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Research on environment and sustainable development education under the background of green ecology

Gang Liu[a,*], Xu Huan[b] and Xin Deng[c]

[a] School of Marxism, Harbin University, Harbin, Heilongjiang 150086, China
[b] Jilin Provincial Institute of Education, Changchun, Jilin 130000, China
[c] Jilin University of Finance and Economics, Changchun, Jilin 130000, China
*Corresponding author. E-mail: gang.liu00qqww@hotmail.com

ABSTRACT

The implementation of environmental and sustainable development goal (SDG) education helps to cultivate people's awareness of environmental protection and the concept of SDG, and is conducive to the protection and management of the environment. However, due to the weak awareness of education and lack of environmental protection knowledge in the environment and SDG education, environmental protection work has been affected. Therefore, this article proposed the implementation strategy of environment and SDG education from the perspective of green ecology. This research utilized datasets agricultural biomass accumulated from five cities of Guandong (i.e., Foshan [F], Heshan [H], Nanxiong [N], and Shantou [S]) province, China. Through experimental research, the utilization rate of agricultural waste and utilization ratio of straw was explored by using data envelopment analysis, and then, the environmental awareness of students and the environmental education level of teachers under the environmental and SDG education strategies of green ecological concept were combined. The results showed that the proportion of straw waste biomass utilization in S city was the highest among the four cities; the implementation strategy of environment and SDG education proposed in this article can enhance students' awareness of environmental protection by 5.21% and improve environmental education level of teachers by 9.51%.

Key words: agricultural waste, data envelopment analysis, education for sustainable development, environmental education, green ecology

HIGHLIGHTS

- This article proposed the implementation strategy of environment and sustainable development goal (SDG) education from the perspective of green ecology.
- The utilization efficiency of agricultural waste and biomass utilization efficiency of straw was explored by using data envelopment analysis.
- SDG education enhanced students' awareness of environmental protection by 5.21% and improve the environmental education level of teachers by 9.51%.

1. INTRODUCTION

With the progress of social productive forces, human beings' ability to develop nature has been continuously enhanced, but unreasonable development methods and waste disposal methods have also caused damage to the natural ecological environment. Taking agricultural production as an example, the excessive use of pesticides would cause the destruction of groundwater resources, and the improper treatment of agricultural wastes such as agricultural plastics and livestock and poultry manure would cause environmental pollution. Faced with this situation, this article studied environment and sustainable development goal (SDG) education based on the concept of green ecology, and put forward the implementation strategy of environment and SDG education with schools as the main position.

Many scholars have explored environmental education and ESD (education for sustainable development). Sinakou *et al.* considered SDG as a comprehensive concept of environmental, economic, and social dimensions, and explored the problems and influencing factors in ESD practice (Sinakou *et al.* 2019). Tristananda discussed the problems in ESD and made suggestions on addressing the challenges and opportunities presented by the concept of SDG from the perspective of educational institutions (Tristananda 2018). Agbedahin analyzed the key interlinkages between education, sustainabile development, ESD, the SDGs, and human development. He discussed the centrality of ESD in the global education discourse and its relevance, role, and relevance to the achievement of all SDGs (Agbedahin 2019). Ardoin discussed the results of students' environmental education programs through literature research and put forward suggestions for strengthening the depth of environmental education and organizing environmental protection activities (Ardoin 2018). Kalogiannakis and Papadakis proposed the integration of mobile learning technology into environmental education in response to the single problem of teaching methods in environmental education (Kalogiannakis & Papadakis 2017). In view of the problems in environmental ethics education, Liu *et al*. put forward suggestions for the whole society, schools, and families to work together to promote environmental ethics education (Liu *et al.* 2019). Many scholars have participated in research on environmental education and ESD and have made valuable suggestions.

Many scholars have conducted research on green ecology and green ecological education. Liu discussed the application of information technology in music ecological education and proved through experiments that music ecological education can improve students' learning initiative and student effect (Liu 2019). Glaab and Heyne conducted experimental research on traditional teaching activities and green ecological teaching activities, and proved that green ecological classroom teaching can better cultivate students' positive learning emotions (Glaab & Heyne 2019). Junior studied the deployment of green ICT in industrial ecological protection by establishing a research model (Junior 2019). Zhang and Yang used Internet technology to build an ecological civilization education system for art education, and discussed the countermeasures of art education for college students from the internal and external ecological environment (Zhang & Yang 2022). Kulmatov and Tajibayev explored the interplay of morality, aesthetics, and ecological education, which provided a valuable reference for the study of ecological education (Kulmatov & Tajibayev 2021). Guo used modern information technology to discuss the ecological teaching of English education, which provided a reference for the construction of English education teaching methods (Guo 2021). Although many scholars have studied green ecology and green ecological education, few scholars have conducted research on environmental education and ESD based on the concept of green ecology.

It has recently been discovered that one of the most efficient way of analyzing environmental system is by using data envelopment analysis (DEA) methodology. DEA has various applications in environmental analysis, particularly in assessing the management of various pollutions (Ye *et al.* 2020; Amirteimoori *et al.* 2023; De Oliveira *et al.* 2023; Huang 2023; Taleb 2023). From the most recent investigations, some practical advantages of DEA are listed. In terms of efficiency evaluation, DEA can be used to evaluate the overall efficiency of agricultural waste recycling entities in terms of their resource utilization and waste recycling processes. It helps identify the most efficient entities as well as areas where improvements can be made. As a benchmarking model, DEA allows for the identification of best practices and benchmarks in agricultural waste recycling. By comparing the performance of different entities, it becomes possible to identify the most effective strategies and practices for improving recycling efficiency. In addition, resource allocation is one of the most striking advantages of the DEA model that can assist policymakers in allocating resources more efficiently by identifying areas with low recycling efficiency and directing resources toward improving their recycling processes. In the application of policy evaluation, DEA can be used to evaluate the impact of different policies and regulations on the recycling efficiency of agricultural waste. This information helps policymakers in making informed decisions and improving waste management policies. Moreover, in terms of technology assessment, DEA can be applied to assess the effectiveness of different technologies and methods used in agricultural waste recycling. This analysis helps in identifying the most suitable and efficient technologies for recycling waste. Furthermore, DEA can be used to assess the overall environmental performance of agricultural waste recycling entities by considering their resource consumption, waste generation, and environmental impacts. Overall, DEA provides a robust and quantitative approach for evaluating the recycling efficiency of agricultural waste and supporting decision-making processes in environmental analysis and waste management.

In view of the current problems of environmental pollution and ESD, this article proposed the implementation strategies of ESD such as guaranteeing and improving the status of ESD and enhancing the awareness of ESD, and conducted experimental research on the implementation strategies of ESD.

