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ARTICLES INCLUDED IN

Volume 6 Issue 3 (December 2023)

- | | | |
|---------|--|-------|
| M-00361 | Assessment of Various Gibberellic Acid Concentrations on Seed Germination and Seedling Growth of Chilgoza (<i>Pinus gerardiana</i> Wall. ex D. Don)
<i>By: Shahidullah Amn, Masih Ullah Jamal, Wasimullah Zaland</i> | 1-14 |
| M-00362 | Reviewing the Impact of Military Activities on Marine Biodiversity and Conservation: A Study of the Ukraine-Russia Conflict within the Framework of International Law
<i>By: Aqib Tahmid, Shahinoor Khanam, Md. Miraj Rashid, Fayeza Ibnat</i> | 15-31 |
| M-00363 | Crop Intensification through Short Duration Stress-Tolerant Rice Varieties with Green Gram for Fostering Agricultural Resilience and Sustainability
<i>By: Sk Mosharaf Hossain, Hrudananda Atibudhi</i> | 32-45 |
| M-00364 | Exploring the Legal Dimensions of Environmental Policy within the Framework of Ukraine's Sustainable Development Strategy
<i>By: Vitaliy Kovalenko, Oleksandr Kolb, Olena Bondarenko, Sandra Boldizhar, Sergii Marko</i> | 46-66 |



Assessment of Various Gibberellic Acid Concentrations on Seed Germination and Seedling Growth of Chilgoza (*Pinus gerardiana* Wall. ex D. Don)

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Abstract

Chilgoza (*Pinus gerardiana*) forests naturally exist on the highest elevations of the Himalaya Mountains in the provinces of Paktia, Kunar, Nangarhar, Nuristan, and Paktika in the southeast of Afghanistan. These forests provide a sizable source of income for the people living in these areas. The spread and natural regeneration of chilgoza pine forests is declining in the natural environment as a result of overharvesting, erratic annual seed production, and prolonged dormancy; therefore, it is necessary to find an effective method to enhance seed germination and seedling growth. Application of different Gibberellic Acid (GA₃) hormone concentrations (50 ppm, 75 ppm, and 100 ppm), the removal of the seed coat, and control (untreated) treatments were used to conduct an experiment for this study. For each treatment, seedling growth parameters and the percentage of seeds that germinated were examined. The results showed that the T₄ treatment had the highest average length of seedling, shoot, and root, measuring 13.34 cm, 8.1 cm, and 8.4 cm, respectively; whereas the T₁ treatment had the shortest average lengths of seedling, shoot, and root, measuring 11.22 cm, 6.5 cm, and 6.2 cm, respectively. The greatest percentage of germination (78.66%) was observed in T₄ (100 ppm), whereas the lowest percentage (26%) was documented in T₁ (Control). The highest average number of leaves was recorded in T₄ (22.25) and the lowest in T₁ (15.02) treatment. The results indicated that treating chilgoza pine seeds in a 100 ppm solution of GA₃ for 24 hours enhances both the seed germination and sprouting seedling growth.

Keywords

Chilgoza; GA₃; Regeneration; Seed treatment; Seed dormancy

Introduction

The nut tree Chilgoza (*Pinus gerardiana*), commonly referred to as pine nut or edible pine belongs to the *Pinus* genus of the Pinaceae family (Khan *et al.*, 2015). According to Luna (2008), Chilgoza

pine trees can be found between 1,600 and 3,000 meters above sea level. Compared to coniferous trees, pine trees require less light and water, and they can grow and survive in any environment. It forms a forest community in forests where it grows both alone and in community (Malik, Shamet and Butola, 2012). Chilgoza is an evergreen tree that can grow to a height of 17-27 m, has a trunk thickness of 2-4 m, and lives for 300-400 years on average (Bhattacharyya, LaMarche and Telewski, 1988). The leaves are shaped like needles and have five needles in a cluster, each of which can reach a length of 5 to 15 cm (Kumar *et al.*, 2014). The wood of pine trees, which have straight trunks and exfoliated brownish-grey bark, is used for both industrial and ornamental purposes (Richardson, 2000). Chilgoza has a major effect on the socioeconomic growth of the surrounding communities as well as Afghanistan's overall economy. About 120,600 households directly depend on the chilgoza forest for their livelihood; each family earns 444-555 USD annually from this species (Rahman, Salari and Wiar, 2021). The species is degrading due to a lack of natural regeneration, dormancy associated with seeds, and other human causes (Peltier and Dauffy, 2009; Ariez, Salari and Zazai, 2023; Kumar *et al.*, 2016). Chilgoza is a significant source of livelihood for people in rural areas where food is scarce and human, wild animal and bird sustainability are threatened. Chilgoza pine production contributed 8% to the global production (Awan and Petennela, 2017). According to Breckle, Hedge and Rafiqpoor (2018), Chilgoza is important for the socioeconomic growth of Afghanistan's rural population. The pine tree is regarded as one of the species that is facing an imminent and serious threat of extinction in Afghanistan as well as some other Asian and European countries. IUCN (2023) has classified the Chilgoza species as near threatened due to grazing, overexploitation, and inherent seed dormancy.

According to Singh *et al.* (2010) and Holl (1999), germination is a complicated process that is influenced by a variety of biological and climatic factors. The extensive collection of pine nuts by locals is the main cause of the very poor natural regeneration of pine (Malik, Shamet and Majid, 2008). Due to pricey edible nuts, pine nut trees have numerous economic advantages, but their widespread use has a detrimental impact on the tree's ability to regenerate because each cone is sought after for maximum profit and no seeds are left over for natural regeneration. Pine nut has issues with dormancy and erratic annual seed production, as a result of which the natural environment experiences a slower germination process (Malik, Shamet and Majid, 2008). Chilgoza is currently propagated only by seed, which shows very low and uneven germination, and slower seedlings growth causing poor natural regeneration. Considering the lack of natural regeneration, it is necessary to protect these forests through artificial regeneration, but to low germination percentage and the high price of seeds are the main barriers to artificial regeneration. Finding a practical way to improve the germination of pine tree seeds is essential because pine trees have difficulty in producing seedlings for reforestation. The ability of various plant hormones to promote seed germination has been investigated by Singh *et al.* (2010). According to Amri (2010) and Ariez, Salari and Zazai (2023), the application of GA₃ can significantly impact seed germination and encourage the vegetative growth of seedlings. Different species of plants responded favorably to growth-promoting hormones, especially GA₃, according to Rawat, Sharma and Ghildiyal (2006) and Bhardwaj (2014), Biochemical changes have a significant effect on seed germination. Studies confirm that increased germination of *Picea smithiana* Boiss., *Abies pindrow* (Royle ex D.Don) Royle, and *Cupressus sempervirens* L. seeds after

treatment with gibberellic acid is correlated with either an increase in the production of hydrolytic enzymes (especially amylase) or an increase in embryo development, which is also a result of the stimulation of hydrolytic enzymes (Amen, 1968). The use of GA₃ in seeds increases metabolism, improves germination, and promotes overall plant growth (Rawat, Sharma and Ghildiyal, 2006). In the study by Rawat, Sharma and Ghildiyal (2006), it was found that treating seeds of *Abies spectabilis* (D.Don) Spach, *Picea smithiana* Boiss., and *Cupressus sempervirens* L. for 24 hours with a 100 ppm solution of GA₃ maximized their germination percentage, which was 45%, 57%, and 56% higher than the control, respectively. The type and size of the growth medium are important factors for seed germination and seedling growth. Seed germination and seedling growth are greatly affected by the sowing medium and GA₃ (Ariez, Salari and Zazai, 2023). Based on the study's findings, it can be concluded that gibberellic acid treatment has an impact on seed germination, but the impact varies depending on the plant. The research is designed to determine the best way to address germination issues by examining the effects of various gibberellin concentrations on the germination of pine seeds under local environmental conditions. The prime objective of this research was to ascertain the ideal GA₃ concentration and to examine the impact of various GA₃ concentrations on the germination of pine seeds and on new seedlings growth.

Materials and Method

This research took place at the Research Farm of the Faculty of Agriculture, University of Sayed Jamaluddin Afghani, Afghanistan during 2021-2022. Morphological (qualitative and quantitative) traits were documented at the Research Farm and the research area was marked on map with coordinates, elevations and other details of the chilgoza (*Pinus gerardiana*) prepared neatly. The pine seeds originate from the forests that surround the Dewa village of Paron in the Nuristan province, which is located at 35°26'54" N and 70°55'47" E. A randomized complete block design (RCBD)¹ was used with five treatments (T₁: control, T₂: 50 ppm, T₃: 75 ppm, T₄: 100ppm, T₅: excision of seed coat) were considered. Three replications of each treatment were conducted, using 50 seeds for each replication and 150 seeds for each treatment. Data were processed and analyzed by using ANOVA and Statistix 8.1 for significance and mean comparison.

Morphological Analysis of Seeds

A digital caliper was used to measure the length, width, and depth of ten randomly selected pine seeds from each treatment before they were planted. The average values were then computed independently. Furthermore, the average weight of fifty seeds sown in one repetition was calculated. Table 1 shows the results of seed dimension.

Table 1: Statistically analysis of seed dimension

Dimensions of seeds	Seed length (mm)	Seed width (mm)	Seed thickness (mm)	Weight of fifty seeds (gram)
Mean size	17.98	6.12	5.18	17.23

¹ https://online.stat.psu.edu/stat502_fa21/lesson/7/7.3

Pre-Sowing Seed Treatment and Cultivation

Pine seeds were subjected to the five different treatments in an attempt to increase germination and to determine which of these treatments the pine seeds responded to the best. The seeds of each treatment were placed in these concentrations for 24 hours. These seeds were sown in polythene bags over a 10 square meter area after the treatments. Each polythene bag had a 12 cm diameter and a 20 cm length. To avoid seed contamination, the right amount of space between the polythene bags was considered. To prevent the growth of fungi, the seeds were periodically checked and the appropriate measures were taken. The bags were kept wet by routine sprinkler watering. Along with the germination of the seeds, the germination count was periodically carefully documented.

Germination Percentage

The purpose of the seed germination test was to determine the amount of seed germination relative to plant production. Germination percentage in each treatment was calculated from the number of seeds that actually germinated in one growing season and the result was calculated with the help of the following formula.

$$\text{Germination Percentage} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown}} \times 100$$

Germination Energy

An indicator of the strength of the seed and seedling, germination energy is a measurement of the rate of germination. The proportion of all seeds in a growing season whose germination was at its highest was used to calculate germination energy and the result was calculated with the help of the following formula.

$$\text{Germination Energy} = \frac{\text{Total number of seeds that germinated up to their maximum number}}{\text{Total number of seeds sown}} \times 100$$

Germination Mortality

The assessment of germination mortality is a crucial component of seed germination. The reason for the failure of seed germination is the seedling that perishes after germination and fails to develop into a plant. Many times, seeds germinate but fail to develop into strong plants, ultimately dying. The following formula was used to determine the pine seed germination mortality.

$$\text{Germination mortality} = \frac{\text{Number of un-survived seedling}}{\text{Total number of germinated seedling}} \times 100$$

Characteristics of Seedling Growth

Five seedlings were randomly chosen from each treatment to examine the characteristics of seedling growth. A metal ruler was used to measure the seedling height, stem length, and root length of each seedling and the average number of leaves was calculated.

Vigor Index of Germinated Seeds

Before sowing, the seed vigor index was assessed against various treatments, and the outcome was determined by the following formula.

$$\text{Seed vigour index} = \text{Seedling length} \times \text{Germination percentage}$$

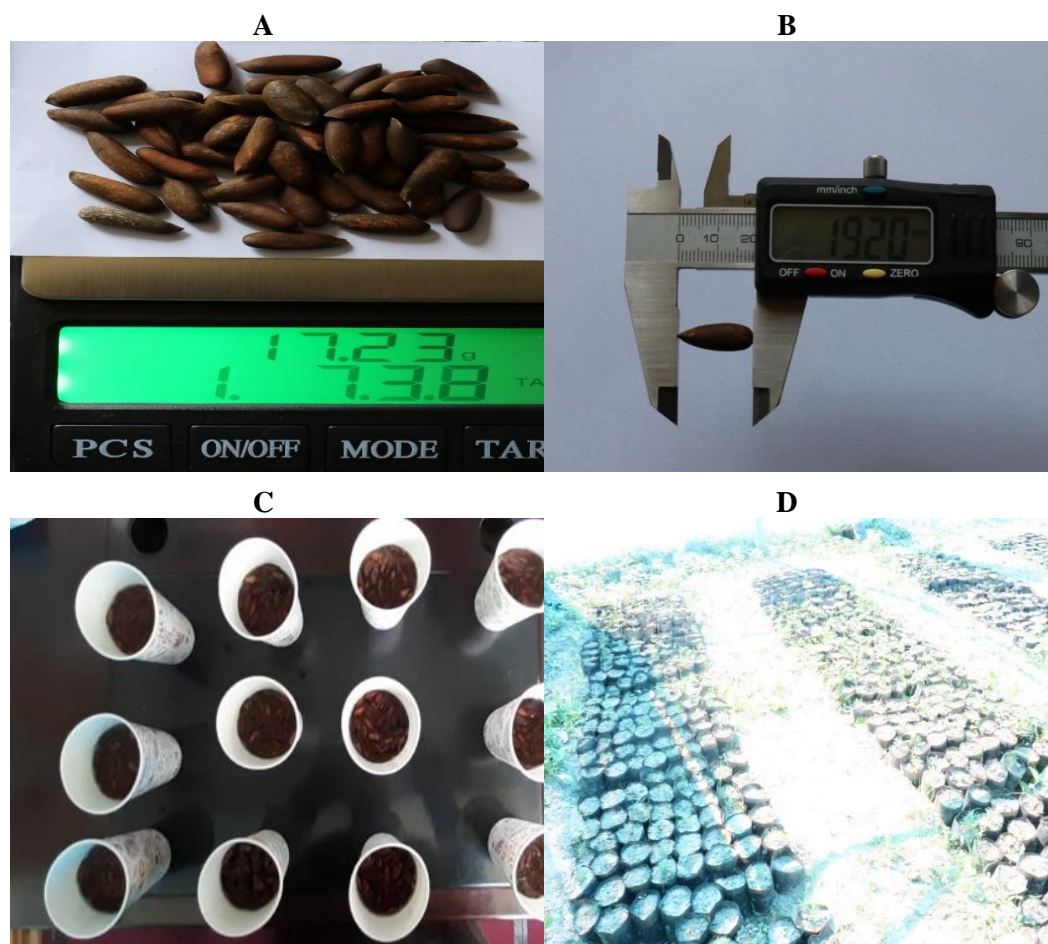


Figure 1: **A:** Measurement of seed weight. **B:** Measurement of seed length with a digital caliper. **C:** Treatment of seedlings with concentrations of GA₃. **D:** Plots of seeds grown in the research farm.

Result and Discussion

Effects of Pre-Sowing Treatment on Seed Germination Percentage

Germination percentage was significantly influence by gibberellic acid concentrations. The germination of the seeds was enhanced using GA₃. The percentage of germination for each treatment and the sum of the three repetitions were calculated. The results obtained are displayed in table 2.

