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Contents

Articles

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Article

Agricultural extension in Turkey within the framework of central and local governments

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Abstract: Agricultural extension and communication is a system that has been subject to very different management by many different institutions in Turkey. In this study, the issue was examined as the period when it was evaluated by local governments with village institutes and the years when it was handled by the central authority. Afterwards, the organizations responsible for agricultural extension today were specified, and their effectiveness was investigated with other studies conducted for the producer. It has been found that the period before 1960, when the desire for enlightenment of the rural area, the belief that one could make a living from agriculture and animal husbandry, and the government policies were based on agriculture, was the brightest period of agricultural extension. It has been determined through secondary data that the effectiveness of the central government's ministries, cooperatives, producer organizations, and private sector extension system is limited, insufficient to solve problems onsite and on time, or cannot be spread throughout Turkey. The aim of the study is to examine agricultural extension within the framework of rural area policies of governments in Turkey.

Keywords: agricultural extension; local government; village institutes

1. Introduction

According to the Turkish Language Association [1], 'central management' is a management style in which authority is concentrated in one place in terms of management, supervision, and operation. Local government, on the other hand, is a public legal entity that meets the common needs of the people of the province, municipality, or village there and whose general decision-making bodies are elected by the people there. It is the local administration. Considering the increasing importance of local governments after 1864, we see that local governments have started to take place in the administrative structure of Turkey [2]. It can be said that local governments in the modern sense emerged in the 19th century in Turkey. The emergence of local governments in western countries has taken place in the historical process starting in the 12th century and up to the present day [3].

In the 16th century and later, thinkers such as Jeremy Bentham and Turgot emphasized the importance of local governments. Socialists such as Webbler and Fabian, the autonomous municipalism movement that emerged in the USA, and French thinkers such as Alexis de Tocqueville, Proudhon, and Sieyes were also influential in the development of local governments in this process [4]. It coincides with the beginning and beyond of the 21st century when local governments generally become stronger and more functional all over the world and provide an ever-expanding service with different organizational structures [5]. In Turkey, on the other

hand, local governments generally have a central organizational structure. This situation causes steps to be taken to strengthen local governments from time to time, and from time to time, steps back to the contrary of this understanding [6]. Regarding the use and development of technology in local governments, there is an expectation that agricultural development will take place from the local [7].

The logic of agricultural extension lies in determining the problem of the producer locally and solving it within itself with the help of consultants. Agricultural policies developed in rural areas in Turkey are relative and vary on the basis of governments. The most successful period of agricultural extension with local governments and village institutes was experienced in the first years of the establishment of the Republic. Although the execution of agricultural extension by various institutions with the central government is relative in terms of situation assessment, there are problems in the system when the issue is handled in a producer-oriented manner. The aim of this study is to examine agricultural extension within the framework of rural area policies of governments in Turkey.

2. Materials and methods

The main material of the study consists of secondary data obtained from publications such as articles, magazines and newspapers.

In this type of research, in order to get to know the research universe and sample set closely, to make observations and to derive correct meanings from the observations, the researcher must enter that community and participate in every stage of their life for a sufficient period of time. The fact that researchers have been working within the provincial organization of the Ministry of Agriculture for more than 10 years provides some advantages such as knowing the socio-cultural structure of the villages they are researching and being aware of the economic situation in the region. Considering these advantages; it provides researchers with facilities such as making observations about the research subject in the field, reaching the source persons, and creating an environment of trust during the interviews. The environment of trust created in the research area enables the people involved in the research to give more accurate answers to the questions posed. All these are important factors that can positively affect the validity and reliability of the study [8]. The fact that the researcher has been working in this village for a long time is also important in this respect.

3. Findings and discussion

Agricultural extension in government programs

Agricultural extension activities until the 1960 Constitution: The Republic of Turkey, which was established on 29 October 1923, is a country that is still quite young, has just come out of the war and has to pay the debts from the Ottoman Period. Despite this, state institutions have started to work with all their strength in the field of agriculture, as in every field, in line with the mission of the founder leader Mustafa Kemal Atatürk, ‘The basis of the national economy is agriculture’.