This article examines the economic pattern performance of agricultural waste recycling entities using the DEA model. Particularly, cooperative DEA formulations are applied, which typically includes modifications to the traditional DEA model to consider the cooperative interactions among decision-making units (DMUs). In this way, this implementation is carried out based on the concept of game theory. The study focuses on the comprehensive utilization efficiency of agricultural waste across five case studies located in Guandong Province, China. Specifically, the recycling efficiency of agricultural waste, including agricultural biomass, forestry biomass, energy plants, aquatic plants, poultry and livestock manure, and domestic waste, were analyzed by using DEA methodology. Then, the utilization efficiency of straw waste biomass is investigated.

Ultimately, the impact of implementing an environmental and SDG education strategy based on the concept of green ecology is assessed.

2. ENVIRONMENTAL EDUCATION AND ESD

2.1. Contents of environmental education

Environmental education covers the earth's natural systems, social systems, and the relationship between natural and social systems, and involves a variety of environmental knowledge. Environmental education can be divided into environmental social education, environmental basic education, environmental professional education, and environmental adult education. Environmental and social education targets all levels of human society; environmental basic education is aimed at university, middle school, primary, and early childhood students; environmental professional education is mainly used to cultivate environmental protection professionals.

2.2. Contents of ESD

ESD involves various fields such as environment, society, and economy. In the socio-cultural field, ESD includes peace and human security education, health education, human rights education, etc. In the field of environment, ESD includes environmental conservation and protection education, sustainable urbanization education, etc. In the economic sphere, ESD includes education for sustainable production and consumption, education for rural reform, etc.

Taken as a whole, environmental sustainability, social justice, and economic development are complex and intertwined, and together they form the core framework of sustainable development. Through research, we can find that there is a close relationship and interaction between them. Environmental sustainability provides resource security and environmental support for economic development; social justice provides a stable social environment and fair development opportunities for economic development; economic development, in turn, provides the material basis and economic impetus for environmental sustainability and social justice. Therefore, we need to consider the coordinated development of these three aspects as a whole to achieve real sustainable development. In addition, ESD plays an important role in driving this holistic approach. Through education, we can increase public awareness and understanding of sustainable development and foster people's environmental awareness and social responsibility. At the same time, education can also provide talent support and innovation impetus for economic development, and promote economic development in a more green, equitable, and sustainable direction.

3. EXPLORATION OF THE PROBLEMS OF ENVIRONMENT AND SDG EDUCATION IN THE CONTEXT OF GREEN ECOLOGY

This article explored the problems of ESD in basic education. The problems include the weak awareness of education, lack of knowledge of environmental protection, insufficient education teachers, lagging education for environment and SDG, and formalization of environment and SDG education as shown in Figure 1.

3.1. Weak awareness of education

In the context of exam-oriented education, environmental and SDG education is not closely related to students' performance assessment, further education, and employment, which makes most schools have weak awareness of education and often do not pay attention to environmental education and ESD. Although some schools have opened open courses on environmental protection, the teaching of environmental protection content is not systematic and comprehensive, which affects students' awareness of environmental protection. A range of environmental issues have failed to alert educators and students. Many teachers and students seriously lack awareness of environmental pollution prevention and control, and do not establish the awareness of laying the foundation for environmental protection education (Ilma & Wijarini 2017; Braun *et al.* 2018).

3.2. Lack of environmental protection knowledge

Some teachers have problems that do not explain common environmental pollution phenomena such as ozone layer depletion and soil acidification, and do not understand the causes of environmental pollution and prevention methods. Teachers still lack knowledge about environmental protection, and the situation of students is even less optimistic. The reason for the lack of environmental protection knowledge among teachers and students is the lack of environmental education and ESD in schools.

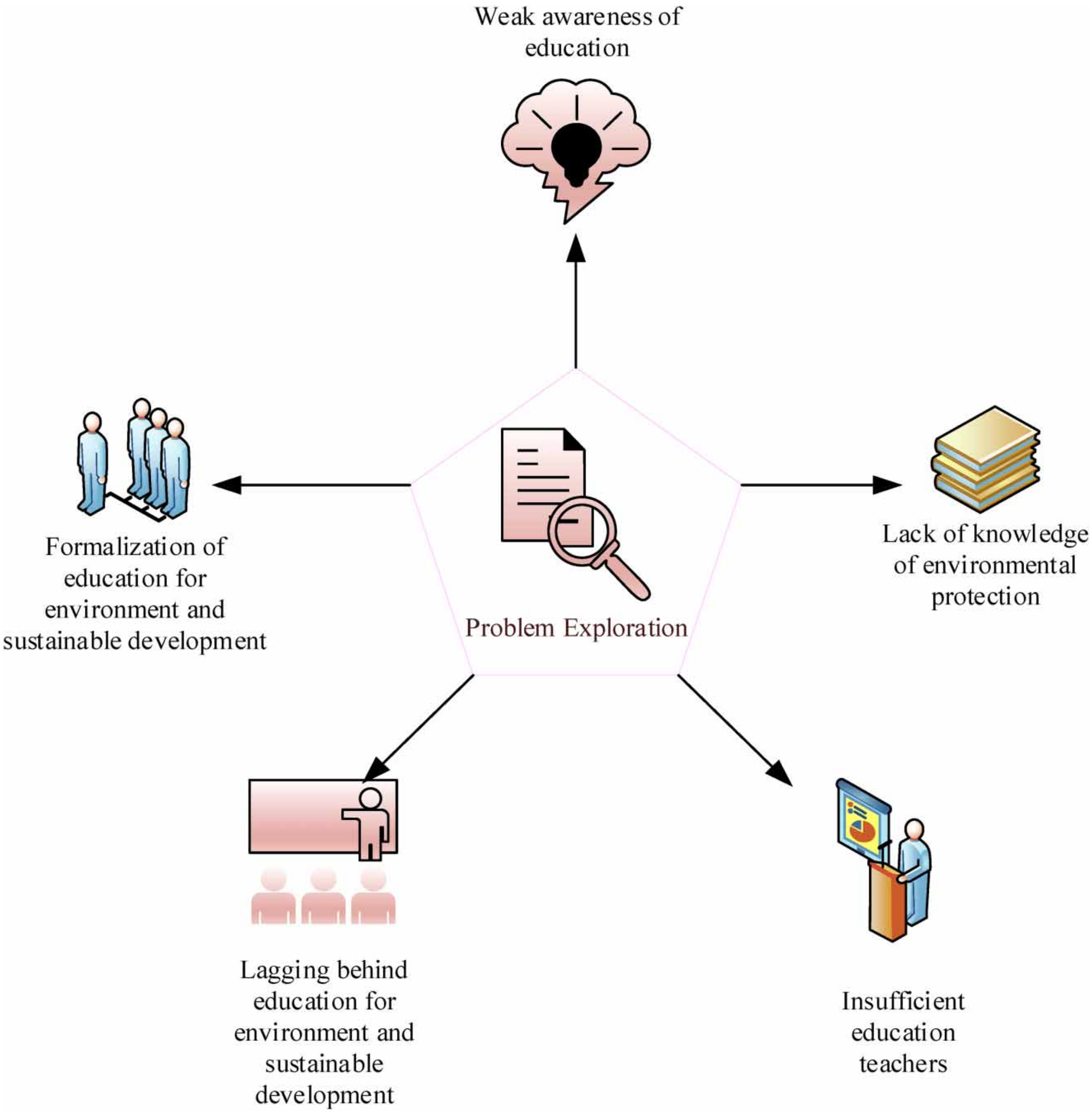

Figure 1 | Exploring the problems of education for environment and SDG.