Table 2: Cumulative germination rate and percentage in different treatments and replications

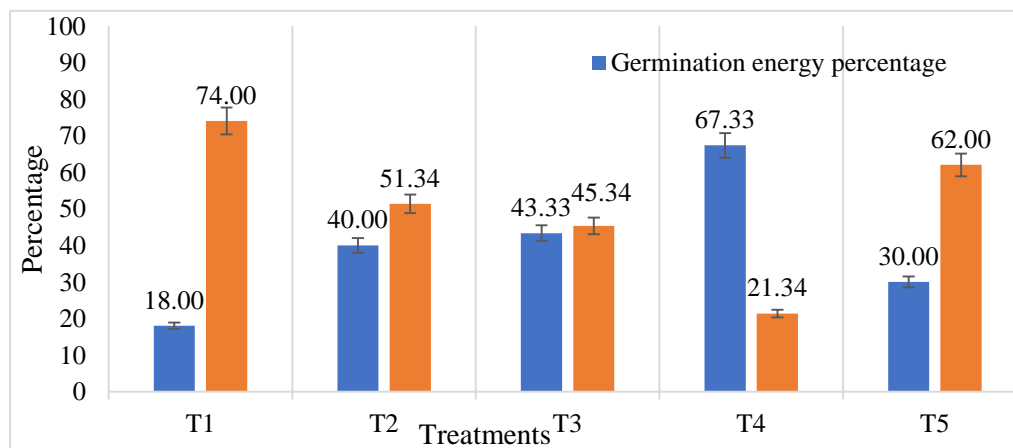
Treatments	Number of germinated seeds				Germination Percentage
	R ₁	R ₂	R ₃	Mean	
T ₁	13	15	11	13.00 *	26.00 *
T ₂	26	22	25	24.33	48.66
T ₃	21	32	29	27.33	54.66
T ₄	39	41	38	39.33 **	78.66 **
T ₅	22	18	17	19.00	38.00
Mean	24.2	25.6	24	24.60	
CD	6.498				
Sem	1.962				
CV	2.775				

**=Highest Germination Percentage, *= Lowest Germination Percentage

The above table demonstrates that the T₄ treatment was significantly high (39.33) and had the highest positive effect of GA₃ concentrations on the germination of pine seeds (78.66%), with 118 out of 150 seeds germinated followed by T₃ and T₂ as 54.66 per cent and 48.66 per cent, respectively; while the T₁ had the lowest recorded germination rate (26.00 %).

Effects of Pre-Sowing Treatments on Seed Germination Energy and Mortality

The percentage of the total number of seeds at the peak of germination was used to calculate germination energy. After the seeds germinated, the percentage of seedlings that did not survive was also calculated and the detailed amounts are given in graph 1. The analysis of results showed that the germination energy was significantly affected by GA₃ concentrations. The following graph shows that T₄ (67.33%) had the highest calculated germination energy percentage, followed by T₃ (43.33%) and T₂ (40.00%), respectively; while T₁ (18.00%) recorded the lowest germination energy percentage. T₁ calculated the highest percentage (74%) of seed germination failure, followed by T₅ and T₂ (62.00% and 51.34%), respectively; yet T₄ calculated the lowest percentage of germination failure (21.34%).



Graph 1: Effects of pre-sowing treatments on germination energy and mortality percentage of seeds.

Effects of Pre-Sowing Seed Treatments on Seedling Growth Characteristics

To ascertain each seedling's growth characteristics, measurements were taken of the length of each seedling, stem length, root length and the number of leaves. The average results are shown in table 3 below.

Table 3: The average values for various aspects of seedling growth

<i>Treatments</i>	<i>Average seedlings length (cm)</i>	<i>Average stem length (cm)</i>	<i>Average roots length (cm)</i>	<i>Average number of leaves</i>
T ₁	11.22	6.5	6.2*	15.02*
T ₂	11.8*	7.3	7.1	16.08
T ₃	12.12	7.7	7.4	16.02
T ₄	13.34**	8.1**	8.4**	22.25**
T ₅	12.17	6.4*	7.1	15.05
CD	1.728	0.468	0.980	0.358
Sem	0.522	0.141	0.296	0.108
CV	4.505	3.398	7.081	1.110

**=Highest Average, *= Lowest Average

The collected data demonstrates that the growth parameters of the seedlings are significantly influenced by the various pre-sowing treatments. T₄ had the significantly high and longest average length of seedlings (13.34 cm), followed by T₅ (12.17 cm); while T₁ had the shortest average length of seedlings (11.22 cm). T₄ had the longest average stem length of the seedlings (8.1 cm), followed by T₃ (7.7 cm), and T₅ had the shortest stem length (6.4 cm). Furthermore, T₄ exhibited the largest root length on average (8.4 cm), whereas T₁ had the shortest root length (6.2 cm). The average number of leaves obtained in T₄ (22.25) was the highest, and the average number of leaves obtained in T₁ (15.02) was the lowest across all treatments.

Vigor Index of Germinated Seeds

Table 4: Seed vigor index

<i>Treatments</i>	<i>Germination Percentage (%)</i>	<i>Average Seedling Length (cm)</i>	<i>Seed Vigor Index</i>
T ₁	26.00*	11.22*	291.72*
T ₂	48.66	11.80	574.18
T ₃	54.66	12.12	662.48
T ₄	78.66**	13.34**	1049.32**
T ₅	38.00	12.17	462.46
CD	0.130	1.728	1.877
Sem	0.039	0.522	0.567
CV	13.815	4.505	16.120

**=Highest, *= Lowest

The percentage of seeds that germinate and the height of the seedling are both factors responsible for the seedling vigor index. This index positively affects the stability of plants and the formation of robust seedlings. Before sowing, the strength index of the seeds was evaluated in comparison to different treatments; more details are given in table 4.

The seed vigor index was significantly high in T₄ (1049.32), followed by T₃ and T₂ (662.48 and 574.18, respectively), and lowest in T₁ (291.72).

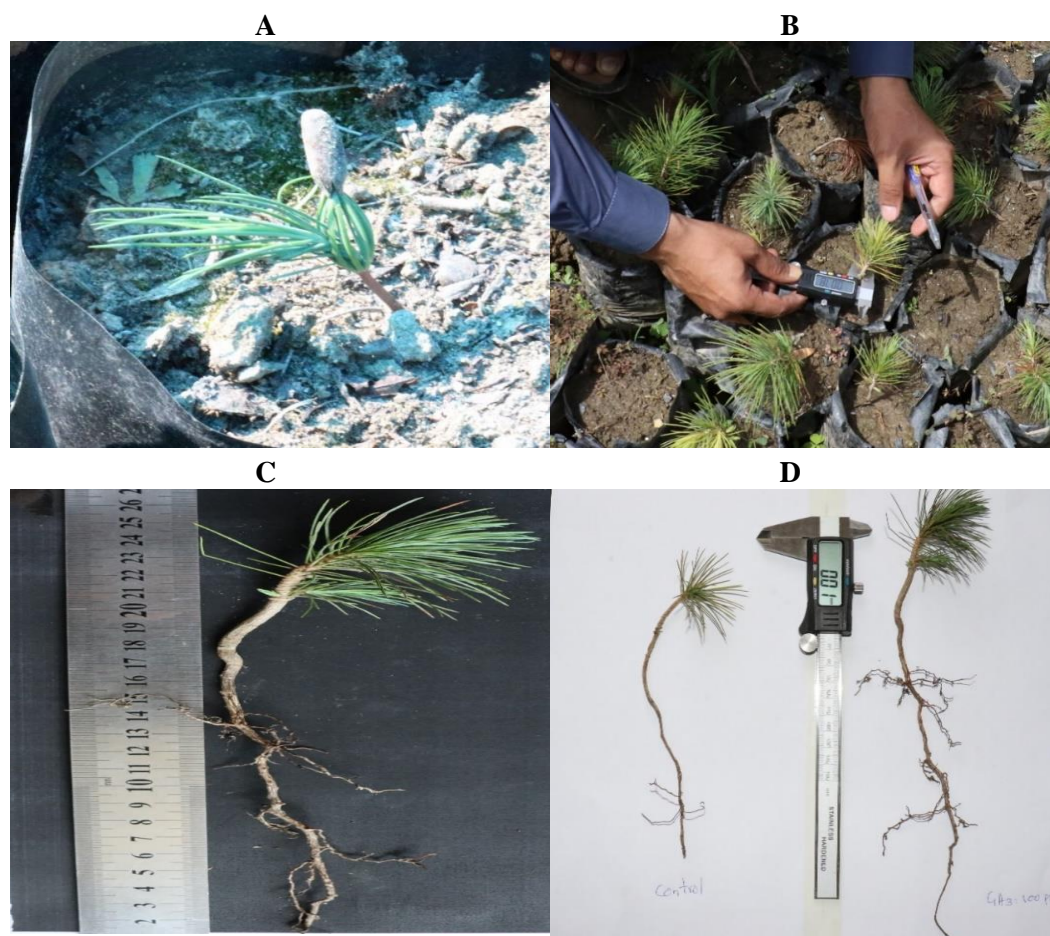


Figure 2: A: Germination of planted pine seeds. B: Measurement of seedling diameter and stem. C: Measuring the seedling length. D: Comparison of control seedling and seedling treated with GA₃.

Discussion

Results of this study showed that various gibberellic acid treatments significantly influenced the germination and seedling growth of the chilgoza pine seeds. The germination percentage and seedling growth had gradually increased with increasing the GA₃ concentration up to 100 ppm. The significantly high germination (78.66) was reported in treatment with T₄ concentration. Similar results were also achieved in the study conducted by Kumar *et al.* (2014) in which the germination was (73.84 and 62.71) percent when seeds were treated with 75 ppm and 150 ppm concentrations of

gibberellic acid, respectively. Additionally, these findings contrast slightly from the study conducted by Sharma *et al.* (2019) in which 67 percent of the seeds treated with 100 ppm gibberellic acid. Similar results were also reported by Sharma *et al.* (2020), Breckle, Hedge and Rafiqpoor (2018), and Ariez, Salari and Zazai (2023).

Among the control and other treatments, the seeds treated with a 100 ppm solution of gibberellic acid for an hour produced significantly high percentage of germination energy (67, 33), as shown in T₄. Gibberellic acid, which is produced in the seeds during germination and aids in seed germination, may be the cause of the increase in germination observed with gibberellic acid treatment (Dhoran and Gudadhe, 2012). Gibberellic acid-treated seeds germinated earlier and finished germination faster, which might have made it easier for cytokinins to penetrate the seed coat and reduce or eliminate growth-inhibitory chemicals found in the embryo. As a result, the embryo can sprout by breaking through the seed coat (Çetinbaş and Koyuncu, 2006).

Seedling quality evaluation is essential to the success of reforestation. Even though plant height and stem length are the most frequently assessed parameters during seedling quality evaluation, above-ground plant morphology is not a reliable indication of seedling stability after planting. Davis and Jacobs (2005) stated that the root system's morphological state may improve the probability of transplant success. The increasing of seedling growth might be due to cell enlargement and turgor pressure events stimulated by gibberellic acid (Kumar *et al.*, 2014). In the light of the reference of the mentioned authors, different quality characteristics of the seedlings were measured. Significantly high average length of seedlings was recorded in the T₄ treatment as 13.34 cm, and the highest average number of leaves (22.25) was recorded in T₂; the maximum stem and root lengths (8.1 cm) and (8.4 cm), respectively, were also recorded in T₄. The minimum length of seedling, shoot and root was found in T₁ (11.22 cm), (6.5 cm) and (6.2 cm), respectively. These results are in harmony with those of Sharma *et al.* (2019), Kumar *et al.* (2014), Gharib (1972) and Sharma *et al.* (2020).

Abdul-Baki and Anderson (1973) declared that seed treatment is highly significant since it is a sign of healthy plant vigor, and increased plant vigor contributes to stability, making it simpler to grow a sapling into a strong tree. T₄ (1049.32) yielded significantly high and strongest plant index, followed by T₃ and T₂ (662.48 and 574.18, respectively). T₁ has the lowest measured seedling vigor index (291.72). These findings are parallel with the results of Sharma *et al.* (2019) and Sharma *et al.* (2020).

Conclusion

The result of the study highlights the critical challenges facing pine forests, including a decline in distribution and natural regeneration attributed to factors such as excessive pine nut collection, irregular seed production, and prolonged dormancy. The conducted experiments using various treatments, including different concentrations of gibberellic acid and seed coat removal, revealed significant impacts on seed germination and seedling growth. Gibberellic acid treatment emerged as the most effective way in exhibiting the highest germination percentage, germination energy, and the lowest rate of germination failure. The associated seedling growth characteristics, including length, shoot development, root growth, and leaf count, further supported the positive influence of the 100 ppm GA₃ solution. These findings

underscore the potential of gibberellic acid, specifically the 100 ppm concentration, as a practical and effective solution for enhancing pine seed germination and fostering robust seedling growth, offering promise for the restoration and sustainability of pine forests in their natural environment.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

<i>Contribution</i>	<i>Author 1</i>	<i>Author 2</i>	<i>Author 3</i>
Conceived and designed the research or analysis	Yes	Yes	Yes
Collected the data	Yes	No	Yes
Contributed to data analysis & interpretation	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	No
Critical revision of the article/paper	No	Yes	No
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The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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Reviewing the Impact of Military Activities on Marine Biodiversity and Conservation: A Study of the Ukraine-Russia Conflict within the Framework of International Law

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Abstract

The severe consequences of military activities on marine biodiversity and conservation have come to limelight as a result of the Ukraine-Russian conflicts in the Black Sea region. The battle has had both immediate and collateral environmental effects on the Black Sea, a hotspot for numerous and uncommon aquatic species. Oil spills, the discharge of toxic substances, and habitat deterioration are only a few of the direct effects that have harmed marine environments and destroyed crucial breeding sites. The fragile balance of the marine life in the area is further threatened by indirect effects caused by fishing practices, increased marine traffic, and advances in coastal infrastructure brought on by conflicts. This ongoing conflict has infringed upon international agreements, including the Basel, Stockholm, and London Conventions, through military activities in the Black Sea, resulting in the violation of regulations governing hazardous waste movement and posing a threat to the biodiversity of the region. This review discusses the breaches and analyzes the harms caused in the marine ecosystem and resources and proposes suggestions as to combine military tactics with conservation and restoration activities.

Keywords

Marine resources; Black Sea region; Marine environment; Military operations; Sustainable methods

Introduction

The Ukraine-Russia conflict has had far-reaching environmental consequences, particularly for the Black Sea region's marine ecosystems. A wide range of land and sea-based military activities are endangering Ukraine's marine ecosystems, while the fighting has directly impacted fragile and environmentally vulnerable coastal habitats (CEOBS, 2023). This protracted conflict has entailed a variety of military activities that have resulted in

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substantial ecological disruptions, threatening the fragile balance of the marine ecosystem. The situation in the Black Sea Region is exceedingly complicated due to Ukraine's severe crisis, the ongoing fires in Donbass, Russia's role in the "frozen conflicts," and the region's increasing militarization. Russia has frequently utilized armed forces outside its boundaries to exert foreign policy pressure (Bekiarova, 2017).

When discussing the environmental effects of the war, most of the people focus on terrestrial repercussions. On the contrary, war has no less influence on the sea, and the marine biodiversity is more sensitive to military impacts than land-based ecosystems, owing to the interconnectedness of water bodies (Kolodezhna and Vasyliuk, 2022). In the ongoing conflict between Russia and Ukraine, the Russian military's launch of cruise missiles through the Black Sea directed to Lviv in Ukraine has had a devastating environmental impact, leading to ecological disasters on the surrounding areas since constant missile testing in the sea impedes marine wildlife (Olajide, 2022). Active marine hostilities and Russian warships currently stationed in the Black Sea's northwestern region not only block Ukraine's seaports, putting the world at risk of global famine, but also create man-made disasters that severely affect the Black and Azov Seas' coastal and marine ecosystems (UWEC Work Group, 2023). The Azov-Black Sea coast of southern Ukraine is a kaleidoscope of distinct coastal and marine environments, including estuaries, lagoons, islands, salt marshes, and sea grass meadows, and is home to hundreds of uncommon species.

In the Black Sea region, the battle also alters migratory patterns and species composition. Military activity such as under-sea explosions, naval operations, and barrier construction can drastically affect marine species' migration paths and behaviour. For their feeding, reproducing, and survival, the fish, marine animals, and sea turtles rely on specialised ecosystems and migration patterns. Any interruption to these patterns can have a negative impact on their populations, potentially resulting in decreased biodiversity and uneven ecological dynamics. Hostilities have an impact on underwater marine environments as well. Sunken ships and missiles, anchor usage, and ammunition blasts can all harm underwater habitats. Chemical and acoustic pollution, physical damage to habitats, and a reduction in conservation activities are the principal effects of the armed conflict on coastal and marine ecosystems (CEOBS, 2023). The article seeks to provide a complete account of the conflict's ecological repercussions and legal difficulties, as well as it investigates international laws and treaties pertaining to marine conservation, as well as their applicability in conflict zones. The article goes on to examine how military activities during the conflict have broken or challenged existing international environmental laws.