With the adoption of the new alphabet on 1 November 1928, an educational

campaign was organized throughout the country. For this purpose, public schools have been opened all over the country. In these schools, it was aimed to teach those who could read and write with new letters, and with the establishment of public houses in 1932, educational mobilization became widespread. The purpose of the establishment of the community centers; to develop the people not only in literacy and basic knowledge but also in the field of cultural, social and fine arts, to process and enrich national values with modern methods, to spread and root Atatürk's revolution and principles [9].

The fact that young intellectuals worked completely devotedly in the public houses led to the development of the public houses in a short time [10]. Folklorists, historians and sociologists had the opportunity to examine the villages in the activities of the public houses. However, the successes achieved in the cities could not be achieved in the villages, which caused attention to be drawn to the villages.

In the villages where eighty percent of the country's population lives, the number of schools is almost non-existent. The educational needs of the village people are not limited to literacy, infectious diseases cannot be combated, production is carried out with primitive methods. The peasants, who bore the heavy burden of the War of National Independence, have not yet attained the qualification of citizens of the republic to keep democracy alive. Most importantly, it was difficult to provide services to the village between 1930 and 1940. The efforts to provide services to the village, which were undertaken with the Republic, were either incomplete because they did not meet the expectations of the villagers or could not be achieved. For success, a new type of intellectual who understands the language of the peasant is needed. These intellectuals will also be able to emerge from the peasant himself. The great educator İsmail Hakkı Tonguç, who understood the importance of the work and was also a peasant boy, started activities for the development of the village as both the theoretician and the founder of the Village Institute system. This task was appointed to him by the Minister of National Education, Saffet Arıkan, one of Atatürk's former staff, and the next minister, Hasan Ali Yücel, embraced his initiatives. It is possible to summarize İsmail Hakkı Tonguç's perspective on the village problem and the liberation of the peasant as follows: İsmail Hakkı Tonguç, who came from the village, first made a very serious village examination and created a 20-year plan draft. According to this plan, by 1954 there will be no village without teachers, protectors, agricultural technicians and health services. This plan is revolutionary in terms of the history of Turkish agricultural extension. Because, for the first time since the Ottoman Empire period, the people will determine their own needs and local solutions will be found for these needs.

Under the conditions of the period, it is a big problem to find literate, village children and students for the institutes to be opened in the villages. Despite the resistance of classical educators to this practice, Tonguç opened a 4-month course in Eskişehir in 1936 to assign a group of literate young people selected from literate young people as "temporary teachers" in the villages. The first 84 trainers who completed these courses and assigned them to Ankara villages were extremely successful and the trainer courses were opened and multiplied in other parts of the country in a short time.

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In 1937, with the "Village Trainers Law", teaching was made legally operative. Based on this law, a trainer course was opened in Eskişehir, Izmir and Edirne. However, considering that it would not be possible to continue education at the primary school level in the villages with instructor courses over time, it was envisaged that "village teacher schools" would be opened with the Law No. 3704. Kızılçullu, Çifteler and Gölköy Trainer Courses, which form the basis of village institutes, will be transformed into village teacher training schools.

However, it was decided that a teacher who only teaches the villagers to read and write would not be sufficient in the education of the villagers, and that the institutions that would train village teachers should train versatile personnel, and it was deemed appropriate to name the new institutions to be opened as "village institutes".

Students studying in village institutes were given authority and responsibility to develop their personalities, and they were told what they should do to eliminate the difficulties they may encounter when they go to the villages as officials. After gaining all these features, the graduates of the village institute, who went to the village as teachers, created an educational environment in the villages, starting from the students and reaching the family. With the courses organized in this educational environment, training was provided for literacy and gaining a profession.