3.3. Insufficient education teachers

At this stage, the government does not pay enough attention to environmental education and ESD professional training and does not invest enough in environmental education and ESD. This has led to a shortage of professional environmental education and ESD talents in basic education. Most schools often hire teachers who are not graduates of environmental studies, and schools rarely provide systematic training in environmental protection knowledge and skills. School administrators usually invite ESD staff to give lectures when conducting environmental education and ESD activities, rather than full-time environmental protection teachers at the school.

3.4. The lag in education for environment and SDG

Environmental education and ESD do not have a proprietary lesson plan and content. Environmental education and ESD are mainly implemented through the teaching activities of other specific disciplines, so that the teaching content of environmental education and ESD is inevitably chaotic and disorderly. This situation is not conducive to students mastering comprehensive environmental education and ESD, and forming a complete environmental protection concept, so as to become high-quality talents in environmental protection (Li 2018; Marcinkowski & Reid 2019).

3.5. Formalization of education for environment and SDG

Teachers are too formal in the process of environmental education and ESD teaching and only make superficial expressions of environmental knowledge and SDG knowledge. In terms of environmental education and ESD practice activities, teachers only make brief publicity on Arbor Day, Earth Day, and Environment Day, and there are few real environmental education and ESD practice activities.

4. IMPLEMENTATION STRATEGY OF ENVIRONMENTAL AND SDG EDUCATION BASED ON THE CONCEPT OF GREEN ECOLOGY

4.1. Guarantee and improvement of the status of education for environment and SDG

This article put forward recommendations for safeguarding and improving the status of education for environment and SDG from two perspectives. On the one hand, it provides teaching courses for environmental and SDG education alone; on the other hand, it integrates subject penetration, which is shown in Figure 2.

Separate teaching courses: Governments should enact specific laws and regulations to make ESD compulsory for students. Based on the concept of green ecology, schools should set environmental and SDG education as a subject related to further education. At the same time, teachers use advanced green ecological teaching methods to take students as the main body in the teaching of environment and SDG courses, so as to impart environmental and SDG education knowledge to students, and have cultivated students' awareness of environmental protection and environmental management.

Combined discipline penetration: Environmental education and SDG education are carried out in combination with the knowledge of specific disciplines. For the content of teaching materials that directly express environmental protection knowledge, teachers should give in-depth explanations. For content that is intrinsically related to environmental protection knowledge, teachers should reveal this internal connection, so that students can naturally think of environmental protection issues, so as to enhance students' awareness of protection (Saribas *et al.* 2017; Genc *et al.* 2018).

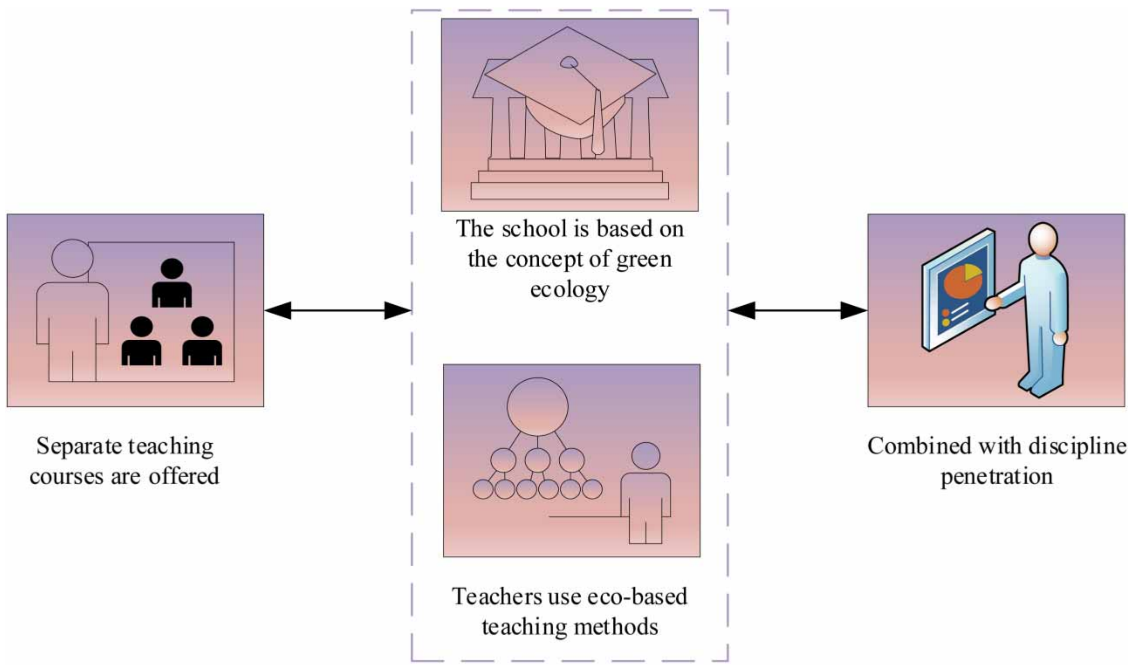

Figure 2 | Guarantee and enhance the status of education.

4.2. Increased awareness of education for environment and SDG

Schools should make full use of publicity tools such as campus radio and campus blackboard newspapers, and take environmental protection festivals such as Arbor Day and World Environment Day as opportunities to carry out a variety of environmental protection publicity activities to promote environmental protection knowledge and the significance of environmental education to students. In terms of specific environmental protection propaganda content, schools can publicize the serious environmental problems of the earth. Schools can promote the concept of SDG and make students fully aware of the close relationship between green ecological environmental protection and economic development. Schools can also publicize laws and regulations on environmental protection. In addition, schools can encourage students to read more environmental education books to increase students' in-depth understanding of environmental protection.

