to alleviate the high fuel prices for users, Germany has officially proposed to reduce the permitted share of crop-based biofuels and increase multiple counting options for biomass renewable fuels to reduce the global food insecurity pressures, and Lativa and Czech Republic have suspended the mandatory blending of biofuels from July 2022 to December 2023 (adding biofuels to gasoline will not be compulsory all through this period) and 1st July 2023 respectively [28]. Efforts are being made by Europe and US to divert crops destined for biofuels into food production instead due to significant challenges resulting from the loss of Ukraine's exports [29].

Recently, increasing the production and application of renewable and sustainable energy resources was part of the important areas of Ukraine's energy policy [30]. In Ukraine, 62 % of domestic gasoline consumption and about 90 % of diesel are imported. Few years back, Ukraine was identified as having high potentials of renewable resources. It was reported that technically, Ukraine renewable energy potential was equivalent to 70 million tonnes of oil. Ukraine had a target of 11 % of energy from renewable sources prior to 2020. In May 2016, Ukraine had joined the International Renewable Energy Agency (IRENA). It is very important to note that Ukraine was the first country to successfully ratify the Paris Climate Agreement [31]. According to the recently published data by Statista Research Department, about 8 million border crossings from Ukraine have been recorded by Poland alone as at December 2022 while over 6884 civilians have been killed.

In EU, wheat and maize which are also part of the 12 million tonnes of grain are converted into bioethanol. Globally, 10 % of all grain is converted into biofuels while in US one-third (1/3) of maize grown is blended into petrol after being turned into ethanol.

Bioethanol is very relevant in the global biofuel market. In USA, the major source of bioethanol is corn, in Brazil sugar cane is the major source of bioethanol but in Europe, wheat and barley which are starchy grains are the major sources of bioethanol [24]. Many researchers have seriously reported that biorefinery of wheat straw appears to be the most available solution for eco-friendly and cost-effective production of bioethanol and other value-added products [32].

Considering the literatures reviewed, much attention have been given to the impact of RIU on food security while there is scarce reports on the direct impact of the RIU on the biofuel potential of Ukraine and other related countries. Therefore, the ultimate purpose of this work is to critically evaluate the immediate and remote potential effects of the 2022 Russian invasion on Ukraine biofuels energy industry capacity, potentials and policies as well as the related global challenges. The objectives will involve reviewing the biofuel capacity of Ukraine and Russian, to make recommendations of useful post-war strategies to arrest the challenges based on the concepts of national energy security and independence. Also, among the tasks of this research is to recommend post invasion-strategic frameworks for management of post-war waste, ensuring strict adherence to EU biofuels sustainable directives, and to evaluate the role of implementation of Bioplus-project for Ukraine government. It is expected that this study shall provide useful information, guidelines and directives that would enable Ukraine government and other countries facing energy insecurity and political crises to restore energy independence and national economy.

2. Research methodology

In collecting data for this work, an encompassing literature survey of official information by government agencies, reports from textbooks, journals, conference proceedings and electronic database records were used. The three phases of timeline of the 2022 Russian invasion of Ukraine are from February 24, 2022 to April 7, 2022 (phase one), from April 2022 to August 2022 (phase two) and from August 2022 to August 2023 as phase three [33]. Consequently, the damages done to Ukraine by Russia from February 2022 to August were reviewed. Critical evaluation on the immediate and remote potential effects of the Russian invasion on Ukraine (RIU) on Ukraine's biofuels energy policies and other related countries were evaluated based on literature reports. Literature review on Ukraine's biofuel capacity and potentials, energy strategies and policies were conducted. Direct impacts of the war on Ukraine, Russia and other countries' biofuels policies were evaluated.

3. Ukraine biofuels capacity and potentials

3.1. Ukraine biofuel background

It is reported that in Europe, Ukraine has the highest potential for renewable and sustainable energy production [34] and among the largest energy consumers [35]. Ukraine has impressive biofuels agencies, an attractive biofuels industries and reliable stakeholders as contained in Table 1. Ukraine has to her credit the following energy agencies and ministries: Renewable Energy Agency, Ukraine Association of Producers of Alternative Transport Fuels, Ministry of Ecology and Natural Resources, Association of Alternative Fuel and Energy Market Participants, and Bio-Energy Association. Also, there exists Institute of Market Problems and Economic and Ecological research of Natural Academy of Science, Natural University of Life and Environmental Science of Ukraine, Scientific Engineering Centre Biomass Ukrainian Biofuel Supplier, Odessa Natural Mechnikoo University Innovative Centre of the National Academy of Science, Institute of Renewable Energy of National Academy of Science and Institute of Engineering Thermo-physics of Natural Academy of Science. These institutional frameworks are available in Ukraine to ensure that the country meets the desired biofuels strategies. More so, Ukraine government can boast of an excellent natural agrarian endowment for biofuels feedstocks such as rape seed, corn, sun flower and wheat as shown in Fig. 2a, b, 2c and 2d respectively.

3.2. Biofuels research outputs from Ukraine

Ukraine has many researchers and scholars who have made impactful contributions through research and innovations in biofuels production and applications [36–39]. Most of the works are in the 21st century with recent technologies. Very recently, impactful inputs and significant research outputs have been made in support of the high potential of biofuels in Ukraine (Table 4).

Table 1
Governments biofuels agencies, industries and research stakeholders in Ukraine.

Ministries, organizations and agencies	Key biofuels industries and research stakeholders
1. Ministry of ecology and natural resources. **2. Association of Alternative Fuel and Energy Market Participants.** **3. Bioenergy Association of Ukraine.** **4. Renewable Energy Agency.** **5. Ukraine Association of Producers of Alternative Transport Fuels.**	1. Natural University of Life and Environmental Science of Ukraine. 2. Scientific Engineering Centre Biomass Ukrainian Biofuel Supplier. 3. Institute of Engineering Thermo-physics of Natural Academy of Science. 4. Institute of Market Problems and Economic and Ecological research of Natural Academy of Science. 5. Odessa Natural Mechnikoo University Innovative Centre of the National Academy of Science. 6. Institute of Renewable Energy of National Academy of Science.