This article is based on a review that used a narrative review approach, which is a traditional method for qualitatively analyzing the existing material. This method entailed selecting relevant research literature while accepting its limitations. The information in the narrative review was arranged in a logical manner to provide a clear and coherent comprehension of the issue. In conclusion, this review work used a systematic technique to analyze the environmental consequences of Russia's war in Ukraine. Formulating research questions, conducting literature searches, screening sources, reviewing the findings, extracting data, and performing qualitative analysis were all part of the process. The narrative review structure was utilized to convey the

synthesis knowledge in a logical order, allowing for a thorough examination of the subject. Before the review began, the following research questions were formulated:

1. How has the Ukraine-Russia conflict affected the Black Sea region's marine ecosystems, and what are the unique environmental effects of this lengthy war?
2. To what extent has military activity in the Black Sea region, including armed engagements and naval operations, had an impact on the environment and violated international law?

Description of the Black Sea Region

The Black Sea is a virtually enclosed and zonally extended basin with a zonal dimension of around 1,200 km and meridional dimensions ranging from 500 km on the western side to 250 km on the eastern side. With a surface area of 423,000 km², it is roughly one-fifth the size of the Mediterranean. Through the Turkish Straits System, it has limited connection with the Aegean Sea. The Black Sea receives freshwater inflows from all across the basin, but the major ones (the Danube, the Dniestr, and the Dniestr) discharge into the basin's northwestern coastal waters (UN Environment, 2017). The Black Sea, which is connected to the Mediterranean Sea through Istanbul, Canakkale (Turk Straits), and Gibraltar straits and to the Sea of Azov in the northeast through the Kerch Strait, is the ocean that is the remotest from the rest of the world. Its surface area to catchment area ratio is more than 6. This makes the Black Sea extremely susceptible to pressure from land-based human activities, and both the coastal and non-coastal conditions of its basin have an equal impact on the health of the Black Sea.

The Black Sea region, which is comprised of the landmass and waters from the Balkans to the Caucasus and from the steppes of Ukraine and Russia to Anatolia, is once more directly in the focus of European policymakers. NATO and the European Union (EU) now share a western border with the Black Sea. Its southern border is shared with NATO member and EU candidate Turkey. On its north and east sides, it is surrounded by Council of Europe members and two potential NATO members (Borou, 2009).

The Black Sea has a surface area of 4:2105 km² and maximum and average depths of 2200 and 1240 meters, respectively. Anoxic water makes up 90% of its total mass. Thus, it contains the world's largest anoxic water mass (Bakan and Büyükgüngör, 2000). The Black Sea is a one-of-a-kind maritime ecosystem with exceptional biodiversity and ecological significance. Its various habitats, which include coastal areas, shallow shelves, and deep basins, sustain a rich diversity of animals. The sea is home to nearly 2,000 plant and animal species, including many rare and endangered species. The Black Sea's diverse biodiversity adds to its ecological resilience and stability. It is essential for the general health and balance of the region's ecosystems. Furthermore, the Black Sea serves as a major breeding and feeding habitat for many migratory species, including dolphins, whales, and seabirds. The conservation and preservation of the Black Sea's biodiversity is critical not only for the long-term viability of its ecosystems, but also for the overall well-being of the neighboring countries and the globe.



Figure 1: Location of the Study Area (Adapted from Cherkez, Dragomyretska and Gorokhovich, 2006)

Military Activities surrounding Ukraine-Russia War

The Ukraine-Russia conflict has seen major military activity on both sides, with far-reaching consequences for the area. Ukrainian military have been engaged in defensive operations to maintain their territorial integrity and sovereignty since the beginning of the conflict. These actions have included increasing border security, mounting counteroffensives, and reinforcing critical strategic sites. In response, Russia has committed significant military assets, including infantry personnel, artillery, and air power, to back their rebel proxies in eastern Ukraine. This has resulted in heavy conflict marked by artillery shelling, tank fights, and aerial bombardment. The military activities in the Ukraine-Russia war have had terrible consequences, resulting in the loss of life, the displacement of civilians, and severe damage to infrastructure. The situation remains dangerous, and efforts to find a peaceful settlement to the conflict continue.

A wide range of land and sea-based military activities have endangered Ukraine's marine ecosystems, while the fighting has directly impacted fragile and environmentally vulnerable coastal habitats (CE OBS, 2023). Coastal wetland ecosystems cover broad areas and connect the vast catchment area to the Black Sea. Wetlands are extremely productive ecosystems and have traits that are determined by the water regime. Because of the steady inflow of water and alternating dry and wet times, they maintain a unique diversity of flora and fauna. The most common types of wetlands in the Black Sea region include lagoons, estuaries, and deltas.

Water is a basic and precious resource for all life on Earth. As a result, it plays a critical role in achieving the Sustainable Development Goals by ensuring societal and environmental well-being (UN-Water Technical Advisory Unit, 2016). At the same time, during violent conflicts, freshwater as a resource (Francis, 2011) and related

water infrastructure (Mason, 2022) are among the most vulnerable sectors. This has heightened interest in the function of water as a source of conflict (Gleick, 2019) as well as the consequences of armed wars on water and water systems (Schillinger *et al.*, 2020; Khilchevskiy and Mezentsev, 2021).

Chemical and acoustic pollution, physical damage to habitats, and a reduction in conservation activities are the principal effects of the armed conflict on coastal and marine ecosystems. Environmental monitoring and control of the Black and Azov seas have also been hampered by the fighting. Chemical contamination in the coastal and marine environment can be caused by damaged industry and settlements. Ecodozor data show that reported damage and disruption to coastal villages has increased as the conflict has progressed, whereas recorded events affecting heavy industry in coastal locales have decreased over the same time period.

Timeline of the Conflict

Since its commencement, the conflict between Ukraine and Russia has gone through several stages. The dispute may be traced back to February 2014 when Russia annexed Crimea, causing tensions between the two countries. Pro-Russian rebels in eastern Ukraine declared independence in April 2014, sparking fighting with Ukrainian soldiers. Contending intensified in 2014 and 2015, with both sides contending for control of key cities such as Donetsk and Luhansk. The Minsk Protocol, a ceasefire deal agreed in February 2015, was repeatedly broken, resulting in the restart of hostilities. The battle raged on, with sporadic clashes and occasional escalation. A prisoner swap and disengagement deal was signed in 2019, indicating some movement toward a peaceful resolution. However, tensions persisted and ceasefire violations continued. When Russia launched a large-scale invasion of Ukraine in 2022, the conflict entered a new phase, resulting in a significant escalation of hostilities. The timeline of the conflict emphasizes the conflict's multifaceted and lengthy nature, with occasional periods of relative peace followed by periods of high violence and instability.

The military confrontation between Ukraine and Russia, as defined by the International Committee of the Red Cross (ICRC, 2008) which began on February 24, 2022, is a remarkable case in terms of its environmental impact (Pereira *et al.*, 2022; Zheleznyak *et al.*, 2022; Rawtani *et al.*, 2022). The effects of Russia's military actions on coastal ecosystems are already visible in several nature reserves on the Crimean Peninsula, which has been occupied since 2014. The state of Opuk Nature Reserve, which has practically been transformed into a military training area, is particularly revealing. During Russian military drills, bombing, military equipment movements, the detonation of sonic bombs in the water, and troop landings have all affected local coastal, steppe, and estuary environments (UWEC Work Group, 2023).

Types of Military Activities

The Russia-Ukraine conflict, which erupted in 2014, has resulted in at least two gray zones: the Black Sea and Eastern Ukraine. The gray zone in the Black Sea included the coastal seas of illegally occupied Crimea and its respective exclusive economic zone (EEZ) (Kormych and Malyarenko, 2022). Initially, the term 'gray zone' was

applied to a specific kind of maritime conflicts; specifically, methods originating from territorial disputes in the Asia-Pacific area in the late 2000s under challenge from coastal States (Holmes and Yoshihara, 2017). Various forms of military activities have been observed in the Ukraine-Russia war, reflecting the conflict's multifaceted nature. Military equipment movements and fortress construction not only cause physical destruction of soil and plants, but they can also endanger coastal marine habitats. Biotopes in the swash and surf zones, which include unique biodiversity among the sand and shells, may also be harmed as a result of coastal minelaying, explosions, and sand mining from beaches for use in fortifications. Conventional warfare is a common sort of military activity that involves the use of conventional weaponry such as tanks, artillery, and infantry in direct combat operations. Several attacks by Ukrainian armed TB2 drones caused damage, but many of these valued weapons were also shot down. The Russian forces on the islet, which are well armed, are becoming capable of repelling attacks. Battles over control of significant areas, cities, and strategic places are included. Another important factor is asymmetric warfare, in which pro-Russian separatist groups, backed by Russia, have used guerrilla tactics such as ambushes, hit-and-run attacks, and insurgency operations. Aerial operations have also played an important role, with both sides carrying out airstrikes, deploying combat helicopters, and engaging in air-to-air combat. The planned introduction of offensive systems such as long-range artillery and S-400 air defence units would allow Russia to dominate the airspace over Ukraine's south as well as the Black Sea's northwestern region.

Scale and Intensity of Operations

The scale and intensity of military actions in the Ukraine-Russia war have been enormous, with far-reaching regional implications. Ukraine and Russia have both deployed major military assets, including as troops, armored vehicles, artillery, and aircraft, demonstrating the gravity of the confrontation. These operations have spanned multiple fronts, particularly in eastern Ukraine, where fierce clashes for crucial territory have raged. The presence of international entities adds to the scope of the conflict, with Western countries supporting Ukraine and Russia supporting separatist troops. The deployment of heavy armament, such as missiles, bombs, and rockets, reflects the intensity of military operations, resulting in widespread destruction, casualties, and civilian displacement. The conflict has also seen significant urban combat, with cities and towns turning into battlegrounds, resulting in massive collateral damage. The magnitude and intensity of military operations in the Ukraine-Russia conflict emphasize the gravity of the situation and the critical necessity for diplomatic measures to bring about a peaceful end and alleviate the humanitarian disaster. Although current military technology allows for the precise destruction of targeted items, environmental damage to industrial targets is not usually local, and many of the attacks have been widespread rather than precise. In highly industrialized Ukraine (Lishchynskyy, 2016) concentrating on urban and industrial infrastructure there are unavoidably wide-ranging and severe environmental implications (Shumilova *et al.*, 2016)

Port infrastructures along the Black Sea and Azov Sea coasts at Mykolayiv, Odessa, and Mariupol were brutally bombed. Other implications on water resources, such as the damage to regional biodiversity, can only be estimated at this time. It has been stated that 14 Ramsar wetland habitats encompassing 400,000 hectares along the

Dnieper River's lower reaches are under threat (Cundy, 2022). . Catchments traverse political boundaries, and toxins released into the environment as a result of violent wars can spread beyond borders. Ninety-eight percent of Ukrainian river catchment area flows to the Black Sea and Azov Sea, with the remaining 2% flowing to the Baltic Sea. Fire also affected the territories of many protected sites. Since the beginning of 2022, the total surface area of fires in Ukrainian forests has climbed a hundredfold (compared to the same period the previous year). Many reserves in Mykolaiv and Kherson regions have been impacted by these fires, including Biloberezhya Svyatoslava National Nature Park, Kinburn Split Regional Park, Black Sea Biosphere Reserve, and Lower Dnipro National Nature Park. Kinburn Spit Park, located on the Black Sea coast and home to rare coastal habitats, burned down in May 2022 (UNEC Work Group, 2023b).

Environmental Impact and Violations of International Laws

The prolonged conflict between Ukraine and Russia has wreaked havoc on the ecology in the impacted areas. The destruction of essential infrastructure, such as power plants and factories, has resulted in the discharge of toxic substances and pollutants into the environment, endangering ecosystems and endangering human health. The current Russia-Ukraine conflict is Europe's most visible conflict since World War II, with geopolitical, economic, infrastructure, and health repercussions (Rawtani *et al.*, 2022). Water resources, such as rivers and groundwater, have been contaminated as a result of damage to water treatment facilities and industrial sites (WWF, 2023). Furthermore, the violence has resulted in the destruction and fragmentation of natural areas, negatively harming biodiversity and ecosystems. The displacements of communities, as well as the existence of landmines and explosive munitions, increase the region's environmental difficulties. Environmental assessments and mitigation efforts have been hampered by ongoing hostilities and limited access to affected areas.

Hostilities have an impact on underwater marine environments as well. Sunken ships and missiles, anchor usage, and ammunition blasts can all harm underwater habitat. Because benthic sea grass or algal populations have the highest biological variety, damage to them may be a deciding factor for the entire ecosystem. While the remnants of wrecked ships can be used to build new habitats on artificial "reefs" colonized by aquatic creatures, the damage caused by long-term pollution outweighs any possible benefits (UWEC Work Group, 2023b)

The current Russia-Ukraine conflict has had serious political, economic, and environmental consequences. As previously stated, the destruction of critical infrastructure, such as power plants and factories resulting in the discharge of toxic substances and pollutants into the environment, and also endangering of ecosystems and endangering of human health clearly contradicts the ideals outlined in the Stockholm Declaration of 1972¹ and the World Charter for Nature². Although war is not specifically mentioned in the Stockholm Declaration of the United Nations Conference on the Human Environment from 1972, it does have consequences for

¹ <https://wedocs.unep.org/bitstream/handle/20.500.11822/29567/ELGP1StockD.pdf>

² <https://digitallibrary.un.org/record/39295?ln=en>

how the environment is protected during hostilities. Reiterating a fundamental rule of international law, Principle 21³ demands that countries refrain from endangering the environments of other countries. This rule applies in both peace and war.

States are required by Principle 7⁴ to take all reasonable measures to prevent marine pollution from pollutants that endanger human health, living resources, marine life, and other legal uses of the sea. This Principle emphasizes a dedication to safeguard the marine environment in both peace and conflict. In addition, Principle 22⁵ requires nations to create cooperative procedures to compensate those harmed by activities within one state that have an impact on places outside of it. This includes harm to the ocean ecosystem brought on by armed warfare. Principle 24⁶ promotes international collaboration to prevent, reduce, and eliminate negative environmental effects caused by international circumstances, especially those brought on by armed conflict. The protection of the environment, including the marine environment, from the effects of weapons of mass destruction, including nuclear weapons, is a last tenet of Principle 26⁷.

The Stockholm Declaration offers a strong framework of Principles that may direct States in conserving the marine environment throughout both peace and conflict, although without expressly mentioning fighting. The Russia-Ukraine conflict, with its vast environmental destruction and degradation, exemplifies the critical necessity for international collaboration and commitment to the ideals outlined in global environmental treaties. The long-term ecological consequences of battle, particularly in biologically diverse and sensitive regions like as Ukraine and Russia, highlight the necessity of global mechanisms such as the Stockholm Declaration and the World Charter for Nature.

The Ukraine-Russia conflict also serves as a reminder that the Principles enshrined in the Hague Conventions⁸, though over a century old, still bear relevance today. Their spirit, rooted in harm minimization, transcends direct human impacts. During the Russia-Ukraine conflict, Russian anti-ship missiles twice targeted an abandoned cargo tanker in the northern Black Sea, which had around 600 tons of diesel gasoline. The tanker, which was carrying thousands of barrels of fuel, was dubbed a "environmental time bomb" by Interfax-Ukraine News, stressing the possibility of oil spills during the fight (Lieber Institute, 2022). The Hague Conventions of 1899 and 1907 are regarded as seminal works of international law, laying the groundwork for the conduct of combat. While these accords did not specifically address maritime environmental protection, the spirit of their principles reflects a broader commitment: limiting harm during conflicts. Recent events in the Ukraine-Russia conflict highlight the importance of revisiting these concepts in light of marine environmental concerns. Article 22⁹ of the Regulations Annexed to the Hague Convention of 1907 states "belligerents' ability to use weapons against their adversaries is limited.