4.3. Improvement of the quality of teachers' environmental education

When schools conduct training on the quality of teachers' environmental education, they should make four clear. *Clear training objectives*: The school has enabled a large number of teachers to master environmental protection knowledge through training. It can not only explain the common environmental pollution phenomena but also understand the causes of environmental pollution and prevention methods, so as to lay a solid theoretical foundation for teaching by word and deed. *Clear training objects*: Middle school teachers and primary school teachers are the objects of environmental education quality training. *Clear training content*: The training content should include the understanding of basic environmental knowledge, the causes of environmental pollution, and the clarification of prevention and control measures, and should also include the training of teachers' ability to penetrate environmental knowledge in the classroom. *Clear training channels*: The main channel to improve teachers' environmental protection knowledge is teachers' continuing education. The education department should reasonably organize teachers to participate in environmental education knowledge training during winter and summer vacations. The education sector can link the evaluation of teachers' professional titles with the effectiveness of environmental education training to enhance the effectiveness of training.

4.4. Cultivate students' practical ability based on the concept of environmental protection and SDG

Environmental protection and SDG education should pay attention to cultivating students' awareness of environmental protection and management and the concept of SDG. It should not only focus on increasing students' knowledge of environmental protection and management but also pay attention to cultivating students' ability to solve practical environmental problems. Therefore, the practical activities of ESD should be actively pursued, which is shown in Figure 3.

Participation in social practice public welfare activities: Teachers should organize students to actively participate in social practice activities, such as campus beautification activities, tree planting activities, public garbage removal activities, etc. This approach can help students cultivate environmental protection and management awareness and can also enhance students' ability to solve practical environmental problems and students' pride in participating in environmental protection. *Participation in environmental competitions*: Participation in environmental competitions can enhance students' sense of practical participation in environmental protection and SDG education. *Theme class meeting*: The content of the theme class meeting can require students to propose an environmental protection aphorism, an environmental protection movie, and an environmental protection fact. *Lectures and speech competitions on environmental protection*: Through voluntary

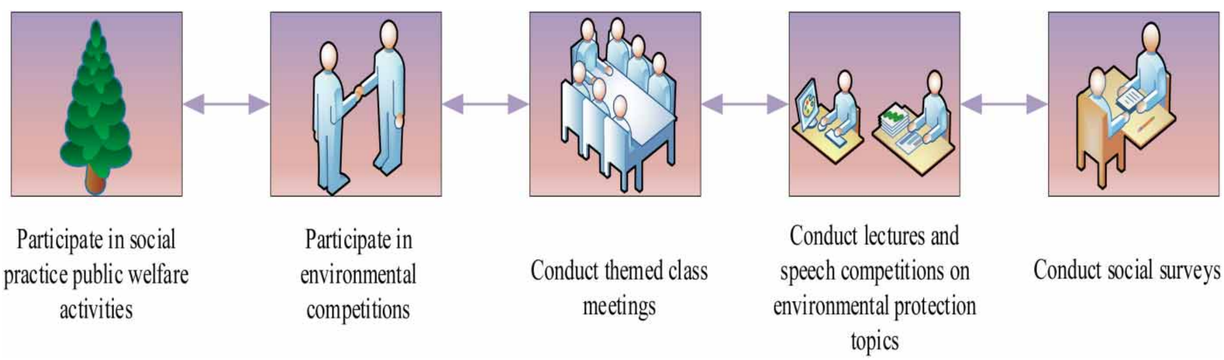

Figure 3 | Students' practical ability development.

consultation and dissemination of materials, environmental protection knowledge can be disseminated to residents. *Social survey*: Teachers can organize students to investigate the ecological environment of cities and villages, including urban garbage classification, agricultural waste disposal (Maina-Okori *et al.* 2018).

5. APPLICATION OF DEA IN AGRICULTURAL WASTE TREATMENT

The treatment of agricultural waste is an important part of environmental ecological protection and environmental and SDG education (Gontard 2018). In this article, the economic behavior performance of agricultural waste recycling entities is analyzed with the help of the DEA model, which is:

$$\begin{cases} \underset{\vartheta,\mu}{\overset{c}{\mathrm{Min}}}\,\vartheta \\ \text{s.t.}\ \sum_{c=1}^{c} \mu_c \chi_{m,c} \leq \vartheta^c \chi_{m,c} \\ \gamma_{n,c} \leq \sum_{c=1}^{c} \mu_c \gamma_{n,c} \\ \mu_c \geq 0 \\ \sum_{c=1}^{c} \mu_c = 1 \end{cases} \tag{1}$$

Among them, m represents the input data in the decision unit, and n represents the output data in the decision unit. For the c DMU, $\chi_{m,c}$ is the input of the agricultural waste recycling entity, and $\gamma_{n,c}$ is the output of the agricultural waste recycling entity. μ_c is the weighting factor of input m and output n, and ϑ^c is the efficiency value of the cth farmer.

Game theory is a mathematical framework used to model the strategic interactions between multiple decision-makers (players) in a given situation. DEA, on the other hand, is a nonparametric method used to evaluate the relative efficiency of multiple DMUs with multiple inputs and outputs. The application of game theory in DEA typically revolves around addressing issues related to cooperation and competition among DMUs. There are quite a few efficient ways in which game theory has been applied in DEA: (i) *Cooperative DEA*: In some cases, DMUs might be willing to cooperate with each other to improve their overall efficiency. Cooperative DEA models allow DMUs to form coalitions and work together to achieve higher efficiency levels collectively. Game theory helps to understand the strategies that DMUs can employ to form effective coalitions and distribute the benefits of cooperation. (ii) *Noncooperative DEA*: Conversely, DMUs might be in a competitive environment where cooperation is not feasible or is not in their best interest. Noncooperative DEA models can capture the competitive interactions among DMUs. Game theory can help analyze how self-interested behavior and competition impact the efficiency levels of individual DMUs and the overall system. (iii) *Game-theoretic efficiency*: Game-theoretic efficiency measures are developed based on cooperative or noncooperative game theory concepts. These measures take into account the interactions between DMUs and quantify the impact of strategic behavior on their efficiency scores. (iv) *Bargaining theory*: In some situations, DMUs may negotiate resource allocations or input/output levels. Game theory, specifically bargaining theory, can be used to model these negotiations and help identify equitable solutions or outcomes. (v) *Coalition formation analysis*: Game theory can be applied to analyze how DMUs might strategically form coalitions to gain bargaining power or to achieve specific goals collectively. (vi) *Transfer pricing*: In a multidivisional organization or in collaborative supply chain management, game theory can be used to develop transfer pricing mechanisms that encourage efficiency improvements and cooperation among different divisions or entities. For example, different regions and provinces may be involved in the treatment of river pollution. In this case, the DEA method can be used to evaluate the relative contribution and efficiency of each participant in the project, so as to provide a basis for the formulation of cooperation strategies. Through the cooperative model, we can analyze how to optimize the allocation of resources, improve the overall efficiency, and reduce the waste of resources and inefficiency that may be caused by noncooperative behavior.