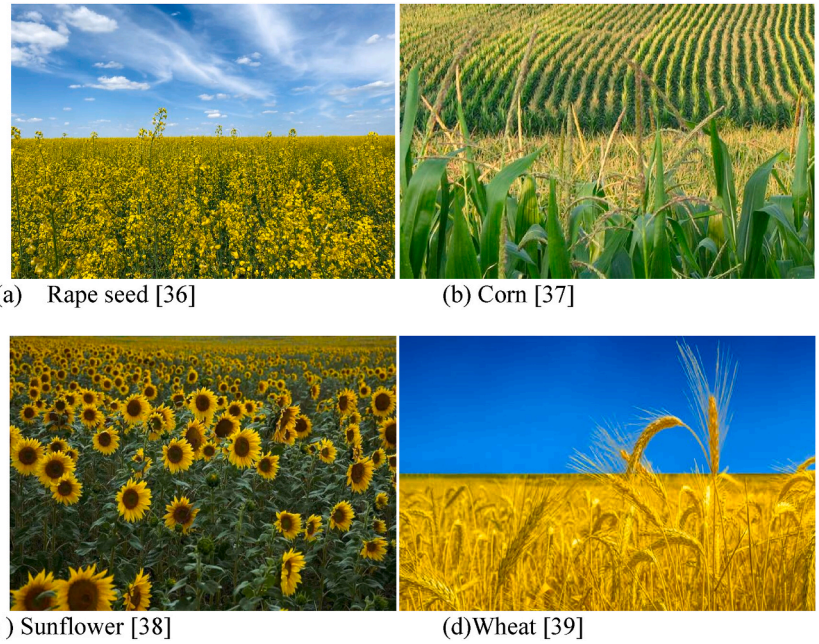


Fig. 2. Ukraine Agricultural fields for Rape seed, Corn, Sun flower and wheat.

3.3. Ukraine bio-ethanol and biodiesel capacity

Ukraine has a mandatory blending of 7 % for gasoline bioethanol with no established biodiesel industry as at 2020 [40]. It was proposed to make at least 70Mtoe biodiesel and 320Mtoe bioethanol available in Ukrainian market in 2020 from domestic production [41]. About a decade ago, the village of Luky (Sambir Raion) was the first in Ukraine to launch a biodiesel facility production of 25 tons capacity fuel per day [42]. Ukraine has about 0.7 % of hydrocarbon gasoline replaced by bioethanol produced from agro waste material of molasses derived from sugar beet [41]. The development of bioethanol production started in 2014 with an envisaged 320, 000 tons based on 5.75 % envisaged increase in share agreement between Association of Ukraine with EU [40]. Ukraine annual gasoline consumption amounts to about 5 million tons. There exists a legislation that proposed annual 5 % (about 250,000 tons of gasoline) of motor fuels with biofuels.

The bio-ethanol concepts existing in Ukraine are:

- Rehabilitation and reconstruction of existing distilleries.
- Production of bioethanol from sugar beets is the only profitable technology.
- Starting of new production lines of low power.
- Placement of production at existing sugar factory.

3.4. Ukraine biogas capacity and potentials

Biogas production is proposed to be very cheap in Ukraine. Very soon, 1.5 to 6 million m^3 of natural gas equivalent is expected yearly and this will promote energy independence in Ukraine [42]. In Ukraine, there is over a total of 246,000 km spread of gas distribution network. It is believed that there existed the possibility of connecting biomethane producers to medium and low-pressure gas distribution for local consumption of biomethane. There is a possibility of the biomethane produced in Ukraine to be exported to Western Europe. This shall be possible via a developed process for stimulating the biomethane generation. Ukraine has the potential to replace 2.6 million m^3 of NG/yr from agro-waste. As at 1993, Zapiorizhstal an impressive pig farm agro-oven, elite, Ukrainian milk coy were established. In 2012, four (4) biogas plants were installed by Ukrainian government. In 2014, 10 biogas plants installations targeted to produce about 15 MW were made while in 2018, 29 biogas plants to generate about 41 MW were installed. Also, Ukraine's maize silage cultivation stood at 150 % of free arable land for 40 tons of green mess/ha with 180 m^3/t output. In 2021, biomass such as woodchips provided 9 % of Ukraine heat production for public buildings [43].

3.5. Available second generation of biofuels in Ukraine

According to the Ukraine Academy of Sciences, there is a gene reservoir of some cereals such as: sugar sorghum, palm millet, millet dumping and miscanthus with the following characteristics: speediness, drought resistance, high yield of seeds or phytomass, and high carbohydrate content on grain. Also, high-altitude crops have been created by Ukrainian scientist for biodiesel production with

additional valuable gene pool of camelina that has 20 forms, hybrids and variety samples. More so, highly promising variety of rice with 3–4+/ha of oil content of 45–50 % given 1–4+/ha of biodiesel is available in Ukraine. It should be noted that wide spectrum dimethyl ether is not in Ukraine as in other countries. It is energy interesting that Ukraine was the first to start growing algae at a commercial level. According to the Institute of Botany and M. G. Aolodny National Academy of Sciences of Ukraine a list of 33 strains of algae – promising species for biofuel has been developed.

3.6. Ukraine's bio-fuel feedstocks export capacity

Ukraine is among the oil seeds producing leaders. They produce seeds such as sunflower, rapeseed and soybean. Also, Ukraine is the largest exporter of seed oil in the world such as sunflower and rape seed (Table 2). Almost all the rapeseed and soybean grown in Ukraine are exported to other countries for biodiesel production [44]. Considering global wheat export records, Russia is the largest exporter (8 billion dollar worth of wheat annually) while Ukraine is the fifth largest exporter (3 billion dollar worth of wheat annually). Over 95 % of Ukraine grains go to Middle East and North Africa (Egypt, Tunisia). About 20 % (106 million tonnes) of crops derived for ethanol supplied to UK between 2017 and 2018 are supplied by Ukraine (Table 3 and Fig. 3).