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According to the official curriculum of the Village Institutes of 1943; culture courses are programmed as 22 h, agricultural courses and studies are 11 h, and technical courses and studies are 11 h. Agricultural courses; it consists of field agriculture, horticulture (nursery, fruit growing, viticulture, vegetable growing), industrial plants agriculture, animal science, poultry knowledge, beekeeping and silkworms, fisheries and aquaculture and agricultural arts courses. In technical courses and studies; village blacksmithing (farrier, motorwork), village dulger (carpentry), village construction (brick and tile maker, stonemasonry, lime making, masonry, plastering, concrete) while village and handicrafts (sewing, sawing, embroidery, knitting and weaving, agricultural arts) courses are available for female students [12]. When the program was examined, in addition to culture and vocational knowledge courses, agricultural and technical courses were taught in order for the villagers to contribute to the development of the village to carry out agricultural activities in accordance with scientific principles. Another remarkable lesson is the organization of the peasant in branches of production such as agricultural enterprises economy and cooperatives, and the introduction of a modern development approach such as cooperatives to teacher candidates.

In the programs of the Institute, the production and evaluation of elements such as fish, sponges and reeds in streams, rivers, lakes and seas are included according to scientific conditions. In addition to these; afforestation of lands, floriculture, drying of swamps, road construction, opening water channels, making barren areas productive, producing new plant varieties according to the environment are examples of other works in the program. In addition, protection measures from diseases that harm animals and plants were among the courses given to students. In the sixth article of the Law on Village Institutes, it is stated that the teachers will carry out all kinds of education and training works of the villagers in the villages where they are appointed, that they will guide the villagers with exemplary fields, vineyards, gardens and workshops for the implementation of agricultural works according to scientific methods, and that the villagers will benefit from these practices [13]. From this, it can be understood that the graduates of the Village Institute will be able to help not only the students with literacy, but also with the education needed by the villagers.

In 1947, with the laws numbered 4274 and 5210, it was accepted that the construction of teachers, health officers, and midwives houses of village schools would be undertaken by the state; all living and inanimate fixtures and equipment tools given to the institutes were taken back, and apart from these, the High Village Institute in Hasanoğlan and all instructor courses were closed. In other words, agricultural extension will be implemented by the central government. With Law No. 5541 enacted in 1949, the administration of admitting only village children to the institutes was abandoned. In 1950, the village institutes were completely closed. In other words, agricultural extension will be handled by the central government.

In 1950, the Democratic Party (DP) came to power. During the DP government, great importance was given to vocational and technical education. The most important reason for this; within the framework of foreign aid received from the USA, the need to train technical and main personnel for the use of many technical tools and machines, especially agricultural machinery, is felt. For this, a three-year development plan has been put into effect in cooperation with the Ministry of Agriculture and the Ministry of National Education (MEB). Within the framework of the plan, motor departments were opened in some art schools. Especially in line with the joint plan made with the Ministry of Agriculture, the foundations of 2 art institutes that will provide training on engines were laid by the Minister of National Education of the time, Tevfik İleri [14]. The first of DP's vocational and technical staff schools, which are based on training different professionals in different fields, is the motor machinery school opened in Izmir. Again, an independent motor and machinery school was opened in the 1953–1954 academic year within the Izmir Mithat Paşa Men's Art Institute. During this period, a different vocational school, the printing school, was established in Istanbul [15].

It can be said that public education studies during the DP government were too weak and weak to be compared with the Atatürk Period and İsmet İnönü Period. The draft law submitted by Manisa Deputy Refik Şevket İnce and 7 of his friends, who submitted the bill on the closure of public houses to the parliament, was passed by the constitutional commission and published in the official gazette. Since the public chambers are entirely the product of the labor of the citizens in the places where they are located, they were accepted as the property of the region and left to the legal entity of the village or the town municipalities depending on their location [14].

After the closure of the community centers, non-formal education functions were continued by the Public Education Bureaus established within the Ministry of National Education and the public chambers in the villages. After these dates, the main development in public education took place after the 1960s, and in 1960, the General Directorate of Public Education was established under the Ministry of National Education [16].