By integrating game theory concepts into DEA, researchers and practitioners can gain a deeper understanding of the dynamics between DMUs and make more informed decisions regarding efficiency improvements and resource allocations in complex decision environments.

In this study, cooperative DEA was used to analysis systems of agricultural waste. This cooperative model is an extension of the traditional DEA model that allows DMUs to cooperate and form coalitions to improve their overall efficiency.

Cooperative DEA formulations typically involve modifications to the traditional DEA model to account for the cooperative interactions between DMUs. One of the commonly used formulations is based on the concept of game theory. To perform this model, there are several stages which should be defined and implemented: (i) *DMUs*: Let's assume there are n DMUs to be evaluated for efficiency. (ii) *Inputs and outputs*: Each DMU has multiple inputs and outputs. Inputs represent the resources consumed by the DMUs, and outputs represent the goods or services produced by the DMUs. (iii) *Efficiency score*: In the traditional DEA model, the efficiency score of each DMU is determined by comparing its weighted outputs to its weighted inputs relative to other DMUs. (iv) *Coalitions and payoff*: In the cooperative DEA framework, DMUs can form coalitions. A coalition is a group of two or more DMUs that agree to work together and pool their resources and efforts to increase their collective efficiency. (v) *Payoff function*: The payoff function represents the total efficiency achieved by a coalition. It is typically the sum of the individual efficiency scores of the DMUs in the coalition. (vi) *Formation of coalitions*: In a cooperative DEA setting, the decision is to find the optimal coalition structure, i.e., which DMUs should form coalitions with each other to maximize the overall efficiency. (vii) *Core solution*: The core solution is a concept borrowed from the cooperative game theory. It represents a stable coalition structure, where no DMU has an incentive to leave the coalition and form a new one because it cannot achieve a higher payoff by doing so. (viii) *Mathematical formulation*: The cooperative DEA problem can be formulated as a mathematical programming problem. The objective is to maximize the total efficiency achieved by all the coalitions subject to certain constraints. (ix) *Constraints*: The constraints in cooperative DEA typically include limitations on the number of DMUs that can be in a coalition, resource constraints, and the requirement that each DMU can only belong to one coalition. (x) *Solving the model*: Solving the cooperative DEA model involves finding the optimal coalition structure that maximizes the total efficiency while satisfying the constraints.

To sum up, agricultural waste recycling is a complicated decision-making process involving multiple stakeholders. In this process, different farmers, agricultural enterprises, local governments, and recycling agencies play different roles, and their decisions and actions directly affect the efficiency and quality of agricultural waste recycling. This constitutes a classic game theory problem, in which each player needs to consider the likely behavior of other players to make a decision that is best for them.

In the agricultural waste recycling market, there is often competition between different recycling agencies. To compete for market share and resources, they will adopt various strategies to enhance their competitiveness. In this case, the noncooperative model of game theory can be used to analyze this competitive relationship. Through the noncooperative model, we can predict the behavior choices of different recycling institutions in competition, evaluate their competitiveness and market position, and provide a basis for decision-making. For example, in the agricultural waste recycling market, there is fierce competition between the two main recycling agencies, A and B. They are trying to improve their recycling efficiency and service quality to attract more farmers to choose their own. In this case, game theory can help us analyze the competitive strategy between A and B, predict the actions they are likely to take, and assess the impact of these actions on each other and the market as a whole.

According to the game theory, the cooperative relationship of various subjects in agricultural ecological environmental protection can be analyzed, and the coordination degree model can be established to measure the coordination degree of agricultural waste utilization subjects:

$$L = 1 - T_e/B_h \tag{2}$$

Among them, L is the coordination degree, T_e is the standard deviation, B_h is the mean, and T_e/B_h is the coefficient of variation.

The standard deviation and mean value of the behavior performance of agricultural waste recycling entities are calculated, and the coordination degree value can be obtained. The calculation process is expressed as follows:

$$T_e = \sqrt{(\sigma_1 - \bar{\sigma})^2 + (\sigma_2 - \bar{\sigma})^2 + \ldots + (\sigma_m - \bar{\sigma})^2/m} \tag{3}$$

$$B_h = \bar{\sigma}^* \tag{4}$$

$$L = 1 - \frac{\sqrt{(\sigma_1 - \bar{\sigma})^2 + (\sigma_2 - \bar{\sigma})^2 + \ldots + (\sigma_m - \bar{\sigma})^2/m}}{\bar{\sigma}^*} \tag{5}$$

The Tobit model is a statistical regression model used for analyzing data that contain both observed and censored or truncated dependent variables. It was developed by James Tobin in 1958 (Tobin 1956) and is particularly useful when dealing with data where a significant portion of the dependent variable values are either not observed (censored) or fall below a certain threshold (truncated). This model is an extension of the standard linear regression model that takes into account the presence of these limitations in the data. The general form of the Tobit model can be represented as follows: for censored observations ($y^* < 0$): $y = 0$ (observed outcome) and for uncensored observations ($y^* > 0$): $y = y^*$ (observed outcome), where y is the observed dependent variable (censored or truncated). y^* is the latent (unobservable) dependent variable that follows a linear regression model. $y^* > 0$ for uncensored observations and $y^* < 0$ for censored observations. The Tobit model assumes that the latent variable y* is linearly related to a set of explanatory variables (independent variables), just like in a standard linear regression model. However, since we only observe y and not y^*, the model simultaneously estimates the relationship between y^* and the explanatory variables and the probability of observing censored or truncated values. To estimate the parameters of the Tobit model, a method called maximum likelihood estimation is commonly used.

The Tobit model is used for regression analysis, which takes the utilization performance of the micro-subject on the recycling of agricultural waste as the dependent variable and takes the characteristics of the micro-subject and the external environment as the independent variables.

$$\begin{cases} \gamma_p^* = b\chi_p + \varphi_p \\ \gamma_p = \gamma_p^*, \ \text{if } \gamma_p^* > 0 \\ \gamma_p = 0, \ \text{if } \gamma_p^* \leq 0 \end{cases} \tag{6}$$

6. EXPERIMENTAL ANALYSIS OF ENVIRONMENT AND SDG EDUCATION AND AGRICULTURAL WASTE UTILIZATION

In this article, the recycling efficiency of agricultural waste in cities F, S, H, and N was first discussed, and then the biomass utilization efficiency of straw waste was studied. Finally, the effect of the implementation strategy of environmental and SDG education based on the concept of green ecology was studied.

6.1. Regional agricultural waste utilization efficiency

The recycling efficiency of agricultural waste in cities (i.e., Foshan [F], Heshan [H], Nanxiong [N], and Shantou [S]), located in Guandong province, was investigated and recorded, and the comprehensive utilization efficiency, pure technology utilization efficiency, and scale efficiency of agricultural wastes in these four cities were obtained. The specific results are shown in Figure 4.