4. Impact of Russia-Ukraine war

4.1. Direct effects on Ukraine

4.1.1. Brief review of the attacks between 24th February and August 2023

The phases of the timeline of the 2022 Russian invasion of Ukraine cover from February 2022 to August 2023. The first phase happened between 24th February - April 7, 2022 which covers when Russia launched a military invasion of Ukraine after which the fighting concentrated away from the Northeast and Kyiv and towards the South and East of Ukraine. The second phase covers between April 2022 and August 2022. This phase covers the area of heavy fighting shifted to the south and east of Ukraine 2022. The third phase is the timeline from August 2022 till August 2023. This phase covers the period of Ukrainian counteroffensives in the south and east. However, since October 2022, Russia started a serious campaign of massive strikes against Ukrainian infrastructure [9] using drones and missiles. This period saw the use of about 3M-54Kalibr, Kh-101 Kh-5555 cruise missiles, 9K720 Iskander ballistic missiles, S-300 air defence missiles, Tarnado rockets, shahed 131, shahed 136 drones. This resulted in over 77 deaths and 272 injured. By mid December 2022, over 1000 missiles or drones have been aimed by Russia on Ukraine energy grid. According to the office of the UN High Commissioner for Human Rights [55] from February 24, 2022 to December 2022, 17,831 civilian casualties have been recorded in Ukraine. This centred on Monetsk, Kharkiv and Luhansk regions. Fig. 4 shows Ukraine's RIU civilian casualties from February 24, 2022 to August 27, 2023 with explosives weapon with wide are effects resulting in 7965 deaths and 16,301 injuries, mines and explosives remnant of war resulted in 307 death and 656 injuries and other war effects resulted in 239 death and 249 injuries [56].

4.1.2. Impact of Russian Invasion on Ukraine agricultural soil

It is obvious as identified by many researchers that Ukraine is endowed with one of the largest agricultural producers, exporters and as well as generates large amount of agricultural waste that can be used to produce biofuels. Consequently, efforts are currently ongoing to ensure that Ukraine is strengthened in the areas of energy security by developing biofuels and biomass. However, a full knowledge on the damage done on the agricultural soil of Ukraine is paramount to help policy makers take right strategic steps.

Many environmental advocates have referred the situation as "ecocide". Russian-Ukraine war seriously affected the environment and the agrarian or arable soils of Ukraine are badly damaged. For example, the pentagon recorded 1200 missiles (containing wastes) and there were about 36 attacks on fossil fuel facility, 29 attacks on electricity station, 7 attacks on water supplies and 6 attacks on Nuwas which was bombed with air clear facilities. These will result in overloading the soil and ground water with heavy metals. Destruction of the farmlands/crops and diversion of manpower (no harvesting of crops) are the major problems currently faced by Ukraine. In February 27, 2022, Russia attacked Vasylkiv air base, south of Kyiv. 20.000 m^3 of diesel and gasoline burned for 24 h causing air pollution over civilian residential area. Also, Ukraine launched a missile against a fuel depot of Russia backed by separatists in Rovenky south of Luhansk and as well in Kirovsky. The attacks can cause serious long term environmental health risks. The risks level depends on the type of fuel/or oil stored, quantity, closeness to populated areas and water sources. Generally, air pollution is the first public health risk. In the long run, the long term effect, the leaked substances and waste water can infiltrate the soil and spread on the surface water (streams). The resultant effect is the destroying of ground water, farm lands (soil fertility) and the farmers will be at the risk of serious disease that can incapacitate them.

Table 2
Major cereals and oil seed exported by Ukraine [45].

S/N	Crop
1.	Maize
2.	Sunflower
3.	Wheat
4.	Rapeseed

Table 3
Position of Ukraine as supplier of crop derived for bioethanol to the UK 2017/2018 [45].

S/N	Country	Amount (million litre)
1.	UK	217
2.	France	109
3.	Ukraine	106
4.	Romania	26
5.	Spain	19
6.	Bulgaria	17

Total = 557.6 million tonnes.

Table 4
Highlight of recent researches on Ukraine biofuels potentials.

Sn	Research Highlight	Ref.
1	Plant industry of Ukraine in biofuels formation	[46]
2	Biofuel boilers' logistics and cost analysis	[47]
3	Food and biofuels market in Russia-Ukraine crisis	[48]
4	State Regulation of Biofuel	[49]
5	Processing of energy crps into solid biofuels	[50]
6	Potential of Agro-waste as feedstock	[51]
7	Development of bioethanol market	[6]
8	Potential of soybean straw for solid-biofuel	[52]
9	Development of transport biofuels	[53]
10	Normative-methodical base of biofuels	[54]

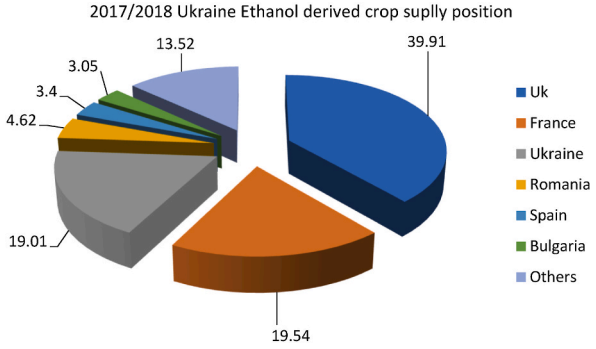


Fig. 3. Percentage of 2017/2018 Ukraine Ethanol derived crop supply position.