During the DP government, foreign experts were brought from abroad to consult their opinions and suggestions in the field of education in our country and reports were prepared. It is noteworthy that all the specialists who came during this period were from the United States. During the Democratic Party period, the influence of the USA in educational institutions is quite clear, as in all institutions of the state. During this period, Watson Dickerman was officially invited in the field of public education, Kate Wolferd for village primary schools and primary schools in

general, John Rufi and Ellswort Tompkins for secondary education institutions, Lester Beals for guidance, and John Rufi for teacher training problems [14].

After making the necessary preparations for village institutes, the DP government made the city primary teacher schools and village institutes a uniform first teacher training school with the law numbered 6234 dated 27.01.1954 and published on 04.02.1954 in line with the reports of foreign experts.

In the mid-1950s, there were 42 teacher training colleges across the country. By the late 1950s, this number had risen to 52. 21 of these schools are the continuation of village institutes and the education period is 6 years. These schools were established almost equally interspersed throughout the country as a requirement of the establishment purposes of the village institutes. The aim of this application is to provide equal opportunities in education to the rural children of the whole country and to enlighten all the villages of the country from the light of these schools.

The educational tradition in the first teacher training schools is very close to the environment of the village institute. Although the students were not directly involved in the production, they attended summer courses for one month during the summer term. In these courses, depending on the characteristics of the region, they were engaged in studies such as walling, beekeeping, fruit growing, poplar growing, and these studies were continued in the agricultural lessons throughout the year. In addition, all students cleaned their own classrooms and contributed to this service by keeping watch in units such as the cafeteria and laundry. In the 1958–1959 period, there were 19,835 students in 52 primary teacher training schools, 75% of whom were rural children. At that time, the first teacher training schools were the educational institutions with the widest range of free boarding opportunities, such as military schools [17].

The DP period, which covers the years 1950–1960, was a period of reproduction and continuity of the Turkish National Education Ideology, which was created and established during the single-party regime in the field of education. However, no significant momentum has been created in terms of the realization of the actions. The most important reasons for this situation are the lack of significant stability in education and the conflict between the traditional education system and the western education system in some ways [14].

As reported by Karakök [18]; When we look at the issue of education and culture collectively in the ten-year life of the Menderes Government, it is seen that the most importance is given to vocational and technical education. As a matter of fact, the 6th Congress, which was convened in 1957. The National Education Council focused only on “vocational technical education” and “public education”.

After the May 27 Coup, which took place as a reaction to the unplanned period between 1950 and 1960, a “planned development” policy was adopted [19]. With the 1961 Constitution, the preparation of development plans in Turkey has become a legal obligation. Since the First Plan, development plans in Turkey have been prepared as “macro”, “central” and “staged” within a “holistic” planning approach that covers the economic, social and cultural fields [20].

Within the framework of the planned development policy, education has taken its place in development plans as a “sector” that meets the “manpower needs of the economy” and contributes to social change by “raising the education level of the

people". Educational planning studies within the development plans have focused on the provision of the resources required to fulfill the tasks required by economic and social development on the one hand, and the distribution of the resources provided among the types and levels of the education system on the other.

Developments in Turkey's economic and social structure and planning approach (mixed economic policy, the new liberal economic policies after the September 12, 1980 coup d'état, agreements with the International Monetary Fund and the World Bank, the European Union membership process, etc.) have affected education planning and the development of the education system. Due to the fact that education is seen as one of the "tools" of economic and social development, this process of influence has reached a power that directly determines educational planning approaches.

In this period, instead of increasing the desire of individuals to study, it was aimed to establish secondary and general high school stages that would prepare the talented ones among those who want to study for higher education and to advance them in this direction. The focus is on directing those who are less talented to vocational-technical high school and non-formal vocational education that will prepare them for the profession [21].