In Figure 4, the comprehensive utilization efficiency of agricultural waste in F city was 37.97%, and the comprehensive utilization efficiency of agricultural waste in S city was 45.02%; the comprehensive utilization efficiency of agricultural waste in H city was 34.12%, and the comprehensive utilization efficiency of agricultural waste in N city was 44.27%. The comprehensive utilization efficiency of agricultural waste in S city was the highest, and the comprehensive utilization efficiency of agricultural waste in H city was the lowest. In terms of pure technical utilization efficiency of agricultural waste, the pure technical utilization efficiency of agricultural waste in N city was the highest, and the pure technical utilization efficiency of agricultural waste in H city was the lowest. In terms of scale utilization efficiency of agricultural waste, the scale utilization efficiency of agricultural waste in S city was the highest, and the scale utilization efficiency of agricultural waste in H city was the lowest.

6.2. The proportion of each crop generated in straw waste

Agricultural waste not only includes agricultural production wastes such as crop straw, weeds, and fruit husks but also includes livestock and poultry excreta such as livestock and poultry manure and livestock pen litter. Moreover, it also includes the processing waste of agricultural and sideline products such as mushroom residue and sugarcane bagasse. This article mainly analyzed straw waste and analyzed the proportion of crops produced by rice, wheat, and other crops, which are shown in Figure 5.

In Figure 5, the proportion of crop straw due to rice cultivation in F city was 63.45%, and the proportion of crop straw due to rice cultivation in S city was 54.27%. The proportion of crop straw due to rice cultivation in H city was 64.74%, and the

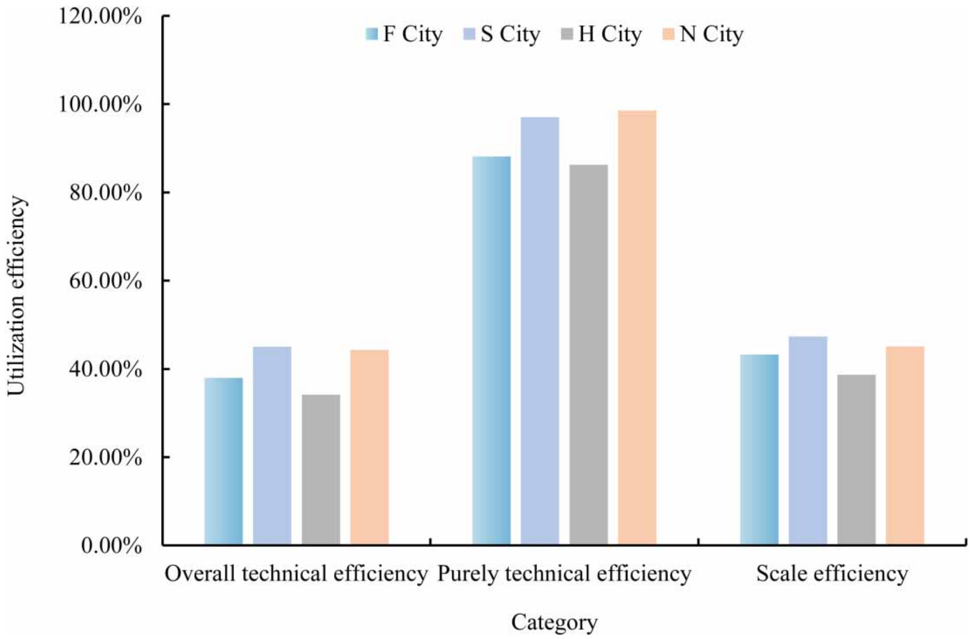

Figure 4 | Regional agricultural waste utilization efficiency.

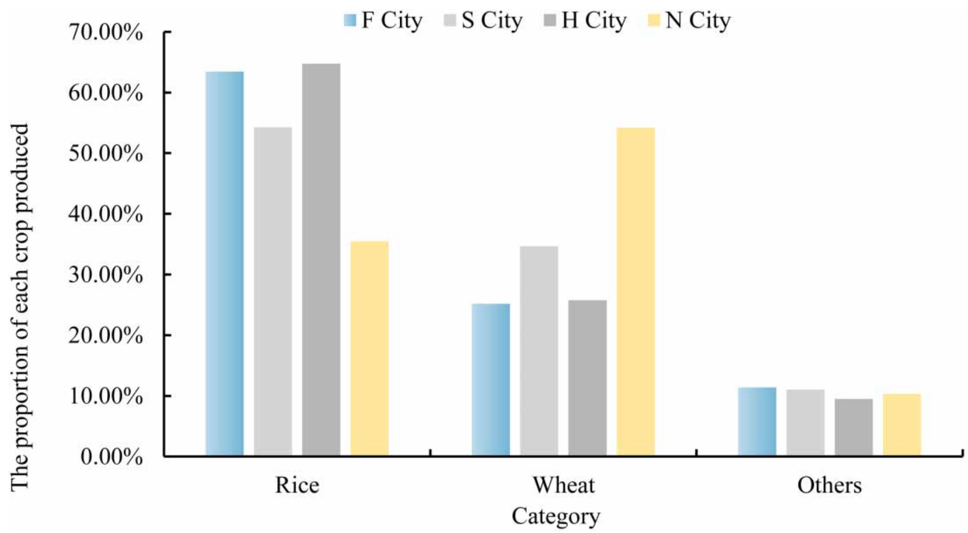

Figure 5 | The proportion of each crop produced in straw waste.

proportion of crop straw due to rice cultivation in N city was 35.47%. It can be seen that the generation of straw waste in cities H, F, and S was mainly rice cultivation. The proportion of crop straw generated by wheat cultivation in N city was 54.23%, and unlike the other three cities, the straw waste generation method in N city was mainly wheat cultivation.

6.3. Biomass utilization measurement of straw waste

Biomass resources can be divided into six categories: agricultural biomass, forestry biomass, energy plants, aquatic plants, poultry and livestock manure, and domestic waste, among which the utilization prospects of agricultural biomass are the most impressive. The utilization methods of crop straw waste can be divided into four types: fertilizer, base, feed, and biomass utilization. The proportion of biomass utilization of crop straw waste is shown in Figure 6.