Within this period, (February 21 to March 08, 2022) seven (7) cities have been attacked in Ukraine through bombing, explosion and missile (cruise and ballistic), destroying fuel storage tankers, depots, tank farm, etc (Table 5). Seven (7) cities responsible for the growing major biofuels crops were heavily attacked thereby destroying large farm lands for rape seed, sunflower, corn and wheat alongside other perennial crops that provide substitute for edible crops in biofuels production (Table 6). Table 7 contains some possible pollutants released on the Ukraine soil and environment due to 2022 Russia invasion.

Since 2013, Ukraine registered the lowest wheat production and wheat area hectare in 2023 while the lowest corn production and area hectare are recorded in 2022/2023 for the past six (6) years as shown Fig. 5a and b [57]. This is not unconnected with the ongoing Russia Invasion of Ukraine (RIU).

The following are further highlights:

- The attack on Sumykhimprom chemical plant in Northern Ukraine resulted in leakage of NH_3 which spread and covered over 2.5 km area [59]. This is a big threat to nearby community which contaminated ground water, the soil and wildlife.
- Forest fires resulting from missiles near Chornobyl nuclear facility caused radioactive materials to be liberated into the atmosphere. Zaporizhia nuclear power plant was bombed with a rocket which almost resulted in a nuclear disaster.
- Oil and gas in Kharkivcame under heavy fire since the beginning of the war. It results in disruption of energy supply, and release of high amounts of green house gas emission and other contaminants that destroy the atmosphere.
- Such cities like Mariupol have been bombarded and now having their infrastructures destroyed with extreme toxicity that affects the environment.
- Wildlife is not left out as Ukraine's agricultural equipment and warehouses serving as the feed strength have been destroyed.

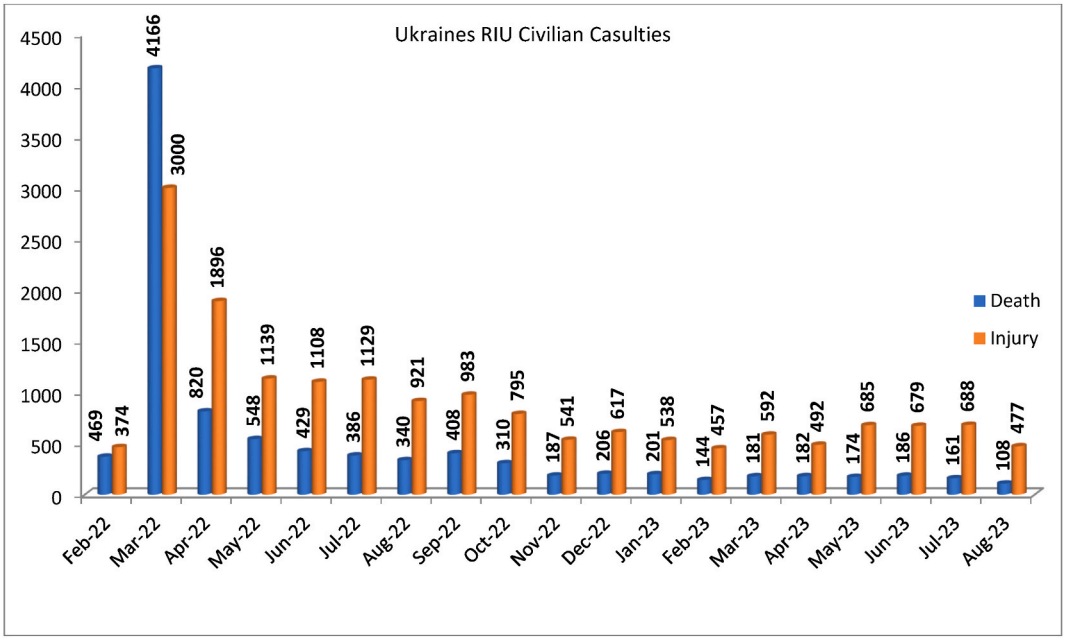


Fig. 4. Ukraine's RIU civilian casualties (adapted from OHCHR HRMMU [56],).

Table 5
Early attack on Ukraine by Russia in the first month of the 2022 invasion.

S/N	Date	Nature of attack	Target	Attacker	City
1.	24-02-22	Bombing	Fuel storage tankers	Russia	Chuhuiv
2.	26-02-22	Explosion	Fuel depot	Russia	Mykolaw
3.	27-02-22	Missile	Air base fuel tanker	Russia	Vasylkiv
4.	27-02-22	Missile	Fuel depot of Russia	Ukraine	Luhansk
5.	27-02-22	Missile	Oil tank farm	Ukraine	Kirovsky
6.	03-03-22	Nuclear power hijack	Oil tank farm	Russia	Chernihiv
7.	03-03-22	Cruise Missile	Nuclear power plant	Russia	Zaporizhzhia
8.	06-03-22	Ballistic Missile	Fuel depot Air base	Russia	Vynnitsia
9.	07-03-22	Ballistic Missile	Fuel depot	Russia	Luhansk
10	08-03-22	Ballistic Missile	Fuel depot	Russia	Chernyahhiv

4.2. Direct effects on Russia

The war in Ukraine has been reported to be having great impact on food and energy prices globally. Egypt is the largest importer of wheat of which 70 % comes from Russia. East Africa, Sweden and Ethiopia eat wheat as staple food and the wheat comes from Ukraine and Russia. UN has reported that up to 30 % of winter crops may not be planted as long as the war lasts. As at December 16, 2022, 1386 individuals and 171 entities associated with Russia-Ukraine war were sanctioned. About 1737 sanctions have been imposed on Russia between February 2022 and November 30, 2022 by United States. Between February 2022 and November 30, Australia, Canada, EU, France, Japan, Switzerland, UK, and United States have imposed restrictions of about 8487 individuals from Russia, with over 1615 targeted entities over the period. Also, on December 15, 2022, the United States placed 59 list-based restrictive measures on Russia with an additional 23 sanctions imposed by New Zealand. More so, about 335 foreign companies have withdrawn from Russia. As of March 2022, Spanish textile retailer temporarily closed its 168 outlets across Russia as well as its online stores. As of November 2022, due to suspension of operation in Russia, or completely exiting the market, due to invasion of Ukraine, British Energy Company B.P lost 24 billion US dollars, Exxon lost 3 billion US dollars, French Societe Generale lost 3.7 billion US dollars.