³ <https://legal.un.org/avl/ha/dunche/dunche.html>

⁴ <https://legal.un.org/avl/ha/dunche/dunche.html>

⁵ <https://legal.un.org/avl/ha/dunche/dunche.html>

⁶ <https://legal.un.org/avl/ha/dunche/dunche.html>

⁷ <https://legal.un.org/avl/ha/dunche/dunche.html>

⁸ <https://guide-humanitarian-law.org/content/article/3/the-hague-conventions-of-1899-and-1907/>

⁹ <https://www.britannica.com/topic/law-of-war/Limits-on-the-methods-and-means-of-war>

The Convention's guiding principle of minimizing unnecessary suffering and destruction is supported by the long-term impacts of oil spills on marine biodiversity and the deterioration of water quality. Despite the agreements' main emphasis on human suffering, one may argue that severe ecological harm indirectly impacts human groups that depend on natural ecosystems. Article 23(g) of the 1907 Hague Convention IV embodies the idea of military necessity (Bouvier, 1992) by stating that one should not damage or capture the enemy's assets unless absolutely necessary for war reasons. This provision has significant environmental consequences because "enemy assets" can include protected areas, environmental and natural resources, providing them with implicit protection.

Oil spills in the Black Sea as a result of the Russia-Ukraine conflict may violate UNCLOS's¹⁰ protective principles, indicating a breach of international duties toward marine conservation. The United Nations Convention on the Law of the Sea (UNCLOS) is a key global convention that addresses marine pollution. Section XII, in particular, emphasizes "Protection and Preservation of the Marine Environment," with Article 194 requiring governments to prevent and decrease marine pollution and to coordinate their efforts in this regard. Dolphins were one of the Black Sea biota dwellers affected by its impact (Renolafitri and Yolandika, 2022). The Turkish Marine Research Foundation stated in February 2022 that the figure of 80 dolphin deaths was based on reports of complaints for mammals stuck on the beach since late February (Istanbul, 2022). According to local media, the majority of dolphins were discovered dead, leading Turkish Marine Research Foundation specialists to infer that dolphin deaths were caused by disrupted echolocation caused by polluted environments (Renolafitri and Yolandika, 2022). According to sources, almost 3,000 dolphins were discovered dead with marks from water mines or bombs (Andreikovets, 2022).

This terrible occurrence is linked to violations of the principles outlined in the Convention on Biological Diversity¹¹ (CBD). The CBD, which was established at the Earth Summit in 1992 and is supported by 157 countries, serves as a bulwark against actions that cause severe biodiversity loss, especially those arising from warfare. The agreement emphasizes the need of protecting our planet's rich biological fabric and encouraging international cooperation in utilizing these resources for humanity's benefit while ensuring their preservation. In a preface to a book (Holdgate and Giovannini, 1994) co-published by the International Union for Conservation of Nature (IUCN) and the International Academy of the Environment in Geneva, the Biodiversity Convention is referred to as:

“[...] simply an enabling document and treaty. It sets out what governments have agreed on regarding mutual support to national efforts to conserve the wealth of the planet, and collaboration to enable biological resources to be developed and used to the maximum possible benefit of people (Holdgate and Giovannini, 1994). Notably, the CBD is more than just a symbol. It explicitly specifies specific responsibilities for states. Article 3 specifically states that governments are responsible for ensuring that their military activities, both within their boundaries and in regions under their control, do not cause environmental harm, either locally or internationally. The heinous episodes in

¹⁰ The United Nations Convention on the Law of the Sea,
https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

¹¹ <https://www.cbd.int/>

the Black Sea, as indicated by extensive dolphin deaths attributed to conflict-related activity, might be considered as a substantial violation of the CBD's ethos and instructions. The CBD's basic purpose — to prevent a significant reduction or loss of biodiversity — appears to have been undermined in this case, underscoring the importance of adhering to international conventions even during times of conflict.”

The Basel Convention¹², ratified by 116 UN member States in 1989, demonstrates the international community's commitment to regulating cross-border hazardous waste flows and ensuring environmentally safe disposal. Within its folds is defined the term "Environmentally Sound Management," which is defined in Article 2(8) as the comprehensive steps required guaranteeing hazardous wastes are managed in order to protect both human health and the environment. The Convention indirectly fortifies maritime environments against negligent waste disposal at sea by encouraging appropriate garbage movement. However, as the current conflict in Ukraine unfolds, evidence reveals possible violations of the same principles outlined in the Basel Convention. The violent conflicts have shattered vital infrastructure, with several Ukrainian communities experiencing disruptions in wastewater treatment, resulting in considerable water pollution. Untreated wastewater poured into the Kakhovka Reservoir due to the shutdown of the treatment facility near Zaporizhzhia runs counter to the Convention's objectives.

Multiple Ukrainian communities have been left without wastewater treatment as a result of the armed conflict, resulting in surface water pollution. Remote sensing pictures, for example, revealed that filthy wastewater was dumped into the Kakhovka Reservoir when the wastewater treatment plant near Zaporizhzhia discontinued operations (Shevchuk, Vyshnevskiy and Bilous, 2022). The United Nations estimated that by 20 April 2022, 6 million people in Ukraine were battling every day to get access to drinking water, with 1.4 million people reported to lack access to safe water in the country's east and another 4.6 million having only limited access (UNICEF, 2022). For the first time, traces of oil products were detected in the area of the surface drinking water intake in the basin of the Siverkyi Donets River in June-July 2022, along with elevated concentrations of mercury, ammonium nitrogen, nitrites, polyaromatic carbons, heavy metals, and the insecticide cypermethrin in some rivers within the basin (State Agency of Water Resources of Ukraine, 2022). The dumping of polluted wastewater into the Kakhovka Reservoir, as well as the alarming contamination of water sources with oil products and other hazardous pollutants, not only endangers human health and livelihood, but can also be viewed as a violation of the Basel Convention's principles. Despite the fact that the Convention focuses primarily on waste transboundary mobility, the spirit of the document stresses the protection of the environment and human health from the hazards of hazardous waste. The enormous environmental deterioration in Ukraine during the armed conflict emphasizes the importance of adhering to and executing international environmental standards and conventions, particularly the Basel Convention, even during wartime. Ninety-eight percent of Ukrainian river catchment area flows to the Black Sea and Azov Sea, with the remaining 2% flowing to the Baltic Sea. Despite the fact that the international community has clearly acknowledged the risk of environmental

¹² <https://www.basel.int/>

degradation in the Donbass region of eastern Ukraine since 2014 (Hook and Marcantonio, 2022), the seaports of Ochakiv and Mykolaiv were frequently attacked. The Dniester Estuary Bridge was shelled five times and entirely destroyed, and intense fights were conducted on the land of the Azovstal facility in Mariupol, which is located immediately on the Azov coastline (UWEC Work Group, 2023a). Nobody knows how many mines were dropped, broken off, or carried into the Black Sea as a result of the battle. The extent of the damage to the marine ecosystem and species caused by the detonation of mines discovered in Turkey and Romania remains unknown.

Razom, a non-profit Ukrainian-American human rights group that works to help Ukraine and raises the voices of Ukrainians, says, "The destruction of vital infrastructure along the Azov-Black Sea coast, such as oil depots and sewage treatment plants, can have devastating consequences, including oil spills and the release of toxic waste into the sea," explaining that this endangers marine life and the protected species that live there (Fowler, 2023). Water infrastructures, such as sewage treatment plants, as well as some facilities storing hazardous items such as solvents, ammonia, and plastics, have been severely damaged, according to the UN Environment Programme (UNEP) (Fowler, 2023). According to the Razom research, ammonia concentrations in Lviv water samples were 165 times higher and nitrate concentrations were 50 times higher than the permitted levels (Rawtani *et al.*, 2022). Agriculture production has been significantly curtailed as a result of the armed conflict, resulting in worldwide food shortages, with the Middle East and Africa bearing the brunt of the burden (Rawtani *et al.*, 2022) the water ways suffered a lot of environmental cost of war."

The battle and occupation have caused or worsened damage and disruption to a variety of coastal and marine habitats, many of which are fragile or extremely vulnerable making the rare species endangered of being extinct. At least 14 Ramsar sites, which are valuable wetland habitats recognized under the Ramsar Convention on Wetlands, are under threat of destruction. The vast shallow marine lagoons and the largest island in the Black Sea in Karkinitzka and Dzharlygatska bays, the Dniro river delta, a haven for nature in a region known for its vast agricultural fields, and the bogs, meanders, and natural meadows of the Desna river floodplains in the Sumy region are among them.(Cundy, 2022). Wetlands and biosphere reserves in the Sea of Azov, Danube Delta, and Gulf of Odessa have the most vulnerable biodiversity. Water pollution and biodiversity loss have an influence on coastal and marine protected areas. For example, various coastline protected areas in the Azov Sea, Odessa, and the Danube Delta, which are vital habitats for migrating birds, are on the verge of being directly or indirectly impacted by this dispute (Pereira *et al.*, 2022). The Cultural and Natural Heritage Convention¹³ states in Article 6 (3) that "Each member state of this Convention is committed to refraining from any intentional actions that could directly or indirectly harm the cultural and natural heritage, as outlined in Articles 1 and 2, located within the territory of other Convention member states." Therefore, any destruction of cultural or natural heritage during a war should be seen as a violation of this requirement. The Convention doesn't directly address marine ecosystems, but because they are a component of natural heritage, its principles can be applied to them. The primary goal of the Convention for the Protection of the World Cultural and

¹³ <https://whc.unesco.org/en/convention/>

Natural Heritage is to safeguard important natural and cultural resources around the world. It places a duty on signatories to protect the natural and cultural assets found in other signatory states.

Conclusion

This review article on the effects of the armed conflict on Ukraine's water infrastructure and marine ecosystem reveals a range of long-term ramifications not only for local populations and ecosystems, but also for progress towards the global Sustainable Development Goals. The maritime environment must be safeguarded to mitigate the long-term ecological and human repercussions of war and conflict. It is recommended that national governments and nations worldwide collaborate in order to create "marine safe zones," which forbid military operations that would damage marine life or destabilize delicate aquatic balances, which are comparable to no-fly zones. Additionally, there should be improved monitoring systems that make use of satellite and maritime sensors to swiftly detect and tackle any environmental degradation. Finally, promoting discourse on the environmental effects of military operations can help decision-makers make more informed choices, ensuring that geopolitical goals do not take precedence over the shared responsibility of protecting our planet's marine resources.

In conclusion, this study emphasizes the important environmental consequences of war actions on maritime ecosystems, especially in the Black Sea as demonstrated by the Ukraine-Russia conflict. The study emphasizes the importance of conducting mitigation and restoration activities, enhancing international legal frameworks, and encouraging joint initiatives to protect marine biodiversity during and after armed conflicts.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3	Author 4
Conceived and designed the research or analysis	Yes	Yes	Yes	No
Collected the data	Yes	Yes	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes	Yes
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The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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Crop Intensification through Short Duration Stress-Tolerant Rice Varieties with Green Gram for Fostering Agricultural Resilience and Sustainability

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Abstract

Rice stands as a critical cornerstone in the pursuit of food security due to its unparalleled significance as a staple crop for billions of people worldwide. Rice in India, is cultivated within diverse cropping systems that harness the nation's rich agro-climatic variations. Eastern India has emerged as a significant contributor to the country's overall rice production. Nevertheless, most of the existing cropping systems of rice in this region suffer from some drawbacks, primarily due to monoculture practices and limited crop diversity. An experiment was conducted in the Eastern Indian State of Odisha to evaluate the efficiency and profitability of promoting a rice-green gram-rice cropping system. The experiment consists of two major interrelated interventions viz., awareness regarding short-duration stress-tolerant rice varieties (STRV) and the introduction of the new crop for higher economic returns. Varietal awareness programs were organized before the onset of the wet season of 2020 and the potential benefits of cultivating STRV over the popular traditional cultivars were communicated to the target farmers, besides advocating the rice-green gram-rice cropping system. The study employed a field experiment design to compare the performance of existing and new cropping systems. The impact evaluation was carried out after recording the comments of the farmers followed by a thorough comparison between the new and existing cropping systems. The available evidence suggests that the introduced short-duration STRVs are better than the already existing varieties and have the potential to change the cropping system of the region. The most desirable trait of these varieties as reported by the farmers is their short maturity duration. The results do unequivocally demonstrate the superior performance of the new cropping system over the existing system in terms of crop yield, diversification, and profitability. This remarkably underscores the potential of the new system to address food security challenges and enhance agricultural productivity.

Keywords

STRV; Green gram; Cropping system; Eastern India; High profitability

Introduction

In the present era of climate change, the issue of food security has emerged as a paramount concern for governments, organizations, and individuals alike. With a global population projected to exceed 10 billion by 2050, ensuring a stable and adequate food supply has become critical (Kumar *et al.*, 2022). Rice stands as a critical cornerstone in the pursuit of food security due to its unparalleled significance as a staple crop for billions of people worldwide. Rice, often referred to as the "staple of staples", plays a central role in the diets of a significant portion of the global population, particularly in Asia and Africa (Dar *et al.*, 2017). In India, rice occupies a position of paramount importance, where it transcends its role as a staple food to become an intrinsic part of the nation's agricultural, cultural, and nutritional fabric. Rice in India is cultivated within diverse cropping systems that harness the nation's rich agro-climatic variations. The predominant cropping systems involving the rice-wheat rotation in the Indo-Gangetic Plains to the rice-pulses sequence enrich soil and diets (Bhatt *et al.*, 2021). The diversification emerges through systems like rice-oilseed, rice-sugarcane, and rice-horticulture, which bolster yields and rural economies. These systems underscore India's agricultural resilience and adaptability, addressing food security and sustainability in the face of changing climate and consumption patterns (Upadhaya *et al.*, 2022).

Eastern Indian states such as West Bengal, Odisha, Bihar, and Jharkhand are significant contributors to India's overall rice production. In these states, the practice of rotating rice with other crops stands as a cornerstone of sustainable agricultural strategies. This region's agricultural landscape is enriched by the harmonious alternation of rice cultivation with diverse crops such as pulses, maize, oilseeds, and vegetables (Alam *et al.*, 2021). This rotational approach not only optimizes land utilization but also rejuvenates soil fertility, curbs pest/ disease pressures, and enhances overall farm productivity. The rotation of rice with pulses, for instance, exploits nitrogen fixation, enriching the soil for subsequent rice crops while providing protein-rich pulses for diets (Chamkhi *et al.*, 2022). Similarly, the rice-maize rotation diversifies cereal production, contributing to the food security (Upadhaya *et al.*, 2022). This dynamic interplay between crops attests to the ingenuity in ensuring a resilient and resource-efficient agricultural system, embodying the essence of sustainable and diversified farming.

Nevertheless, most of the existing crop rotations of rice in Eastern India suffer from some drawbacks, primarily due to monoculture practices, e.g., low varietal options of fitting duration, poor knowledge about varieties and seeds, and limited crop diversity. Continuous cultivation of rice and related crops depletes soil nutrients, leading to degradation and reduced fertility (John and Babu, 2021). This, coupled with the absence of diverse crops, exacerbates pests and disease pressures, necessitating higher pesticide use. The lack of rotation with nutrient-fixing crops disrupts the soil's nutrient balance, hindering optimal plant growth (Selim, 2020). Additionally, the reliance on a single crop undermines biodiversity, threatens farmers' income stability, and leaves the agricultural ecosystem less resilient to climate change impacts (Gomiero, 2016). The pressing need is to transition the more diversified and intensified cropping systems to ensure long-term agricultural viability and overall agricultural sustainability. By implementing innovative rotations, farmers can bolster their income

streams, foster biodiversity, and create a more adaptable and robust agricultural system, capable of meeting future challenges, and ensuring sustainable food production for oncoming generations (Dar *et al.*, 2021).