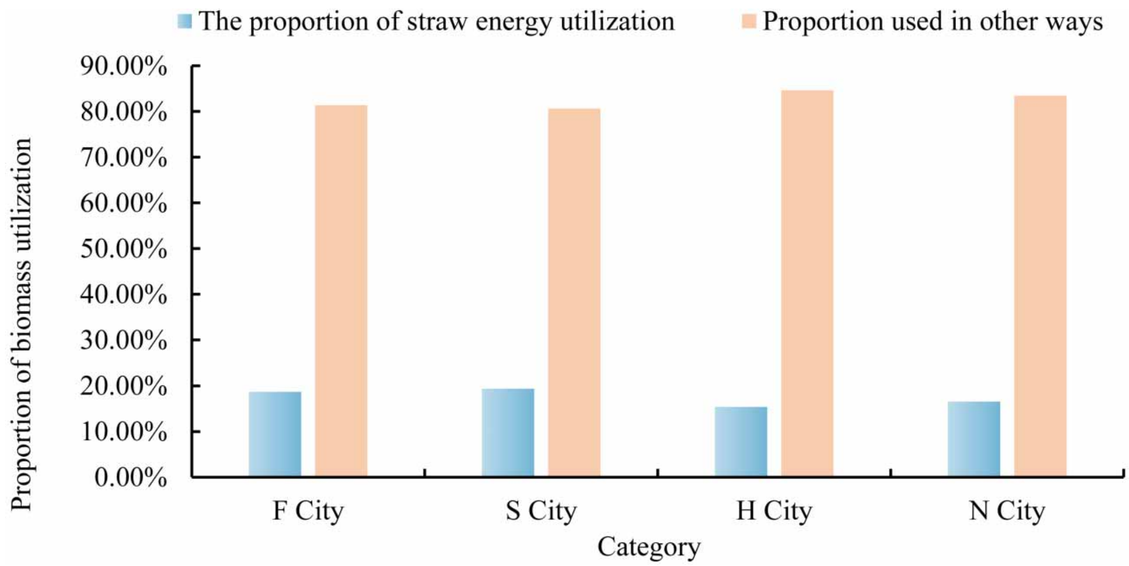

Figure 6 | Biomass utilization measurement of straw waste.

In Figure 6, the proportion of straw waste biomass utilization in F city was 18.67%, and the proportion of straw waste biomass utilization mode in S city was 19.36%, the proportion of straw waste biomass utilization in H city was 15.37%, and the proportion of straw waste biomass utilization mode in N city was 16.52%. It can be seen that the proportion of straw waste biomass utilization mode in S city was the highest, and the proportion of straw waste biomass utilization mode in H city was the lowest.

6.4. Students' awareness of environmental protection

The traditional education method of environment and SDG is referred to as general education method, and the education method combined with the education strategy of environment and SDG proposed in this article is referred to as green ecological education method. Five weeks of environmental and SDG education activities were conducted, and the students' level of environmental awareness was observed. The specific results are shown in Table 1.

From Table 1, it can be seen that on the whole, the index of students' environmental protection awareness under the green ecological education method was higher than that of the environmental protection awareness level index of students under the general education method. From the specific data, in the first week, the environmental protection awareness index of students under the green ecological education method was 79.36%, and the environmental protection awareness index of students under the general education method was 75.35%. The environmental protection awareness index of students under the green ecological education method was 4.01% higher than that of the general education method. In the 5-week period, the average environmental protection awareness index of students under the general education method was 77.13%, and the average environmental protection awareness index of students under the green ecological education method was 82.34%. The average environmental awareness index of students under the green ecological education mode

Table 1 | Students' awareness of environmental protection

	General means of education (%)	Green and ecological education methods (%)
1	75.35	79.36
2	76.24	81.78
3	78.26	82.35
4	78.33	83.65
5	77.46	84.57

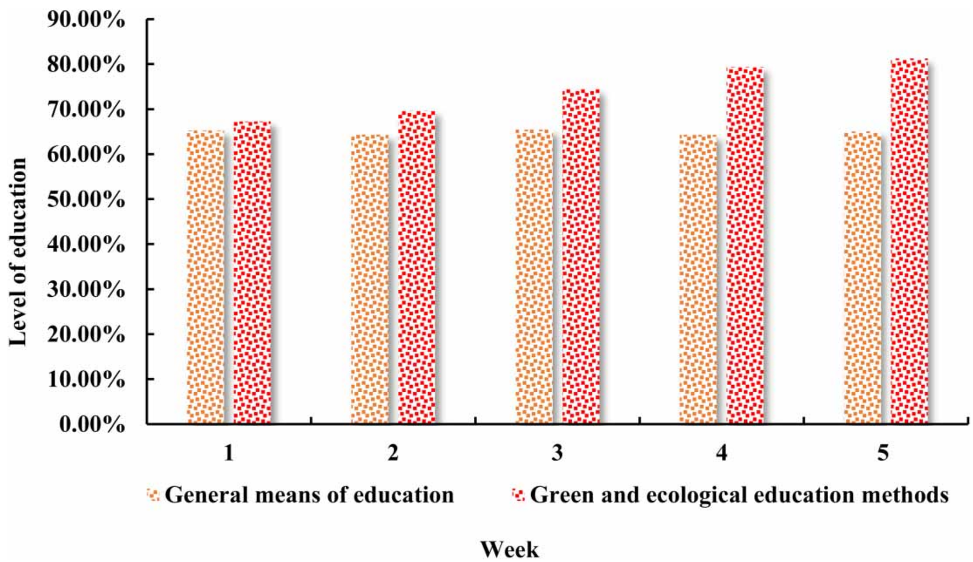

Figure 7 | The level of environmental education of teachers.

was 5.21% higher than the average environmental protection awareness level index of students under the general education mode.

6.5. The level of environmental education of teachers

After cultivating the quality of environmental education of teachers, the level of environmental education of teachers under the general education method and the green ecological education method was recorded. The specific results are shown in Figure 7.

From Figure 7, it can be seen that the environmental education level index of teachers under the general education mode had not changed much in 5 weeks, and the environmental education level index of teachers under the green ecological education mode had shown an upward trend in 5 weeks. From the specific data analysis, in the first week, the environmental education level index of teachers under the general education mode was 65.23%, and the environmental education level index of teachers under the green ecological education mode was 67.25%; the difference between the two was 2.02%. In the fifth week, the environmental education level index of teachers under the general education mode was 65.04%, and the environmental education level index of teachers under the green ecological education mode was 81.24%; the gap between the two was more pronounced. The average environmental education level index of teachers under the general education mode was 64.85%, and the average environmental education level index of teachers under the green ecological education mode was 74.36%; the average environmental education level index of teachers under the green ecological education mode was 9.51% higher than that of teachers under the general education mode.