Obviously, there is insignificant impact of the war on Russia biofuel industry when compared to the impact on Ukraine. In Russia, there is low priority on the development of Liquid biofuels (bioethanol and biodiesel). This is due to low production of biofuels, high excise taxes for ethanol in Russia, high production costs and increasing demand for grain for other applications other than biofuels. The majority of biofuel ventures in Russia are owned by regional governments or foreign investors and in most cases in pilot phases generating for their own facilities.

However, experts have projected 121,200 GWh and 169,344 GWh of electricity from 66 billion m^3 biogas from vast supplies of agricultural wastes, food processing wastes and municipal wastes Also, In Forestry Processing sector of Russia, about 29.0 % wood biomass fuel structure is consumed by energy sources of heaters, boilers and power stations. Although Russia consumes small amount

Table 6
Some of the attacked regions and the biofuels feedstocks grown in the area.

S/N	Attacked regions	Crops Grown			
		Rapeseed	Sunflower	Wheat	Corn
1.	Backhmut	-	-	-	-
2.	Chernihiv	-	-	-	-
		-	*	*	-
3.	Chernobyl	-	-	-	-
4.	Chuhuiv	-	-	-	-
		-	-	-	-
5.	Crimea	-	-	-	-
6.	Dnieper	-	-	-	-
		-	-	-	-
7.	Donetsk	-	*	*	-
8.	Hostomel	-	-	-	-
		-	-	-	-
9	Ivano-Frankivsk	-	-	*	*
10.	Kalynivka	*	-	-	-
		-	-	-	-
11.	Kherson	-	*	*	*
12.	Kyiv	-	*	*	*
		-	-	-	-
13.	Kharkiv	-	*	*	*
14	Lutsk	-	-	-	-
		-	-	-	-
15.	Mriupol	*	-	-	-
16.	Ochakiv	-	-	-	-
		-	*	-	-
17.	Odessa	-		*	*
18.	Shchastya	-	-	-	*
		-	-	-	-
19.	Sievierodenetsk	-	-	-	-
20.	Sumy	-	-	-	-
		-	-	-	-
21.	Uman	-	-	-	-

Table 7
Possible pollutants released on the Ukraine soil and environment due to 2022 Russia invasion.

S/N	Metals	Propellants	Explosives	Pyrotechnics and Obscurants
1.	Iron (Fe)	Nitrocellulose (NC)	Trinitrotoluene (TNT)	Hexachloroethane (Hc)
2.	Aluminium (Al)	Nitroglycerine (NG)	Hexogen (RDX)	Antharcene
3.	Copper (Cu)	Dinitroulene (DNT)	Octogen (HMX)	White phosphorous (WP)
4.	Chromium (Cr)	Nitroquanidine(NQ)	Pentaerythritol tetranitrate (PET_{10}	Red phosphorous (RP)
5.	Tungsten (W)	Ammonium Perchlorate (AP)	Dinitroanisole (DNAN)	–
6.	Uranium (U)	Lead (Pb)	Nitrotriazolone (N_{10})	–
7.	Beryllium (Be)	–	–	–
8.	Zinc (Zn)	–	–	–

Environmental Protection of Heavy Weapons Ranges: Technical and Practical Solutions. Ministry of Defence, Finland (2019).

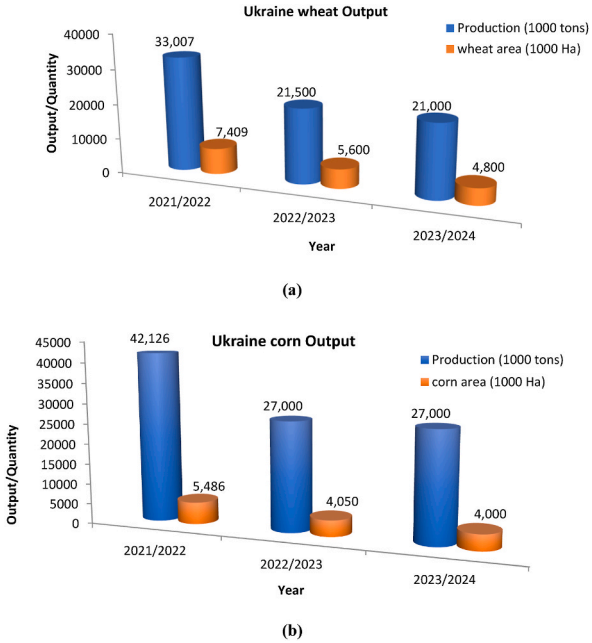


Fig. 5. Ukraine wheat and corn area, yield and production from 2021 to 2023 [58].

of bioethanol (0.175 million litres) as fuel a substantial amount of bioethanol (49.475 million litres) were exported as fuel by Russia in 2015 out of 107.575 million litres. Therefore, there must be some impact on the above biofuel related activities in Russia by the above sanctions.