Among the various crop rotation systems, the integration of rice (*Oryza sativa*) and green gram (*Arachis hypogaea*) has garnered substantial attention due to its synergistic benefits and potential to address multiple agricultural challenges (He *et al.*, 2021). The current cropping pattern is mostly rice-rice. The experiment introduced a new crop — green gram. In this context, an evaluative experiment was conducted in the Eastern Indian state of Odisha to understand the efficiency and profitability of promoting a rice - green gram - rice cropping system. The combination of these two staple crops offers a unique opportunity to optimize soil nutrient dynamics, pest/disease management, water use efficiency, and economic viability (Dhanda *et al.*, 2022). Besides, the benefits of introducing the short-duration stress-tolerant rice varieties (STRV) in the cropping system were also investigated. The yields obtained from the newly introduced rice - green gram - rice system were studied in comparison to the existing cropping systems. The impacts of the new cropping system in terms of yields and income for farmers were also duly appraised. Embracing the new types of cropping systems holds the promise of revitalizing the agricultural landscape, promoting ecological balance, and securing a prosperous and sustainable future for both farmers and the region as a whole (Bhatt *et al.*, 2021).

Materials and Methods

Study Design and Site Selection

This research employed a field experiment design to compare the performance of existing and new cropping systems. The study was carried out in 2020-21 and 2021-22 among the 120 randomly selected farmers from 5 villages belonging to two development blocks, one each from Mayurbhanj and Bolangir districts. Shyamakuntha block from Mayurbhanj and Loisinga block from Bolangir district were selected for this experiment where mostly rice as a solo crop is cultivated. The cultivation of the non-paddy second crop is constrained by the unavailability of suitable non-paddy crops and little scope to utilize residual soil moisture after growing a long-duration rice variety. The selected farmers usually cultivated rice during the wet season, followed by maize during the dry season.

The study area encompassed diverse agroecological zones to ensure comprehensive representation. Site selection was based on a combination of factors, including soil type, climatic conditions, and historical crop rotation practices. One bigha (1333 square meter) area of land was selected from each of the farmers, selecting a total of 20 bighas as the experimental plot for intervention. Before the onset of wet season in 2020, the farmers were informed and supported for the adoption of a rice - green gram - rice cropping system and likewise, only those farmers who adopted this cropping system were selected for the present study. The introduction of short-duration and high-yielding rice (Binadhan 11) and green gram (Virat) variety was a key factor in convincing farmers to a third crop in between the wet and dry seasons. Currently, farmers were growing long-duration rice varieties in the wet season and, thus, a little time window was left for taking another crop before the dry season. Both male and

female farmers were randomly selected, and the benefits of cultivating short-duration STRV were discussed. The immediate outcomes of this initiative were measured through the following three positive changes.

1. Adoption of short-duration rice varieties and a second crop (green gram)
2. Economic benefits of the crop intensification
3. Crop diversification

Data Collection and Variables

Comprehensive data was collected to evaluate various aspects of the pre- and post-intervention cropping system. The farmers were interviewed after the harvesting of summer rice in 2021. The farmers were asked about the STRV (Binadhan 11) being cultivated during wet season of 2020. Besides, the information regarding the date of sowing, date of harvesting, the yield obtained, produce sold, produce kept for home consumption, the price fetched for the sold produce, cost of production, and labour involved for the cultivation of second/boro crop (green gram) during 2021-22 was also obtained. Similarly, the farmers were asked about the second/boro crop they cultivated during the last year (2020-21). The comparison was made for the date of sowing, the yield obtained, the cost of production, income generated.

The comparison of two seasons for two different cropping patterns is indicative of the program's impact. The comparison included varieties grown, date of sowing, date of harvesting, the yield obtained, produce sold, produce stocked for selling, and the price fetched for selling the produce. The farmers also responded that the fitment of the new cropping system was better and economically viable than the existing ones. The information related to sharing of knowledge regarding the new cropping system amongst the other farmers has also been evaluated. The respondents also expressed their views about the short-duration STRV has the potential to change the cropping systems of the region. Moreover, information on whether the farmers have saved the seeds of new STRVs from wet 2020 for sowing in the next wet season was also obtained. Besides, the intention of the farmers to cultivate the STRV in subsequent seasons also recorded.

Results and Discussion

In the pursuit of a sustainable and resilient agricultural future, the introduction of innovative cropping systems emerges as a pivotal strategy (Shah *et al.*, 2021). The challenges posed by population growth, climate change, and diminishing natural resources necessitate a departure from traditional cropping systems and varieties (Majid *et al.*, 2016; Dar *et al.*, 2018; Morel *et al.*, 2020). Therefore, comparison between different cropping systems is vital to ensure evidence-based decisions, enabling us to identify superior practices that enhance productivity, sustainability, and resource management in agriculture (Zaidi *et al.*, 2018; Jehangir *et al.*, 2022). The targeted results against the evinced outcomes are discussed below.

The Ecology Suitable Landraces in the Region

Odisha is home to several traditional rice varieties. These varieties are known for their special characteristics and are grown by farmers despite the availability and promotion

of modern varieties. In several of those varieties, special market-demanded traits like aroma, short-grain dimension, and suitability for special delicacies are found. In some of those varieties, climate resilience can be observed to a considerable extent. The older varieties like Lalat, Swarna etc are also known for having a low Glycemic Index (GI), suitable for people with elevated sugar levels. However, in the absence of a proper extension mechanism, weak seed system, and poor market facilities, farmers are increasingly cultivating modern varieties. Department of Agriculture, Govt of Odisha has collected and conserved ex-situ about 750 germplasm belonging to different districts of Odisha. Kalachampa, a photosensitive tall variety suitable for the coastal ecology, was one of the landraces purified and released by the Directorate of Agriculture and notified by the Govt of India for cultivation by farmers based on its performance. It is the only traditional variety currently in the seed chain. Three aromatic varieties released in the state (Nua Kalajeera, Nua Chinikamini, and Nua Dhusra) can be promoted appropriately through assured access to the markets. The traditional varieties being grown are tabulated below (Table 1).

Table 1: Major traditional varieties in Odisha

<i>Major traditional Varieties/Landraces</i>	<i>Major growing districts</i>	<i>Maturity Duration (Days)</i>
Kalashree	Jajpur, Khurda	145
Kalabati	Jagatsinghpur, Kalahandi	150
Kala Tulasi	Nayagarh	145
Kalajeera	Khurda, Bolangir, Kalahandi	150
Kalamanik	Puri	150
Pipiribasa	Mayurbhanj	140
Jabaphool	Bolangir, Kalahandi	140
Dubraj	Bolangir, Kalahandi, Nuapada	135

Adoption of Short-Duration Rice Varieties

The predominant rice variety before the intervention was Swarna (MTU 7029). This is a long-duration (140 days) genotype, generally sown in the second fortnight of July and harvested towards the end of November. Since the maturity of this variety takes a longer period, farmers are not left with any feasible options to grow a second crop (non-paddy) of a fitting duration. However, the introduction of Binadhan 11 (a shorter duration, high-yielding variety) received legitimate varietal substitution. Binadhan 11 is also a stress-tolerant variety (STRV) variety. It possesses *sub-1* gene that makes it tolerate submergence upto 14 days. Thus, this variety brings in benefits in the areas recurrently impacted by floods. The experimental location has a considerable area, suffering the setback of flash floods during monsoon months periodically, especially in low-lying areas adjacent to the water stream. Binadhan 11 matures in 120 days, while Swarna the dominant variety in the region takes 140 days to become harvest-ready (Figure 2). The advantage of the 20-day early maturity with Binadhan 11 is a substantial factor for taking a second crop. However, this trait will be visible to the growers only when the field is inundated caused by flood or submergence. Before the intervention, farmers in the area did not know this variety. Within a year, 81% of

farmers who received the seeds (in mini kit) adopted the variety the following year, indicating a high acceptance and adoption of this variety. Yield-wise, this new variety (Binadhan 11) proved to be superior as it offered 0.3 tons/ha more yield compared to the popular variety Swarna. The yield gain of the new variety (Binadhan 11) is graphed below.

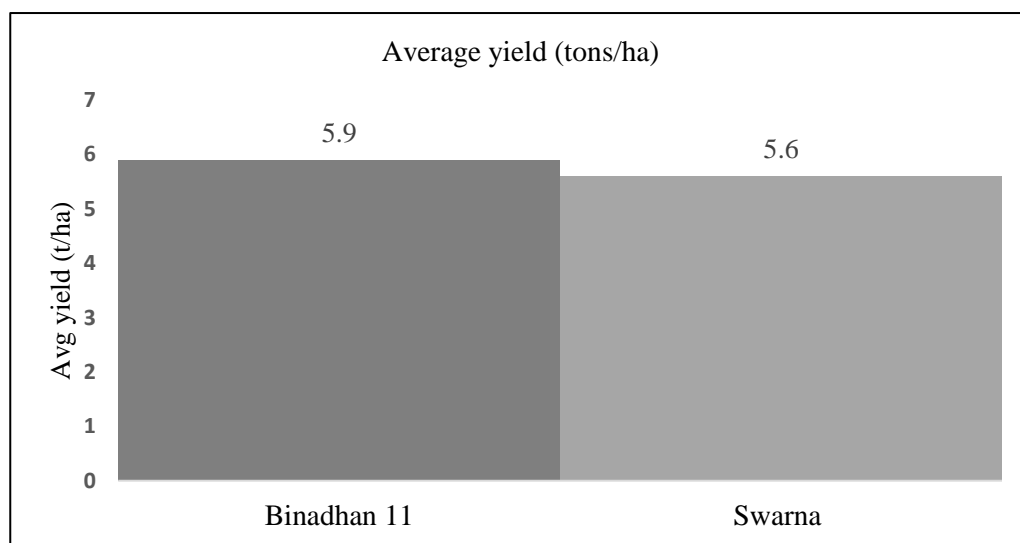


Figure 1: Average yield of new and predominant varieties

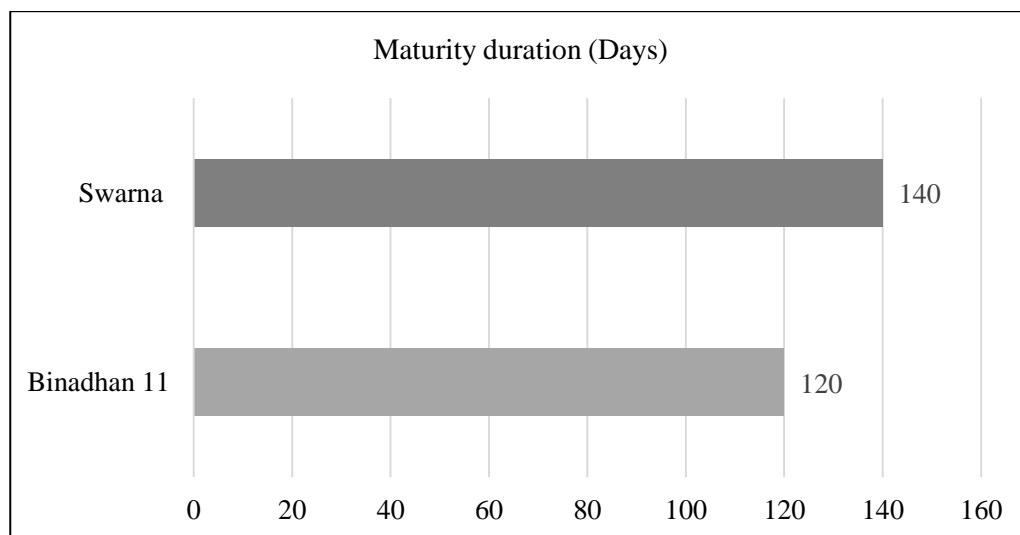


Figure 2: Maturity duration of the demonstrated variety vis-a-vis the dominant variety.

Adoption Drivers

It has been observed that, in the 2021 wet season, 81% of participating farmers who used to grow Swarna have adopted the Binadhan 11. The major variety-substitution drivers as found from the study were: 1. Yield gain, 2. Shorter duration, and 3. Special trait of submergence tolerance of Binadhan 11.

Unlike Swarna, the new variety (Binadhan 11), because of its shorter duration, enables farmers to harvest the crop at least 20 days earlier. This early maturity leaves the soils with considerable residual moisture for a second crop like green gram. This benefit is more pronounced as the study area does not have an assured irrigation source in the dry season. The additional but critical trait present in Binadhan 11 is the flood-tolerance ability without any yield penalty. It can sustain the water submergence for up to 14 days — a huge benefit for farmers in flood-prone areas. Out of 120 farmers who evaluated the variety in their field, 97 of them have grown it in the next crop years (2021-22), translating to an impressive adoption rate of 81%. Among those who have adopted Binadhan 11 cited advantages of the variety. Whereas 84% of farmers believed that yield gain was the first reason that influenced them to adopt, 72% also think the shorter duration of the variety acted as the second most important (Figure 3). Submergence tolerance trait has been rated as the third most important character of the variety for adoption..

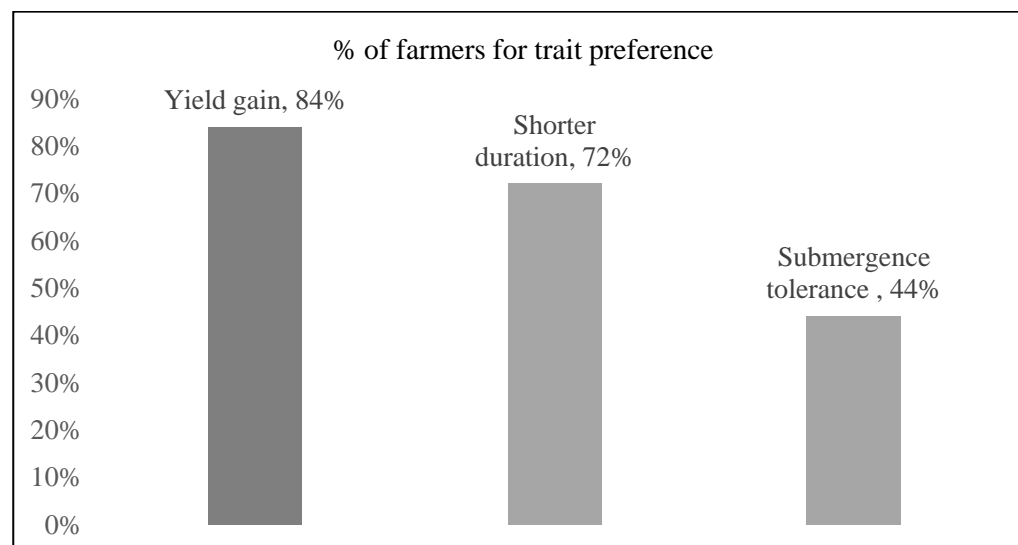


Figure 3: Adoption drivers of Binadhan 11

Table 2: Adoption drivers of Binadhan 11

<i>Key Traits of Biandhan 11</i>	<i>No of the farmers responded "Yes"</i>	<i>No of the farmers responded "No"</i>
Yield gain	101	19
Shorter Duration	86	34
Submergence tolerance	52	68

Second Crop (Green Gram)

Of those, who had cultivated Binadhan 11, got a time window towards the end of October to grow a second suitable crop — green gram. It has been observed that 64% of the Binadhan 11 adopters (62) have taken the green gram. While growing the Swarna rice variety, none of these farmers had the time opportunity for taking this second crop. Thus, it is a significant way forward to promote such shorter-duration

varieties for crop diversification which is high on the agriculture agenda of state governments in India.