7. CONCLUSIONS

This article introduced the content of environmental education and ESD, and explored the existing problems of environment and SDG education. This article not only proposed some implementation strategies for ESD but also conducted research on ESD and agricultural waste utilization. The results showed that the utilization rate of agricultural waste was 37.97% in F city, 45.02% in S city, 34.12% in H city, and 44.27% in N city. In terms of the proportion of straw waste generated, it was 63.45% in F city, 54.27% in S city, 64.74% in H city, and 35.47% in N city. The biomass utilization ratio of straw waste was 18.67% in F city, nd 19.36% in S city, 15.37% in H city, and 16.52% in N city. It can be seen that the comprehensive utilization efficiency and scale utilization efficiency of agricultural waste in S city were the highest, and the pure technology utilization efficiency of agricultural waste in N city was the highest; S city had the highest proportion of straw waste biomass utilization. While compared with the general education method, the average environmental protection awareness of students and the environmental education level of teachers under the green ecological education method have been significantly improved.

While DEA is a valuable technique for evaluating the efficiency and performance of environmental pollution management strategies, it also has some limitations when applied in this context such (i) limited consideration of external factors, (ii) single-dimensional analysis, input and output measurement issues with accurate performances, homogeneity assumption, scale and aggregation problems, time dimension, and subjectivity in selection of DMU. To overcome these restrictions, further studies can be improved by using artificial intelligence models (prediction, optimization, and classification) and multi-decision criteria methodology for driving interactions of environmental issues and education systems.

AUTHORSHIP STATEMENT

L.G., H.X., and D.X.: performance of the methodology for DEA and analyses; D.X.: analyzing environmental studies of six cities; L.G., H.X., and D.X.: reviewing educational systems; L.G., H.X., and D.X.: preparing initial draft; L.G., H.X., and D.X.: reviewing and editing manuscript.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Agbedahin, A. V. 2019 Sustainable development, education for sustainable development, and the 2030 agenda for sustainable development: Emergence, efficacy, eminence, and future. *Sustainable Development* **27** (4), 669–680.

Amirteimoori, A., Allahviranloo, T., Zadmirzaei, M. & Hasanzadeh, F. 2023 On the environmental performance analysis: A combined fuzzy data envelopment analysis and artificial intelligence algorithms. *Expert Systems with Applications* **224**, 119953.

Ardoin, N. M. 2018 Environmental education and K-12 student outcomes: A review and analysis of research. *The Journal of Environmental Education* **49** (1), 1–17.

Braun, T., Cottrell, R. & Dierkes, P. 2018 Fostering changes in attitude, knowledge and behavior: Demographic variation in environmental education effects. *Environmental Education Research* **24** (6), 899–920.

De Oliveira, M. S., Steffen, V., De Francisco, A. C. & Trojan, F. 2023 Integrated data envelopment analysis, multi-criteria decision making, and cluster analysis methods: Trends and perspectives. *Decision Analytics Journal* **8**, 100271.

Genc, M., Genc, T. & Rasgele, P. G. 2018 Effects of nature-based environmental education on the attitudes of 7th grade students towards the environment and living organisms and affective tendency. *International Research in Geographical and Environmental Education* **27** (4), 326–340.

Glaab, S. & Heyne, T. 2019 Green classroom vs. classroom–Influence of teaching approaches, learning settings, and state emotions on environmental values of primary school children. *Applied Environmental Education & Communication* **18** (2), 179–190.

Gontard, N. 2018 A research challenge vision regarding management of agricultural waste in a circular bio-based economy. *Critical Reviews in Environmental Science and Technology* **48** (6), 614–654.

Guo, M. 2021 Construction of college English classroom ecological teaching mode based on modern technology. *International Journal of Social Science and Education Research* **4** (5), 101–107.

Huang, S. 2023 The comprehensive environmental efficiency analysis based on a new data envelopment analysis: The super slack based measure network three-stage data envelopment analysis approach. *Journal of Cleaner Production* **400**, 136689.

Ilma, S. & Wijarini, F. 2017 Developing of environmental education textbook based on local potencies. *Online Submission* **3** (3), 194–201.

Junior, B. A. 2019 A retrospective study on green ICT deployment for ecological protection pedagogy: Insights from field survey. *World Review of Science, Technology and Sustainable Development* **15** (1), 17–45.

Kalogiannakis, M. & Papadakis, S. 2017 Combining mobile technologies in environmental education: A Greek case study. *International Journal of Mobile Learning and Organisation* **11** (2), 108–130.

Kulmatov, P. M. & Tajibayev, M. A. 2021 Interaction of moral, aesthetic and ecological education. *Scientific Progress* **2** (1), 1149–1154.

Li, Y. 2018 Study of the effect of environmental education on environmental awareness and environmental attitude based on environmental protection law of the People's republic of China. *Eurasia Journal of Mathematics, Science and Technology Education* **14** (6), 2277–2285.

Liu, Y. 2019 Effects of information technology integrated music ecological education on learning interest and performance. *Ekoloji* **28** (107), 3441–3448.

Liu, Q., Cheng, Z. & Chen, M. 2019 Effects of environmental education on environmental ethics and literacy based on virtual reality technology. *The Electronic Library* **37** (5), 860–877.

Maina-Okori, N. M., Koushik, J. R. & Wilson, A. 2018 Reimagining intersectionality in environmental and sustainability education: A critical literature review. *The Journal of Environmental Education* **49** (4), 286–296.

Marcinkowski, T. & Reid, A. 2019 Reviews of research on the attitude–behavior relationship and their implications for future environmental education research. *Environmental Education Research* **25** (4), 459–471.

Saribas, D., Kucuk, Z. D. & Ertepinar, H. 2017 Implementation of an environmental education course to improve pre-service elementary teachers' environmental literacy and self-efficacy beliefs. *International Research in Geographical and Environmental Education* **26** (4), 311–326.

Sinakou, E., Pauw, J. B.-d. & Van Petegem, P. 2019 Exploring the concept of sustainable development within education for sustainable development: Implications for ESD research and practice. *Environment, Development and Sustainability* **21** (1), 1–10.

Taleb, M. 2023 Modelling environmental energy efficiency in the presence of carbon emissions: Modified oriented efficiency measures under polluting technology of data envelopment analysis. *Journal of Cleaner Production* **414**, 137743.

Tobin, J. 1956 The interest-elasticity of transactions demand for cash. *The Review of Economics and Statistics* **38** (3), 241–247.

Tristananda, P. W. 2018 Membumikan Education for Sustainable Development (ESD) di Indonesia dalam menghadapi isu–isu global. *Purwadita: Jurnal Agama dan Budaya* **2** (2), 42–49.

Ye, F.-F., Yang, L.-H., Wang, Y.-M. & Chen, L. 2020 An environmental pollution management method based on extended belief rule base and data envelopment analysis under interval uncertainty. *Computers & Industrial Engineering* **144**, 106454.

Zhang, F. & Yang, J. 2022 The ecological civilization education construction in art education under the background of 'Internet + '. *Alexandria Engineering Journal* **61** (11), 8955–8962.

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