4.3. Direct effects on EU and other related countries

Many countries of the world such as China, United States, Malaysia and Indonesia have biofuel mandates. The mandate stipulates refiners to blend certain biofuels such as ethanol derived from corn or wheat, biodiesel derived from palm oil and soy bean and others into fuel each year or make purchases on credits from those that do have. Since the Russian-Ukraine war commenced there have been a rapid surge in food prices globally. On 9th March, Ukraine banned most of food exports to ensure that her people do not go hungry as Russian forces invade. There are efforts by Europe and US to compensate for the loss of Ukraine's exports by diverting crops destined to be made into biofuels into food production instead. Ukraine and Russia combined is responsible for about 75 % of world's sunflower oil exports and over 26 % of wheat exports. Consequently, efforts are gradually being made by different countries to ensure that the biofuel feedstocks channelled towards food production. Wheat is a promising substitute for corn for bio-ethanol production. Used cooking oil from the countries where rapeseed and sunflower are basic feedstocks for biodiesel production. Over 120 million litres/kg of used cooking oil is used for biodiesel production in UK followed by food waste. Also, in Europe, over 160 million litres/kg of bioethanol is obtained from wheat followed by 40 from sugar beet. Table 8 contains some of the adjusted mandates by some countries while Table 9 contains some of the countries that import crops from Ukraine. These countries will have to feel the direct and indirect impact of the Ukraine's stoppage on exportation of cereals and oil crops. As of December 4, 2022, one half of Ukrainian agricultural exports secured by the black Sea Grain Initiative went to high income countries while lower income countries accounted for less than on quarter of the experts in physical teams.

5. Policy recommendations

The outline of the policy recommendations presented below while they are further discussed in details.

Table 8
The impact of the Russian invasion on Ukraine on EU countries biofuels mandate.

	EU country	Bio-fuel mandate adjustment
1.	Sweden	Proposed to freeze the mandate for 2023 at 2022 levels
2.	Croatia	Withdrawn penalties issued to blenders who fail to meet mandate target
3.	Finland	Plans to reduce its biofuels mandate
4.	Lobby groups	Suggested diverting crops meant for biofuels into food crops

Table 9
Other vulnerable countries that imports crops from Ukraine.

S/N	Country	Crops imported
1.	Yemen	Wheat, corn, sunflower
2.	Egypt	Wheat
3.	Turkey	Wheat, maize
4.	Bangladesh	Wheat
5.	Sudan	Wheat
6.	Nigeria	Wheat
7.	Azerbaijan	Wheat
8.	Vietnam	Wheat, maize
9.	United Arab Emirates	Wheat
10.	Tanzania	Wheat
11.	Iran	Maize
12.	South Korea	Maize
13.	Lebanon	Maize
14.	Netherlands	Maize
15.	Japan	Maize
16.	Lahva	Maize
17.	Georgea	Maize
18.	Greece	Maize

- Implementing the 2023 Ukraine energy strategy.
- Following strictly on ESU strategic objective
- Strategizing through the concept of natural energy security and independence
- Ensuring strict adherence to EU biofuels sustainable directives
- Development of frame work for management of post-war waste
- Implementation of Bioplus Project (ERA-ARD)
- Providing holistic master plan renewable energy from the Ukraine government.
- Addressing the incompatibility of wind and crop farming.
- Subjecting each bio-fuel feedstock to life cycle analyses (LCA) before application.
- Diversification of economy away from oil
- Enhance agriculture and transport system that is friendly to the environment
- Development of large scale and distributed energy storage infrastructure
- Artificial intelligence application is suggested to take care of infrastructure and equipment management, load forecasting and generation forecasting in energy sector
- Considerations should be given to the impacts of biofuels on soil, water and environment.

Additionally, the draft of United Nations Economic Commission (UNECE), Food and agriculture Organisation (FAO) and United Nations Environment Programme (UNEP) on policy recommendations: existing barriers and possible solutions to support biofuels market development in Ukraine capturing Technology, Identified barriers, possible solution and recommendations and responsible institutions for implementations are available for further consultations [60].

5.1. Implementing the 2023 Ukraine energy strategy

In August 2017, Ukraine structured the Ukrainian energy strategy (ESU) in three phases: Energy sector reform (up to 2020), optimization and innovation of energy sector infrastructure (up to 2025) and sustainable development (up to 2035). Ukrainian energy strategy (ESU) is a policy master plan of security, energy efficiency and competitiveness for producing strategic guidelines for the development of Ukraine's fuel and energy complex for the period up to 2035 [61]. However, a more recent and robust energy strategy for a period up to 2050 has just been approved by the Cabinet of Ministers of Ukraine in April 2023. This invalidates the above earlier strategy that had a completion target of 2035. The current strategy expects the ministry of energy together with other central bodies to provide within a three-month period a robust energy development plan centering on security, energy efficiency and competitiveness that will span up to 2050 [61].

5.2. Following strictly on ESU strategic objective

The cardinal objective of ESU is to form a strong foundation for the sustainable development of a highly competitive economy and to be an indispensable integral part of the European energy sector. Energy security, reliability and stability of the fuel and energy sector require the application of best practices in the wide spectrum of environmental production [61]. The following steps shall be very necessary to achieve the above robust objective.

(i) Necessary equipment, expertise and funding for property identity, monitor and remediation of environmental hotspots shall be provided.

(ii) Strict enforcement of environment control and regulations to prevent and minimize environmental hazards and risks will be very cardinal to protect people and their environment in Ukraine.
(iii) Immediate restoration of environmental governance in urban area, to institute and implement solid waste collection and disposal to fore store sound public health and minimize environmental hazards and risks.
(iv) An introduction and enforcement of an appreciable fossil/biofuels mix.
(v) Also the following areas requires deep attention: large availability of unused land, need to reduce dependence on oil and gas imports, possibility of steady development of agriculture, good geographical location, creation of more jobs and improvement of environment.