Economic Benefits of the Crop Intensification

The results of the study unequivocally demonstrate the superior performance of the new cropping system over the existing system in terms of crop yield and profitability (Table 2). The economic gains resulting from the introduction of the new cropping system are meaningful. The increased productivity drives higher yields and subsequently larger harvests. Farmers, on average earned INR 46742 (USD 572) from one ha of land with the conventional cropping pattern (Rice-Rice). However, the adoption of the demonstrated new cropping pattern (Rice-Green Gram-Rice) enabled farmers to receive per hectare net earnings of INR 64511 (USD 777) (Figure 4). This extra income is earned from higher rice yield and the new crop (green gram). Per hectare monetary gain of INR 17,769 (equivalent to USD 213) from the demonstrated new cropping pattern can help farmers maximize their profits. This encourages long-term investment and planning, further enhancing economic resilience. The growth of agribusinesses and ancillary industries, driven by the increased demand for processing, packaging, and distribution, generates additional employment and entrepreneurial avenues, magnifying the economic impact. Therefore, the introduction of the new cropping system (rice-pulse) not only enhances agricultural productivity but also stimulates economic growth, fosters rural development, and contributes to a more robust and sustainable economy. In this context, embracing new cropping systems is not merely a choice, but an imperative. It is a conscientious investment in the well-being of present and future generations, a commitment to nourishing the planet while safeguarding its ecosystems (Meng *et al.*, 2017). The importance of this transition cannot be overstated — it is a transformative journey that aligns agriculture with the imperatives of sustainability, resilience, and prosperity.

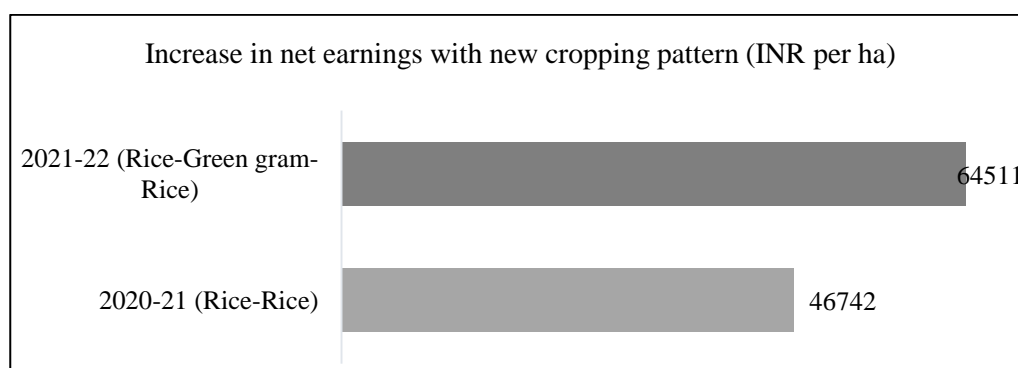


Figure 4: Increase in net earnings with new cropping pattern (per ha)

The experimented and adopted cropping pattern is rice - green gram - rice. The additional crop included in the pattern is green gram. This was possible majorly due to the shorter maturity rice crop in the wet season as it creates a reasonable time window for green gram. The measurable benefits are earnings from one additional crop and yield advantages from new variety (Binadhan 11).

Crop Diversification

The experiment has also produced a desired effect on crop diversification. The incorporation of short-duration stress-tolerant rice varieties into crop rotation offers a range of benefits, including enhanced land utilization efficiency, reduced vulnerability to adverse climatic conditions, improved soil health through diversified root structures, optimized nutrient and water use efficiency, and economic diversification. The cropping intensification as measured by cropping intensity $[(\text{Gross Cropped Area}/\text{Net Cropped Area}) \times 100]$ showed a significant improvement. The total net cropped area of the sampled farmers was 105.8 acres and the gross cropped area as estimated in 2021-22 is 174.57 acres. It explains that 68.77 acres which were otherwise to be fallow is being used for green gram cultivation. The cropping intensity, because of this experiment, has gone up from merely 100 to 165. This is the direct contribution of the experiment that introduced the short-duration rice variety followed by a fitting crop like green gram. The cultivation of green gram will also act as an atmospheric nitrogen fixer for subsequent crops, thus, environmentally it is good to increase crop diversification through pulse crops. Thus, the overall system productivity is supposed to rise with the continuation of this cropping pattern. It should also be noted that, because of a diversified cropping system with the introduction of green gram, farm production is relatively more stabilized. The positive impact on dietary patterns is also a significant impact as 47% of farmers have explicitly said that the daily intake of protein-based pulse (green gram) is enhanced by 25% because of increased availability.

Table 3: Key factors for crop diversification

#	Factor	No of respondents	%age
1	Shorter duration of rice	94	78
2	Shorter duration of green gram	98	81
3	Timely seed availability	106	88
4	Market opportunities	113	94

This study also attempted to identify the major factors that enabled farmers to adopt the diversified and intensified cropping pattern. As found, farmers are often challenged by knowledge gaps, poor irrigation facilities, and crop seeds to diversify the cropping pattern. Notably, 78% of farmers thought the shorter duration of Binadhan 11 was critical to plan and grow a second crop — green gram. Among those who adopted this diversified cropping pattern, 81% were of the view that the duration of green gram (65 days) also played a significant role in designing the rice-green gram-rice cropping pattern. The second crop duration of more than 70 days would not fit into the system, as the irrigation facilities are limited. The shorter duration green gram could be grown with residual moisture left in the preceding rice crop. When it comes to seeds, 88% of farmers believe the timely availability of seeds was crucial for adopting this cropping pattern. The lack of access to seeds on time deters farmers from fully utilizing this residual moisture and in the absence of secured irrigation, farmers do not take up the second crop after rice harvest in the wet season.

One of the other challenges, for crop diversification with the promotion of green gram is market constraints. The study revealed that 84% of farmers who adopted green gram

between two rice crops have a marketable surplus. However, 94% of those farmers believe the marketing scope is limited and they received lesser than expected prices.

Conclusions

The present study underscores the significant potential and multifaceted advantages of adjustment in the cropping pattern through the introduction of shorter-duration rice varieties and succeeding green gram cultivation. The findings presented the possibility of boosting agricultural productivity through crop diversification leading to resource efficiency, resilience, and sustainability. The adoption and practice of multi-cropping by exploiting available resources is a significant step towards intercropping capitalizes on the complementary traits of each crop, optimizing land utilization throughout the cropping season, mitigating the risks associated with climatic uncertainties, and promoting soil health through diversified root structures and nutrient utilization patterns. Furthermore, the economic diversification facilitated by this approach offers farmers increased income streams and a more stable livelihood. By advocating for the integration of short-duration stress-tolerant rice varieties into green gram-based cropping systems, this study advocates for a transformative shift towards agricultural practices that address food security, resource scarcity, and climate adaptation. As we navigate the complexities of modern agriculture, embracing such innovative intercropping strategies emerges as a sustainable pathway toward a more resilient and prosperous future for farmers and ecosystems alike.

There exists an opportunity to improve the productivity of the cropping pattern with the adoption of suitable traditional varieties/landraces. However, key determinants here are seed availability, productivity, and seed access by the farmers. The district and block-level agriculture officials believe that market development of these traditional is vital to promote the varieties for the economic benefit of the farmers. Furthermore, most of these landraces are of longer duration (>130 days), therefore the careful selection of the landraces is important if a new crop needs to be introduced between two seasons of rice. A high-yielding, shorter duration (within 120 days) and market-preferred grain-type rice variety (or landrace) will be a fitting option in such cases where the rice system productivity improvement is the major goal.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2
Conceived and designed the research or analysis	Yes	Yes
Collected the data	Yes	Yes
Contributed to data analysis & interpretation	Yes	Yes
Wrote the article/paper	Yes	Yes
Critical revision of the article/paper	No	Yes
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The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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Exploring the Legal Dimensions of Environmental Policy within the Framework of Ukraine's Sustainable Development Strategy

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Abstract

This article is devoted to the theoretical and practical analysis of the organizational and legal problems involved in the evolution and implementation of the environmental policy as integral part of the sustainable development strategy of Ukraine. This research is based on the international documents defining the goals of sustainable development and that are guidelines for harmonizing legal instruments in rationalizing natural resource use conforming the European Green laws. Based on the analysis of the current environmental legislation of Ukraine and its application, as well as inculcating the views of scientists, a conclusion is drawn about the need for prioritizing sectoral environmental reforms in the fields of biodiversity protection, curbing industrial pollution, waste management, emission monitoring and reporting, environmental control, and statutory responsibility. The grey areas of improving Ukraine's environmental policy ensuring effective, transparent and modern post-war reconstruction are identified as: strengthening control over compliance with standards and environmental regulations concerning natural resource management; improving the mechanism of payments for harming the environment; giving tax benefits and other financial incentives to environmentally innovative practices; encouraging the environmental audit and certification; pricing flexibly the ecological products; stimulating scientific temperament in solving environmental problems; and so on.

Keywords

Environmental policy; Sustainability; Management of natural resources; Environmental legislation

Introduction

The crux of the sustainable development lies in effectively addressing the intricate relationship between economic growth and environmental protection. In this context, the existence of human

existence transcends mere economic development; but also by maintaining the ability to control and protect the ecological environment. The contemporary phase of human progress is marked by rapid transformations across all facets of life, where interconnected changes dynamically evolve, mutually reinforcing one another, often with unpredictable consequences. Many of them are real threats to the further development of society. The rapid pace of world's economic growth and multiplication of production and consumption hinder the restoration of the natural environment; Consequently, visible indicators of an ecological crisis have emerged, encompassing issues such as climate change, the depletion of essential non-renewable resources, neglect of environmental safety protocols in economic endeavors, and transgressions of legal norms governing waste management, contributing to widespread environmental pollution. In turn, environmental challenges hinder global economic development and the normal life of society, leading to adverse effects on public health, increased expenditures on environmental protection, the exacerbation of the struggle for natural resources (in particular, in the form of armed conflicts and wars).

Sustainable development stands out a paramount focus in the contemporary world. The concept of sustainable development is now recognized by all countries of the United Nations as one of the priorities of humanity, the transition to which should take place at the national and global levels. The term "sustainable development" is increasingly used not only by the business community but also in official political and economic documents across various echelons. In recent decades, the international organizations have underscored the importance of achieving sustainable development. Achieving sustainable development is impossible without creating an effective decision-making system that incorporates the collective experience of social development rooted in pluralism and universal values. In line with the tenets of sustainable development, individuals emerge as active agents and prime drivers of progress. They play a direct role in shaping the contours of their lives, actively participating in decision-making processes, and overseeing the execution of those decisions.

The leading democracies of the world have chosen the path of sustainable development and successfully combined the pace of economic growth and a high standard of living with minimal environmental burden. This success is attributed primarily to a well-crafted environmental policy and proactive integration of ecological innovations into both production processes and social life. Ukraine, aligning its domestic and foreign policy, has committed to the principles of sustainable development. Within Ukraine, sustainable development holds a pivotal role in environmental policy, fostering the judicious use of natural resources, environmental protection, and the fulfillment of human needs. However, current challenges require constant attention to the interlinked issues of the economic, social and environmental development, necessitating their regulation through the lens of the concept of sustainable development (Chernik, 2019).

The primary goal of Ukraine's sustainable development is to ensure dynamic socio-economic growth while concurrently preserving the environment quality and prudently utilizing natural resources. This goal aims to meet the needs of both present and future generations through the establishing highly efficient economic system. Such a system would not only incentivize environmental sustainability, productive work, and scientific and technical progress but also exhibit a strong social orientation.

The foundational conditions of sustainable development include an economic framework rooted in a substantially modified market system, ecological sustainability based on the theory of biotic regulation of the environment, extensive international cooperation to realize sustainable development goals, and sustainable social development founded on the principle of justice. Additionally, fostering an environmentally consciousness public mindset is deemed crucial, achieved through the integration of environmental education within the education system and mass media platforms (Paton, 2016).

The recent alignment of Ukraine's environmental legislation with the regulatory framework of the European Union, prompted by the implementation of the Association Agreement, underscores the imperative for domestic laws to primarily address objective and priority requirements. This entails a comprehensive legal framework governing environmental relations, incorporating both public and private interests, and integrating the necessity for regulatory oversight in key industries. Such an approach aims to ensure the stability of societal functions and promote the sustainable development of Ukraine (Hetman and Anisimova, 2017).

In above contexts, purpose of this article aims to analyze the organizational and legal aspects of environmental policy within the framework of Ukraine's strategy for sustainable development. To fulfill this objective, the following key tasks are addressed:

- Characterizing contemporary scientific perspectives on the development and execution of environmental policy;
- Exploring the international legal facets of environmental protection in the countries of the European Union; outlining special foreign approaches to implementing environmental policies;
- Carrying out an analysis of the legal foundation of environmental policy as an integral part of Ukraine's sustainable development strategy; and
- Gauging the prospects for the implementing Ukraine's environmental policy amidst European integration processes.

These identified issues on a conceptual level deem to be pertinent, given the significance of harmonizing the interests of contemporary society with the imperative of maintaining a sound environmental state.

Evolution of Modern Scientific Thought on Environmental Policy Development

It is noteworthy to highlight the significant interest of scientists in the environmental policy issues. Over the past decade, global ecological and economic sciences have developed approaches involving information-ideological, administrative, and economic tools within environmental policy. Roberts (2010) in his study, "Environmental Policy", examines the opportunities and limitations of ecological systems and economic development. The study suggests that environmental policy serves as a potential avenue to modify the human systems to operate within environmental constraints. using essential socio-scientific concepts (political, social and economic), the work elucidates the prerequisites for the formation and implementation of environmental policy. The author further examines the development, implementation, and evaluation of environmental policy within three specific contexts: the corporation, the State, and the international level (Roberts, 2010).

Renowned British researchers E. Jordan and D. Liefferink in their publication "Environmental Policy in Europe" analyzed the evolving impact of the European Union development on politics and environmental policy within member countries, and potentially, a broader array of prospective members. This work also presents an original assessment of the extent to which Europeanization has given rise to greater convergence of environmental policy in Western Europe (Jordan and Liefferink, 2004). The study's proposal of the actual implementation mechanism of European integration, especially in the realm of environmental protection, holds particular relevance for this research. In another thorough study, "British Environmental Policy and Europe: Politics and Policy in Transition", F. Lowe and S. Ward analyzed the effectiveness of the response of environmental groups and organizations in Great Britain referring the challenges of European integration. This study explores the European orientation of British environmental policy and delves into the repercussions of "Brexit" on European environmental policy. It investigates environmental diplomacy, institutional dynamics, and policy debates concerning issues like pollution, land use, and transport (Lowe and Ward, 2005). This work contributes to the development of a more integrated European-oriented environmental policy in Ukraine, drawing insights from the experience of environmental policies in Great Britain and other European countries.

In "The Origins of Energy and Environmental Policy in Europe", Thomas Herber examines the evolution of European environmental consciousness in tandem with the successive steps of European integration in modern energy policy. The author highlights the pivotal role of the 1973 oil crisis in reshaping the integration trajectory of energy and environmental policies. Instead, environmental policy took shape through overarching measures such as energy conservation. The European Commission incorporated both energy and environmental policies into the EU political agenda, establishing an institutional framework for their development (Hoerber, 2012). In the comprehensive scientific work, "Theoretical and Empirical Analysis in Environmental Economics", diverse perspectives are explored to address current environmental challenges in developed countries, both theoretically and empirically. The book proposes effective new economic and environmental policies to tackle environmental issues, highlighting areas where traditional policies may fall short. The importance of this work lies in its in-depth analysis of key challenges faced by individuals and governments in developed countries during the transition from economic growth to the pursuit of life stability and environmental preservation amid societal development. Environmental issues addressed in this paper encompass the forest environment, air pollution reduction, adoption of renewable energy sources and fuel cell technology, agglomeration growth and urbanization, and the measurement of environmental sustainability (Nakayama and Miyata, 2019).

The 'Environmental Policy Paradox' offers an introduction to the process of environmental policymaking in the United States for air, water, land use, agriculture, energy, and waste disposal, introducing readers to global and international environmental issues. This article analyzes why some environmental ideas shape policy and others do not, explaining that even when the best short- and long-term solutions to environmental problems are identified, the task of executing these solutions often remains undone or is completed too late. Readers are offered a

comprehensive history of the environmental movement combined with a state-of-the-art account of current environmental policy (Smith, 2017).

In the work "Environmental Policy: Implementation and Enforcement", Hawke (2018) analyzes the intersection between the formation of environmental policy and its eventual implementation and enforcement through legal frameworks. Hawke (2018) further explores this subject with a focus on variables shaping the natural resource base and significance of law as a mechanism for executing environmental policy. Factors explored include changes in the form and natural resource base of EU and individual country laws, as well as a legal culture fostering a clear pattern of response to directives. It provides a nuanced exploration of the realities surrounding the implementation and enforcement of environmental principles, considering policy objectives and the constraints and expediency of law (Hawke, 2018). This research proves valuable for understanding the political challenges confronted by environmental protection specialists, aiding in the delineation of policy options for addressing contemporary Ukrainian environmental problems.