5.3. Strategizing through the concept of natural energy security and independence

The government of Ukraine should harness the potentials of the government policies, public, private and non-governmental organizations, the media, international biofuel markets, to ensure rapid and successful biofuel diffusion [62]. This will entail full attention to market creation, waste management, policy and legislation, financial incentives etc (Fig. 6). Strategizing through the concept of National Energy Security and Independence (NESI) will be of immense help to Ukraine. It should be of great interest to various countries of the world to understand that energy security is a key element of national security. Until countries begin to work towards energy independence, their national security will remain far-fetched. Biofuels are synonymous to food and good health. Countries of the world should strive to ensure that their agricultural policies are sound enough to promote sufficient production of crops to serve for food and biofuels. Researchers have currently identified the present challenges of Russian invasion of Ukraine as a necessary and critical reason for energy independence [35]. Russia has recently hijacked one of the major nuclear power plants and suggestions have been for Ukraine to prioritize the alternative energy sources with its high agricultural potentials (where it has more than 1,742,000 tonnes of oil capacity from only one region (Kyiv)) [35]. This will help Ukraine to save more than 42 % of its fossil fuel. Most recent researches have proven that agro-wastes are very viable as biofuel feedstocks. Therefore, countries that depend on Russia and Ukraine for biofuel feedstocks should defend their energy independence. For example, there exists the energy independence and security act of 2007 in US. This act has the mandate of ensuring that America's dependence on foreign nations through the Renewable Fuels Association (RFA). Many biofuels interests have suggested that instead of US moving towards reduction in ethanol and biodiesel use now, efforts should be made to implement the use of more ethanol and biodiesel to bring low pump prices [62]. Other countries should follow the same trend.

5.4. Ensuring strict adherence to EU biofuels sustainable directives

Fig. 7 contains the various EU sustainable biofuels directives [63,64]. Strict adherence to these directives will definitely help Ukraine to restore its biofuels mandate in line with the energy independence strategies.

5.5. Development of frame work for management of post-war waste

Ukraine government should develop a framework for management of post-war waste in line with the energy independence and biofuels diffusion strategies. Obviously, there are huge volumes of demolition and waste arising from damaged buildings, and related facilities and infrastructures. In Libya for example, estimate of 82 million tonnes of post conflict waste (PCW) were generated, 200,000

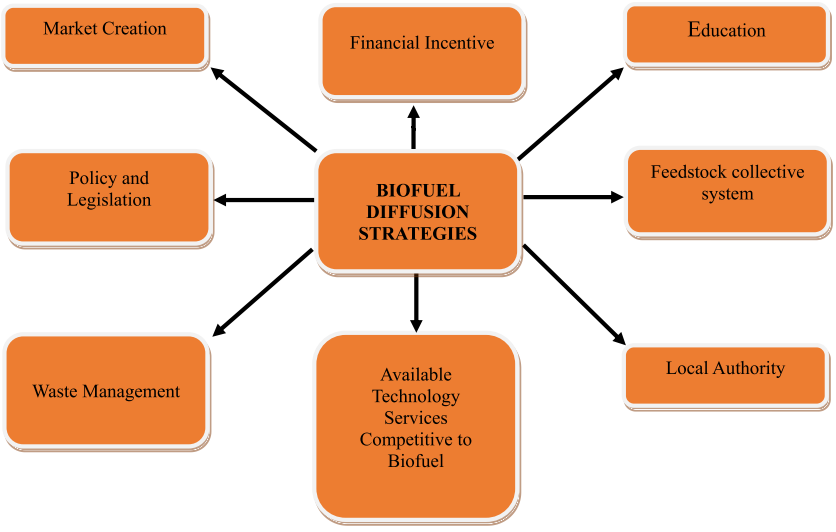


Fig. 6. Biofuel diffusion concepts and strategies [62].

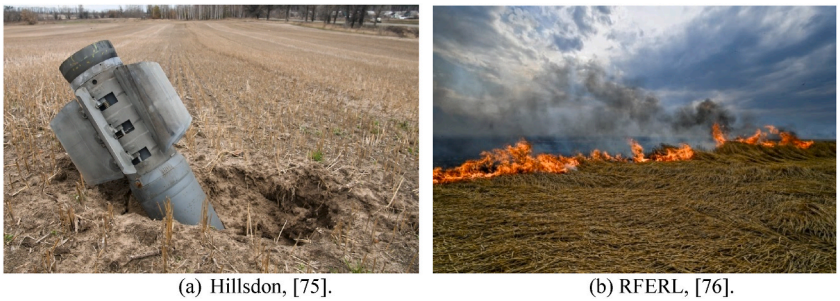
Fig. 7. EU sustainable biofuels directives.

tonnes in Mostor and 10 million tonnes in Kosovo [64]. Fig. 8a and b, show some of the building already damaged while Fig. 9a and b shows some affected farmlands in Ukraine due to the attacks and the wastes generated by these destructions. The activities will go beyond environmental sanitations as some of these wastes find their ways into the arable lands of Ukraine. It would be efforts in futility planning the cultivation of new energy crops in the Ukraine lands already polluted by the waste and debris from the war attacks. These are not only dangerous and hazardous to the farmers but would destroy the fertile lands unless they are professionally cleared off.

By August 2022, Russia's invasion of Ukraine has damaged about 764 kindergartens, 105,200 cars, 1991 shops, 43,700 agricultural

(a): Daily Sabah, [73]. (b) Scott, [74].

Fig. 8. Images of some destroyed buildings in Ukraine during the war.



(a) Hillsdon, [75]. (b) RFERL, [76].

Fig. 9. Images of some affected farmlands during the war in Ukraine.

machines, and 634 cultural facilities. It is summarily estimated that 140,000 residential buildings have been destroyed [65]. It implies that it is expected that over 15 million tonnes of waste might have been generated already in Ukraine in comparison with waste generated in Libya and others countries during the war (Table 10). This is very heavy to be received by the Ukraine soil and environment. The ongoing war in Ukraine will generate organic waste, plastics, paper cardboards, metals, textiles, glass and timbers, dust, stones and ashes, etc which will come from demolitions. All these would fill and pollute the Ukraine environment including the arable lands for growing food and energy crops. Consequently, there should be:

(i) Development of a proposed framework
(ii) Waste estimation and establishment of transport protocols
(iii) Transformation by reducing negative environmental impacts
(iv) Resources creation
(v) Waste resources

All the above stages need meaningful support from legislative and regulatory inputs while the following strategies (focusing on safety/reduction/reuse/recycle/recovery and landfill measures) should be adopted.

(i) Ensure that the area is free of explosions.
(ii) Ensure that cleaning work is supervised in a professional manner.
(iii) Apply efficient plan and strategy for deconstruction and demolition works.
(iv) On-site separation of materials.
(v) Provision of storage sites for inert materials.
(vi) Development of infrastructure of recycling and recovery.
(vii) Efficient landfill site application and design with pollution-prevention measures.

5.6. Implementation of Bioplus Project (ERA-ARD)

It is recommended that the inherent advantages of bioplus project (ERA-ARD) implemented by Institute of Technology and Life Sciences (Poland) and Lithuanian University of Agriculture Institute of Agro-Engineering in association with National University of Life and Environmental Sciences of Ukraine Institute of Eco-biotechnologies and Bioenergy should be activated [67].

5.7. Other suggestions

- Renewable energy highly needs a holistic master plan from the Ukraine government. The master plan will be arising from consultations from appropriate stakeholders that will make up experts, business and religious leaders as well as political office holders and Community Development Committees (CDC) [22]. More so, for the EU countries including Ukraine, to ensure that biofuel is so indispensable in the fuel market, exemptions of taxes and other policy tools (quotas) are to be highly considered and critically reviewed under the current scenario [22].
- There is much need to meticulously address the incompatibility of wind and crop farming; and each bio-fuel feedstock should undergo life cycle analyses (LCA) before application.
- There will be need for diversification of economy away from oil and in the same vein enhance agriculture and transport system that is friendly to the environmental. This will in no small way help to reduce emissions of pollutants, health improvement, job creation and provision of other economic and environmental and other benefits.
- Development of large scale and distributed energy storage infrastructure would help to arrest the common problem of instability of wind energy resource.
- Artificial intelligence application is suggested to take care of infrastructure and equipment management, load forecasting and generation forecasting in energy sector [68]. Successful implementations have been recorded in China. In taking care of stability and security challenges that has to do with biofuel, wind and solar energy, AI can be very much needed [69–71].

Table 10
Comparison between Countries estimated damages during the war and that of Ukraine.

S/n	Country	Estimated facilities damaged	Estimated waste generated	References
1	Mostror	1000 buildings	200,000 tonnes	[66]
2	Kosovo	70,000 buildings	10 million tonnes	[66]
3	Gaza	2692 houses	600,000 tonnes	[66]
4	Lebanon	125,000 houses	4 million tonnes	[67]
5	Libya	233 buildings	82 million tonnes	[66]
6	Ukraine	140,000 buildings	>15 million tonnes	This study

•Considerations should be given to the impacts of biofuels on soil, water and environment.

It has been established that biomass crops poses great challenge on the good management of soil and threatens the pressure of growth on biodiversity. However, using perennial crops (in accordance with EU biofuels sustainability directive) can reduce soil disturbance, create soil cover, and lower soil erosion, improve soil organic matter and increase biodiversity [22]. Also, negative effects may arise due to the introduction of energy crops on local or regional hydrology, discharge of effluents and in-filtration of herbicides, fertilizers and insecticides. Notwithstanding, non-tiller buffer zones and perennial crops can be of help in reduction of the BOD and COD levels in water ways. Local water and air quality are not without some environmental cost implications owing to reforming, transportation and combustion process of biofuels which also increase significantly to match the rapid increase in global demand. In order to curb the air and water pollution, there should be increased efficiencies in water and energy use. More so, the establishment of small-scaled facilities should be promoted which will help communities in controlling and managing waste.

6. Limitations of study

Irrespective of the sound policy and practical recommendations of this paper, there is also need for further studies which will go a long way in expanding the scope of the subject matter. This will help in gathering more comprehensive data and information that is more recent in order to facilitate generalizability and adoption for policy. Also, considering the fact that secondary data and statistics might be error-prone, manipulative and politicized, the use of primary data alongside secondary data to easily get a first-hand information of residents in the area studied will help in further studies.

Other limitations of the study include the inconclusive nature of the subject matter owing to the fact that the fight has not come to an end which means that the study might not really be wholesome. However, this paper will be a good background for subsequent studies. Those subsequent studies will help in broadening our understanding of the problem and effect of the fight on biofuel energy security on the affected countries as we cannot work beyond the available data as at the time of writing this paper.

7. Conclusion and policy implication

This work has recommended a framework for managing post-conflict challenges of biofuels policies in Ukraine and other related countries. Generally, this article presents through a broader spectrum that Ukraine has excellent renewable energy policies and high potentials for biofuels as a substitute energy source to fossil fuel. Ukraine has high agricultural potentials which has more than 1,742,000 tonnes of oil capacity from only one region (Kyiv) which will help Ukraine to save more than 42 % of its fossil fuel with a total land capacity of 41.9 million hectares (available land is 32.5 million hectares and agricultural land/resident of 0.93 ha). Urgent actions will be expected from the Ukraine government to enhance concepts of national energy security and independence. Also, clearly highlighted here are the needed Ukraine post invasion strategies such as development of frame work for management of post-war waste, ensuring strict adherence to EU biofuels sustainable directives, and implementation of Bioplus Project (ERA-ARD). It is believed that experts in renewable and Bioengineering, Social Sciences, Economics, international biofuel markets and other related areas who are at the centre of making policies for the governments of the world would benefit from this research.

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Data availability statement

Data associated with this study has not been deposited into any publicly available repository by the authors. Data used were secondary data sources and all are included in article.

CRediT authorship contribution statement

Chizoo Esonye: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Constance Okechukwu Esonye:** Formal analysis, Investigation, Project administration, Resources,

Validation, Writing – review & editing. **Emmanuel Obiahu Agha:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources. **Cyril Sunday Ume:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Project administration, Resources. **Chizoma Vivian Njemanze:** Funding acquisition, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. **Chimezie Emmanuel Eyisi:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources. **Tunde Folunsho Adepoju:** Investigation, Project administration, Resources, Software, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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