In the exploration of organizational and legal aspects of environmental policy within the context of the strategy of sustainable development of Ukraine, Feloniuk's monograph, "Modern Environmental Policy of Ukraine: Legal Principles of Institutional and Functional Support for the Formation and Implementation", holds relevance (Felonyuk, 2023). This scholarly work conducts a comprehensive comparative analysis of environmental programs across leading countries worldwide. It suggests considering the legal concept of "institutional and functional provision for the formation and implementation of environmental policy" broadly, encompassing a system of State, non-State and supranational institutions that directly and indirectly influence State's environmental policy. The monograph underscores the pressing need for Ukraine to engage diverse social, political, public, economic and educational entities in active ecopolitical endeavours. It advocates for the subsequent active involvement of these entities in direct activities related to environmental protection, monitoring expertise, and control over quantitative indicators of natural resources use, among other aspects (Felonyuk, 2023).

The legal aspect of this issue is crucial, as highlighted by Kantsurak (2020). Throughout the years of independence, Ukraine has witnessed the active creation of various concepts, laws, recommendations and proposals by public organizations. However, at the same time, despite the vigorous declarative and recommendatory activities, a coherent and systemic environmental policy has yet to materialize (Kantsurak, 2020). Such a situation underscores the imperative to formulate a comprehensive and purposeful national environmental policy. This policy should effectively balance the efforts of all stakeholders, including the State, citizens, public organizations, producers and consumers.

In modern times, it is axiomatic to assert that the socio-economic development of a region, individual country, and the world at large is directly dependent on the effectiveness of environmental policy, the rationality of its formation, as well as the extent to which measures for environmental conservation and protection are implemented (Felonyuk, 2021). At the same time, achieving a balanced use of natural resources, and, consequently ensuring ecological safety, an environment conducive to

human life and health, and the preservation of ecological equilibrium, requires coordinated from all stakeholders without exception – including State and supranational entities, public representatives, and individuals.

The theoretical and methodological challenges that are often overlooked or underestimated, yet crucial for integration into the "practical component" of environmental policy implementation, encompass the following: studying the features of the environmental policy implementation at both macro and micro levels; identifying the optimal tools for conducting environmental policy taking into account economic interests and associated risks; crafting tools for educational initiatives and enhancing public awareness, including avenues for public participation in environmental decision-making processes. Modern legal studies addressing the challenge of upholding the environmental principles within sustainable development should incorporate the latest trends in social, humanitarian, and natural sciences.

International Legal Dimensions of Environmental Protection in European Union Countries

The detrimental impact of anthropogenic influence on the quality of life and substantial economic losses has underscored the imperative for the development of effective environmental policies. European countries emerged as pioneers in recognizing the direct correlation between quality of life, and a conducive environment for humanity. In the 1960s, some countries began to adopt appropriate legislation to establish environmental standards and forming governmental bodies that deal with environmental issues (Kremer and Winter, 2007).

However, it has become evident that addressing many environmental problems is attainable within the framework of individual States, because issues such as climate change, ozone layer depletion, and marine pollution transcend national borders. The realization drawn that environmental protection requires consideration of both national and supranational dimensions. In Europe, where small States and an intricate river network prevail, the transboundary transport of pollutants significantly affects the environment. Until the late 1980s, in many countries, the primary contributor to air pollution was emissions into the atmosphere, often attributed to neighboring States.

In Europe, an active supranational environmental policy was initiated in 1973 with the adoption of the First Environmental Action Program, coinciding with the first wave of EU expansion. To implement this program, in 1972, the Council of Heads of Government of the EEC member states adopted a decision to broaden the Community's competence, extending it to the environment realm. The program, developed at that time, foreshadowed aspects of the modern concept of sustainable development. In particular, it included the provision that economic development, prosperity and environmental protection are interdependent processes. The document underscored that "environmental protection is one of the main tasks of the Community"¹. Key objectives within the program encompassed the prevention,

¹ Council Decision of 14 May 1973 adopting a research program for the European Economic Community on the protection of the environment Council Decision of 14 May 1973 adopting a research program for the European Economic Community on the protection of the environment. Available online at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31973D0126&qid=1510074506525>

reduction and limitation of environmental damage, the preservation of ecological balance, and rational use of natural resources.

In 1992, during the UN Conference on Environment and Development in Rio de Janeiro, several documents were adopted, outlining key provisions for a new paradigm of human development. Central to this concept was the recognition of the close interrelationship among ecological, economic and social aspects of human development. The resolution emphasized that comprehensive solutions, taking into account the balance of the interests in the development of natural resources and society, were essential to address these challenges collectively forming the bedrock of world civilization. The transition to sustainable development was identified as a universal task for humanity in the 21st century (UN, 1992). The concluding document recommended that each country formulate a national strategy for sustainable development grounded in mutually agreed economic, social and environmental plans. One of the goals was to ensure socially responsible economic development, incorporating measures to safeguard the natural environment for the benefit of future generations.

In 2015, the UN General Assembly adopted a pivotal document titled "Transforming Our World: Agenda for Sustainable Development for the period up to 2030"², encompassing 17 goals and 169 targets aimed at eradicating poverty, conserving the planet's resources and ensuring well-being for all. Additionally, the agenda outlined 232 indicators to measure progress towards these objectives (Moyer Jonathan and Hedden, 2020). The document draws special attention to the fact that achieving goals in the field of sustainable development is possible only through joint work of administrative bodies, institutions of civil society, and citizens. Referred to as the goals of sustainable development (GSD), they represent a harmonious fusion of economic, social and environmental development priorities, as along with the tools necessary for their achievement. The attainment of ecological balance and the promotion of sustainability are integral components of this overarching framework of sustainable development.

The implementation of the GSD assumes special importance in light of the signing of the Association Agreement between Ukraine and, on one hand, the European Union, the European Atomic Energy Community, and their member states, on the other hand. This agreement outlines a commitment to advancing the long-term goals of sustainable development and a green economy. The key principles governing cooperation in the environmental sphere are enshrined in the provisions of Article 363 of Chapter 6 titled "Environment" and Annex XXX to the Association Agreement.

State Environmental Policies in Pursuit of Sustainable Development

Nowadays, it is expedient to look at all spheres of life through an ecological prism, making environmental policy an integral part of the national agenda of countries. Environmental policy encompasses the collective efforts of society and the government with the objectives of protecting and enhancing the natural environment,

(assessed on 17 December 2023).

² Transforming our world: Agenda for sustainable development for the period up to 2030. Available online at: <https://www.un.org/sustainabledevelopment/ru/about/development-agenda/> (assessed on 17 December 2023).

effectively harmonizing natural resource management and environmental protection functions, ensuring environmental safety of citizens, promoting the adoption of waste-free and low-waste environmentally friendly technologies, fostering the development of environmental education (Yatsenyo, 2021).

The UN Sustainable Development Agenda (Agenda 2030) stands as a "comprehensive program for achieving peace and prosperity for all people and the planet" (Koff, 2021). As the program emphasizes, the fight against poverty depends on reducing global inequality, mitigating climate change and conserving natural resources. The resulting GSDs signify a shift in international cooperation towards a globally transformative development approach, aiming to meet the social and environmental needs of local communities while simultaneously eliminating power imbalances at the global scale. The 2030 Agenda promotes interconnectedness and complex interactions within and between individual development goals. The UN, along with its member countries, has set an ambitious task, acknowledging that accomplishment of these goals significantly relies on the actions of individual nation-states. Consequently, a question arises: what methods are countries employing to achieve the Goals of Sustainable Development, and how suitable are these approaches for the monumental task at hand?

One of the traditional political tools used by the countries of the world is environmental impact assessment (hereinafter - EIA). Originating in the USA in 1969, EIA has evolved into a crucial component of numerous international documents, including the UN Framework Convention on Climate Change and the UN Convention on the Law of the Sea. EIA requires that those who make decisions about the implementation of projects and strategies consider their environment impact and explore feasible alternatives. The assessment highlights on two principles: ensuring decision-makers are well-informed and providing accessible information to the general population (He, 2020).

In the People's Republic of China, EIA is recognized as the cornerstone of environmental reform. While EIA was initially incorporated into legislation in the 1970s, it was often perceived as a mere formality rather than a practical decision-making tool, limiting its preventive efficacy (He, 2020). To address this, subsequent legislative amendments have been introduced aiming to streamline procedures, elevate fines, and promote public participation, thereby enhancing the substantive role of EIA in environmental decision-making. He (2020) singles out three aspects of the Chinese reality that reduce the legitimacy and quality of EIA decisions. First, the EIA reform diverges from the broader environmental reform characterized by centralization. Secondly, the judicial system's lack of independence hinders the accountability of officials. Thirdly, concept of "public participation" in decision-making and oversight is narrowly construed, involving only groups directly affected by the project. The determination of public interest in such cases is ambiguous, and mechanisms for involving wider range of persons, including non-governmental organizations, are lacking. Although the State offers procedural opportunities for non-governmental organizations to protect public interests against polluters, the overall framework for their participation remains limited.

Undeniably, EIA plays an invaluable role in the management of sustainable development. Its significance lies in providing criteria to assess the socio-economic impact of projects, programs and strategies. In addition, EIA has opened up opportunities for public participation in development planning, fostering industry transparency. Global recognition of this tool further underscores its importance. However, its effectiveness in achieving GSD is compromised by "defensive" positioning.

Wales, for example, encountered difficulties in implementing the principles of sustainable development. Jenkins (2018) examines the context of natural resource management and the recently enacted Environment Wales Act 2016. She observes that applying principles of sustainable development in this field is complicated due to the dependence of ecosystems well-being on external factors - both natural and human. This means that regulating them requires consideration of the complex nature of socio-ecological relations rather than a purely technical approach (Jenkins, 2018). Modern scientific literature highlights several key ideas in the field of sustainable development, with representative management standing out prominently. Representative management is considered as a basic principle in environmental decision-making, ensuring the incorporation of local and traditional environmental knowledge, as well as active participation from local communities in solving problems. Equally important is the adaptive management. While legal and political systems often emphasize long-term predictability, adaptive management requires increased flexibility in decision-making to effectively respond to new information. This requires the flexibility of decision makers (Jenkins, 2018). Given these ideas and the foundational principles of sustainable development, such as principles of prevention, precaution and participation, which underpin natural resource management in Wales, the Welsh Environment Act should be recognized as an important step forward in achieving GSD. Primarily, it creates a "space" for institutional self-reflection. However, in pursuit of creating flexible procedures, legislators missed the crucial aspects of monitoring and reporting on the program implementation process. While the law enshrines the principles of participation and interaction, it falls short in providing procedural rights to ensure them. The absence of mechanisms for transferring information from the grassroots level to the national policy-making level in resource management poses a risk. This deficiency undermines all efforts and compromises the development of a robust legal framework for adaptive management in this field.

Likewise, Chile stands out as a notable success story in reforming State policy of sustainable development, transforming from a "green laggard" to a regional leader in just a few years. Since 2017, the country shifted its focus, prioritizing environmental protection over economic and investments. This shift in priorities enabled Chile to rapidly overhaul its policy sustainable development in a remarkably short timeframe. Acknowledging the international significance of Chile's sustainable development policy formation, it's crucial to recognize the impact of several internal factors. Firstly, the institutional and political legacy played a pivotal role in determining how international norms were implemented at the national level, influencing the timing and the content of the reform. Secondly, environmental protests created a window of opportunity for reform and increased the influence of civil society organizations (Madariaga, 2019). Thirdly, the government strategically used the window of

opportunity created by civil society, fostering a favorable political environment for reform. The primary antagonist to those reforms was the business sector, consistently prioritizing its narrow interests. This suggests that the further success of reforms in Chile and the broader region hinges on the ability of society, the state and the international community to persuade businesses of the need to contribute to the implementation of the sustainable development agenda (Madariaga, 2019).

Legal Foundations of Environmental Policy: A Key Component of Ukraine's Sustainable Development Strategy

Ensuring ecological safety and maintaining ecological balance on the territory of Ukraine, as stated in Art. 16 of the Constitution, is a fundamental duty of the State. Everyone has the right to an environment safe for life and health and is entitled to compensation for damages resulting from the violation of this right. Constitution places upon all citizens of our country the responsibility to protect nature and its resources. Fulfilling one's constitutional duty (Article 16 of the Constitution of Ukraine)³, in 2000, the Government of Ukraine directed its efforts towards guaranteeing citizen's rights to an environment safe for life and health (Article 50 of the Constitution of Ukraine). To achieve this goal, the following main priorities were identified:

- 1) Development and improvement of environmental legislation;
- 2) Institutional improvement of the system of public administration in the field of environmental protection and resource management;
- 3) Increased public participation in the development and decision-making processes in this domain;
- 4) Establishment of an extensive system of institutions of environmental education and upbringing;
- 5) Development and improvement of the economic mechanism of natural resource management;
- 6) Deepening international cooperation in environmental protection, along with the harmonization of national environmental legislation with European standards;
- 7) Creation of an effective state system for monitoring the environment and the use of natural resources⁴.

The implementation of these specified priorities required the execution of a comprehensive set of legal measures aimed at creating a safe environment for human activity. In the modern development of Ukrainian environmental legislation, a noticeable trend is evident towards its detailed specification and the continual improvement of its individual parts. A number of basic legal acts have been put in place to regulate almost all facets of environmental protection and the use of natural resources. The groundwork for legislation in the realms of environmental protection, the use of natural resources, and environmental safety have been established (Galushkina, Musina and Potapenko, 2017). Thus, in particular, the Parliament of

³ Constitution of Ukraine: official text. Kyiv, 2020. 141 p. <https://rm.coe.int/constitution-of-ukraine/168071f58b>

⁴ On the Basic principles (strategy) of the state environmental policy of Ukraine for the period until 2020: Law of Ukraine dated 12.21.2010 № 2818-VI (expired). Available online at: <https://zakon.rada.gov.ua/laws/show/2818-17#Text>

Ukraine has passed the key laws, including but not limited to, "On Environmental Protection", "On Nature Reserve Fund", "On Atmospheric Air Protection", "On Animal Life", "On the Use of Nuclear Energy and Radiation Safety", "On Handling of Radioactive Waste", "On Waste", "On Plant Life", "On Energy Saving", "On Alternative Sources of Energy", "On Alternative Types of Fuel", "On Energy Lands and the Legal Regime of Special Zones of Energy Objects", "On the Electric Energy Market", "On Heat Supply", and others.

Throughout Ukraine's years of independence, additional environmental protection legislation has been established, complementing existing laws, including the Law of Ukraine "On Environmental Protection". This legislation regulates legal relations in areas where humans and nature interact⁵. Key components of this legal framework include:

- *Constitution of Ukraine*: Fundamental legal norms ensuring the effective use and protection of lands, subsoil, waters, forests, and the overall environment are concentrated in Articles 13, 16, 50, 92)⁶
- *The Forest Code of Ukraine*: Addresses issues related to the conservation, restoration, and rational use of forests.
- *The Water Code of Ukraine*: Provides legal protection for waters against clogging, pollution, depletion and regulates the procedure for their use.
- *The Code on Subsoils of Ukraine*: Ensures the rational, comprehensive use of subsoils to meet the needs of society while protecting and guaranteeing the safety of people and the environment during the use of subsoils.
- *The Code of Civil Protection of Ukraine*: Ensures the protection of the population, territories, natural environment and property, as along with environmental safety.

The specified normative legal acts determine the principles and limits of activities related to environmental protection, the utilization of various natural resources, the maintenance of environmental safety, and the preservation of unique territories and natural objects integral to the the historical and cultural heritage of Ukraine. Aligned with the global goals of sustainable development until 2030 outlines in the UN General Assembly Resolution No. 70/1 dated September 25, 2015, and considering the adaptations tailored to Ukraine's specific development context as detailed in the National Report, at the aims include:

1. *Urgent Climate Action*: Implementing immediate measures to combat climate change and address its consequences.
2. *Water Resource Preservation*: Preserving and utilizing water resources in a manner that supports sustainable development.
3. *Terrestrial Ecosystem Protection and Restoration*: Focusing on the protection and restoration of terrestrial ecosystems, promoting their rational use, and ensuring sustainable forest practices.
4. *Land and Biodiversity Conservation*: Halting the processes of land degradation and biodiversity loss⁷.

⁵ On environmental protection: Law of Ukraine dated 06.25.1991 № 1264-XII. Available online at: <https://zakon.rada.gov.ua/laws/show/1264-12#Text>

⁶ Constitution of Ukraine: official text. Kyiv, 2020. 141 p. <https://rm.coe.int/constitution-of-ukraine/168071f58b>

⁷ On the Sustainable Development Goals of Ukraine for the period until 2030. Decree of the President of

The goals of the sustainable development of Ukraine for the period until 2030 serve as guidelines for formulating forecasting and program documents, as well as normative and legal acts. These efforts aim to ensure a harmonious balance among the economic, social and environmental dimensions of the sustainable development of Ukraine⁸. According to the Association Agreement, the purpose of cooperation between Ukraine and the EU is designed to achieve environmental objectives. These include the preservation, protection, improvement and sustainable reproduction of environmental quality, as well as the protection of public health. The Agreement emphasizes the prudent and rational use of natural resources, and encourages measures at the international level to address regional and global environmental problems. To realize these objectives, the parties commit to a range of collaborative actions:

1. *Information and Experience Exchange*: Both parties commit to sharing information and experiences related to environmental issues.
2. *Joint Research Activities*: Collaboration on joint research endeavors to deepen understanding and address environmental challenges.
3. *Exchange of Environmentally Friendly Technologies*: The agreement encourages the exchange of information about environmentally friendly technologies to promote sustainability.
4. *Disaster and Emergency Response Planning*: Both parties agree to plan and coordinate responses to natural disasters and other emergency situations.
5. *Regional and International Collaboration*: The parties commit to joint activities at regional and international levels, in line with multilateral agreements on environmental protection ratified by both parties. Additionally, they may engage in collaborative efforts within relevant agencies⁹, as deemed appropriate.

These provisions highlight the shared commitment of Ukraine and the EU to collaborative efforts in the spheres of environmental protection and sustainable development.

The legislation of Ukraine is expected to align with EU legislation in various critical areas. These include climate change management, education and training, access to information regarding environmental issues and the decision-making process, air quality, water and water resources management, waste and resource management, nature conservation, ecosystem preservation and protection, industrial pollution, industrial threats, the use of chemicals, and more. The harmonization of Ukrainian laws with EU standards in these domains reflects a commitment to fostering compatibility and cooperation in environmental policies and practices. On February 28, 2019, the Law of Ukraine "On the Basic Principles (Strategy) of the State Environmental Policy for the Period Until 2030" was approved, which states: "The goal of the state environmental policy is to achieve a good state of the environment by introducing an ecosystem approach to all areas of socio-economic development of Ukraine in order to ensure the constitutional right of every citizen of Ukraine to a

Ukraine dated September 30, 2019 № 722/2019. Available online at:

<https://zakon.rada.gov.ua/laws/show/722/2019#Text>

⁸ On the Sustainable Development Goals of Ukraine for the period until 2030. Decree of the President of Ukraine dated September 30, 2019 № 722/2019. Available online at:

<https://zakon.rada.gov.ua/laws/show/722/2019#Text>

⁹ Association Agreement between Ukraine, on the one hand, and the European Union, the European Atomic Energy Community and their member states, on the other hand, dated November 30, 2015.

Available online at: https://zakon.rada.gov.ua/laws/show/984_011 (assessed on 17 December 2023).

clean and safe environment, the introduction of balanced natural resource management and the preservation and restoration of natural ecosystems"¹⁰.

The State environmental policy aims to achieving strategic goals, including the formation of environmental values and principles of sustainable consumption and production in society. It seeks to ensure the sustainable development of Ukraine's natural resource potential, integrate environmental policy into the decision-making processes regarding the socio-economic development of Ukraine, and reduce environmental risks to minimize their impact on ecosystems, socio-economic development and public health. Additionally, the policy focuses on the improvement and development of the State environmental management system¹¹.

Simultaneously, the state determines the anticipated results of the execution of the aforementioned initiatives. By 2030, Ukraine aims to attain a level of balanced (sustainable) development wherein dependence on non-renewable natural resources and environmental pollution will be reduced to ecologically acceptable levels. Performance indicators are established to assess the implementation of the State environmental policy in the future. In pursuit of Sustainable Development Goals (SDGs), Ukraine signed the Presidential Decree "On the Goals of Sustainable Development of Ukraine for the Period Until 2030". This decree established key guidelines for the development of projects, forecasts and program documents, and regulatory and legal acts, aiming to ensure equilibrium among the economic, social and environmental dimensions of the sustainable development of Ukraine¹². Thus, the environmental policy of Ukraine is aligned with the concept of sustainable development, which is confirmed by the provisions of approved legal acts.

Charting the Course: Ukraine's Environmental Policy Prospects amidst European Integration Processes

Prior to full-scale war, experts claimed that bridging the gap between the state of the environmental protection in the EU and Ukraine in one leap was deemed impossible. They emphasized that, to successfully align with the requirements of the European Green Course, Ukraine must consistently fulfill certain prerequisites. However, the large-scale destruction caused by Russian aggression ushered new realities and conditions. Today, in the current wartime context, significant opportunities for rapid modernization and development are witnessed. With Ukraine having received the status of a candidate for joining the EU, it is imperative to transition to EU legislation, where the green economy stands as the primary development vector. Simultaneously, as rightly noted in the doctrine, the journey towards fulfilling environmental and climate obligations is neither short nor simple. This complexity arises from approximately 200 normative legal acts in the field of environment and climate within

¹⁰ On the Basic principles (strategy) of the state environmental policy of Ukraine for the period up to 2030: Law of Ukraine dated February 28, 2019. № 2697-VIII Available online at: <https://zakon.rada.gov.ua/laws/show/2697-19>

¹¹ Ibid

¹² On the Sustainable Development Goals of Ukraine for the period until 2030. Decree of the President of Ukraine dated September 30, 2019 № 722/2019. Available online at: <https://zakon.rada.gov.ua/laws/show/722/2019#Text>

the EU, according to the European Commission. Ukraine must align its legislation and policies with these acts (Golubovska-Onisimova *et al.*, 2023).

The Ukrainian environmental community staunchly advocates for the assertion that, in the long term, the post-war economic development process should be the cornerstone of the country's shift towards a green and clean economy. To facilitate green reconstruction of post-war Ukraine, improving the ecological landscape and enabling integration into European markets and political arenas, it is imperative to not only secure investments, but also establish effective public administration institutions and a well-defined legal framework. These institutions and frameworks must possess the capability to ensure a seamless transition to European standards concerning industry, utilization of natural resources, and environmental protection¹³. When considering the pivotal reforms in the realm of environment and climate change that serve as the foundation for a green recovery and simultaneously showcase Ukraine's genuine intentions to the EU, the following sectoral reforms are essential:

Protection of Biodiversity

Ensure the preservation of natural habitats for wild flora and fauna is of utmost importance, and this can be achieved through the establishment and proper management of the Emerald Network territories. Specialists have repeatedly emphasized that the preservation of biodiversity requires drastic changes in the State policy of Ukraine, particularly shifting from the notion of an agrarian country to one that prioritizes the well-being of all natural resources. This entails the establishment of a robust system for the protection, management and monitoring of natural territories, species and habitats. It also involves a transition from an exclusively consumerist model in the use of forest, water and land resources towards a more balanced approach that promotes sustainable development¹⁴. Hundreds of thousands of hectares of Ukrainian forests suffered extensive damage due to Russian aggression, coinciding with significant administrative changes in the forest management system. To prevent further degradation of forests during post-war reconstruction, it is important for forestry to evolve in alignment with the goals outlines in Ukraine's State Forest Management Strategy until 2035¹⁵. This entails switch to discontinuous logging systems, expanding the area of naturally originated forests, normalizing the wood market, and other essential measures.

Reduction of Industrial Pollution

Certain industrial processes in Ukraine, characterized by emissions of volatile organic compounds, currently lack regulation. Therefore, it is urgent to align national legislation with key EU directives aimed at improving atmospheric air quality. This

¹³ Priority environmental reforms for the green recovery of Ukraine. Available online at: <https://epl.org.ua/announces/pershochergovi-ekologichni-reformy-dlya-zelenogo-vidnovlennya-ukrayiny/> (assessed on 17 December 2023).

¹⁴ Priority environmental reforms for the green recovery of Ukraine. Available online at: <https://epl.org.ua/announces/pershochergovi-ekologichni-reformy-dlya-zelenogo-vidnovlennya-ukrayiny/> (assessed on 17 December 2023).

¹⁵ On the approval of the State Forest Management Strategy of Ukraine until 2035. from the Decree of the Cabinet of Ministers of Ukraine No. 1777 dated December 29, 2021 Available online at: <https://zakon.rada.gov.ua/laws/show/1777-2021-%D1%80#Text>

synchronization is essential for regulating emissions of pollutants that pose significant risks to health and the environment.

Waste Management

The main step towards the implementation of European standards in this realm occurred with the adoption of the Law of Ukraine "On Waste Management" in 2022. This legislation establishes the groundwork for implementing an extended producer responsibility, fostering a circular economy, and introducing a waste management hierarchy. However, to activate the mechanisms and tools outlined in the law, additional legislation, including laws and by-laws pertaining to waste electrical and electronic equipment, batteries and accumulators, waste packaging, safe disposal of waste and management of waste from the extractive industry, must be enacted. Enhancing the state management system can be achieved through the establishment of a new central body of executive power. This entity would improve the management process, oversee permitting activities, streamline accounting procedures, and provide regulatory and methodological support in the field of waste management.

Monitoring of Emissions and Reporting

To fulfill EU environmental protection standards, Ukraine took significant step on September 20, 2022, with the adoption of the Law of Ukraine "On the National Register of Emissions and Transfer of Pollutants"¹⁶, and the corresponding procedure was also approved¹⁷. According to the provisions of the law, the national open electronic register of emissions should become operational as early as 2024. Its implementation will obviously allow State bodies to better understand the quantitative and qualitative indicators of industrial emissions of the major polluters. This, in turn, will empower governmental bodies to make informed decisions aimed at reducing emissions. Simultaneously, the public will gain access to vital environmental information, allowing them to influence the authorities if necessary, based on the disclosed data.

Environmental Control and Responsibility

Ukraine should thoroughly reboot the system of State environmental control to guarantee adherence to environmental legislation and enhance the state of the environment. For this, endowing the the environmental control body with the requisite authority, eliminating existing obstacles and legal conflicts. Legislation should clearly define the forms of state environmental control measures, including scheduled and unscheduled inspections, raids, patrols, and swift response to calls, along with the corresponding grounds for their implementation.

It should be noted that, in line with the implementation of the European Green Deal, environmental and climate considerations must be integrated into various sectors such

¹⁶ On the National Register of Emissions and Transfer of Pollutants. Law of Ukraine № 2614-IX dated September 20, 2022. Available online at: <https://zakon.rada.gov.ua/laws/show/2614-20#Text>

¹⁷ On the approval of the Procedure for maintaining the National Register of Emissions and Transfer of Pollutants. Resolution of the Cabinet of Ministers of Ukraine № 560 of June 2, 2023. Available online at: <https://ips.ligazakon.net/document/KP230560?an=1>

as energy, agriculture, industrial policy, the single market, and transport. In addition, in Ukraine, majority of environmental protection reforms endow local authorities with new responsibilities and create new opportunities for regional advancements. The effectiveness of the implementing the Association Agreement is intricately linked to the successful establishment of novel mechanisms, standards, and practices on the grassroots level. This correlated is particularly significant within the framework of State regional policy, in particular, in the environmental domain (European Green Deal, 2021).

It is crucial to highlight that major reforms in areas such as environmental impact assessment, strategic environmental assessment, water resources management, pollution monitoring, and access to environmental information were initiated either before or during the full-scale invasion of Ukraine. In the aftermath of the conflict, any programs and projects for post-war reconstruction must be meticulously developed and approved, accounting for environmental considerations through the procedures like strategic environmental assessment and environmental impact assessment, and with mandatory incorporation of public opinion. Aligning with practices in the EU, an effective dialogue between central and regional authorities, local self-government, civil society and expert circles should be established in Ukraine. This collaborative approach aims to jointly formulate develop approaches and solutions for carrying out the necessary transformations and achieving ambitious environmental goals that will positively affect the lives of citizens.

Conclusion

The concept of sustainable development delineates the overall trajectory of societal progress, with a focus on the environmental sphere. Sustainable development entails harmonious interaction between humanity and natural resources, emphasizing balance and interdependence. This involves rational and efficient consumption of natural resources while minimizing negative impacts during the satisfaction of individual needs. Humanity's understanding of the need to take into account the possible risks associated with harmful effects on the environment contributes to constant cooperation at the international and regional levels. Global environmental problems require joint efforts and the execution of appropriate policies. International agreements articulate the primary goals of sustainable development, serving as guiding principles for the pursuit of nations. At the national level, various normative legal acts have been approved to consolidate and actualize the concept of sustainable development. These legislative measures establish the foundation of environmental policy, outlining tasks, goals, and principles that guide national-level environmental initiatives.

The Association Agreement with the EU and the European Green Deal has set the course for a substantial transformation of Ukraine's environmental policy. However, due to the military invasion of its territory, not all planned measures have been implemented. The war has unsurprisingly catalyzed State measures focused on economic and infrastructure development, aligning with the principles of the European Green Deal. To achieve this, prioritized horizontal and sectoral environmental reforms are imperative. These reforms aim to align the field of environmental management with European standards, ensuring a swift, high-quality, transparent, open, and modern restoration process from an ecological perspective. First of all, among these

reforms are biodiversity protection, reduction of industrial pollution; waste management; emissions monitoring and reporting, as well as environmental control and responsibility.

The key areas for enhancing Ukraine's environmental policy encompass several aspects. These include:

- *Strengthening Regulatory Oversight:* Enhancing control over adherence to norms, standards, and environmental regulations in natural resource management.
- *Organizational Improvement:* Reforming the structure of environmental management bodies for increased efficiency.
- *Technical Enhancement:* Bolstering the technical capabilities of environmental control mechanisms.
- *Impact Payments Mechanism:* Improving the mechanism for assessing and compensating negative environmental impacts.
- *Financial Incentives:* Utilizing tax benefits and other financial incentives to promote eco-innovation processes.
- *Environmental Management Tools:* Actively applying environmental audit, environmental certification, and flexible pricing for ecological products.
- *Emission Quota Trading:* Introducing a system for trading emission quotas.
- *Ecological Development System:* Establishing an effective system for ecological development and incentivizing scientific activities to address environmental challenges.
- *Funding Approach:* Moving away from the residual financing principle for environmental protection activities.

Addressing these challenges necessitates the adoption of modern tools for environmental policy implementation, innovative approaches to production and economic processes, and the revitalization of technical and technological resources.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

<i>Contribution</i>	<i>Author 1</i>	<i>Author 2</i>	<i>Author 3</i>	<i>Author 4</i>	<i>Author 5</i>
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes	Yes
Collected the data	No	No	Yes	Yes	Yes
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes	No
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes
Critical revision of the article/paper	Yes	Yes	Yes	Yes	Yes
Editing of the article/paper	Yes	Yes	No	No	Yes
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The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)

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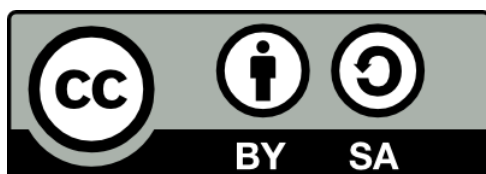
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