(see **Figure 1**) As reported by Demirtürk [22]. After the 27 May 1960 operation, the issue of primary education became even more important by political circles. In 1962, the education programs implemented in 14 provinces of Turkey for trial purposes were applied to the whole country in 1968–1969 and progress was made in primary education. The period in which an important move was made in education after the 1960 Operation was the proposal of the Nihat Erim Government, which was established after the 12 March 1971 Intervention, to increase primary education to eight years.

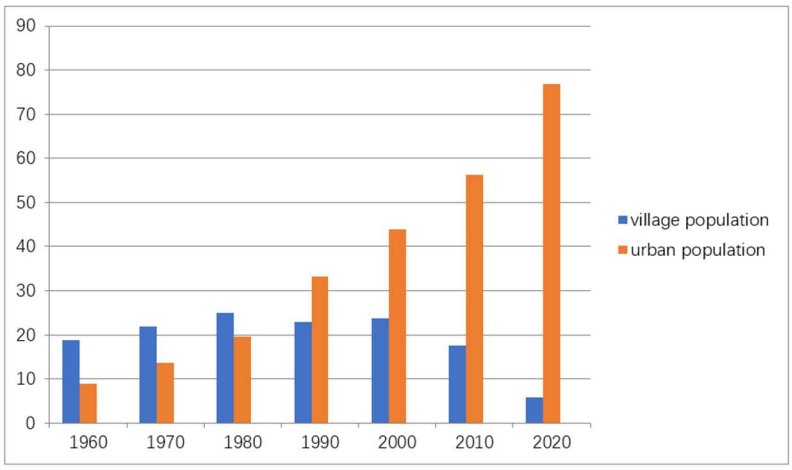

Figure 1. Changes of population in village and urban between 1960-2020

Between 1987 and 1994, there were 5 separate government periods. The most decisive of these is the abolition of the schools in the villages over time and the transition to mobile education. Because this decision, which was taken with the central authority, forced the people to migrate from the village to the city rapidly. This practice, which was carried out with 24,754 students in 29 provinces, 1394

villages, neighborhoods and hamlets in the 1991–1994 academic year, was expanded in 57 provinces in the 1993–1994 academic year. In these provinces, 4346 village primary schools with a small number of students and a total of 83,749 students continue their education and training by moving to 1654 centers on a daily basis [23].

According to the results of the address-based population registration system in 2020; The population of Turkey is 83 million 614 thousand 362 people. The proportion of people living in provincial and district centers in Turkey, which was 92.8% in 2019, increased to 93% in 2020. On the other hand, the proportion of people living in towns and villages decreased from 7.2% to 7% [24]. As in the world, there is a continuous migration trend from the village to the city in Turkey. In addition, the village population is getting older. In the study titled "Partnership structure and evaluation of cooperative activities in agricultural cooperatives in Edirne", Başaran and Irmak [25] determined the average age of farmers as 52.16 years. In a study conducted by Cengiz [26] in Antalya Province, it was determined that the majority of producers (91.2%) were male, primary school graduates, and more than half of the surveyed producers were over 51.1 years old. In other words, the population engaged in agriculture in today's Turkey constitutes 7% of the Turkish population. The majority of this group is over 54 years old and is predominantly a primary school graduate. Education is all social processes that are effective in helping individuals acquire society's standards, beliefs and ways of life [27]. Education level is accepted as an indicator of social development [28].

The concept of agricultural extension has changed considerably according to the conditions of the current period, the expectations, wishes and goals of producers and governments. For example, Mounter introduced the concept of agricultural extension in 1973. According to Mounter, agricultural extension is defined as "a service or system that helps farmers improve agricultural production methods and techniques through training, increase productivity in production and agricultural income, improve living standards, and raise the social and educational level of rural life." [29].

While creating the concept of publication here, the importance of income and information was emphasized. Russell [30] defines the concept of agricultural extension as: "Increasing the productivity of farmers' products and raising their living standards; it is defined as "providing the necessary knowledge and skills for the adoption of new agricultural production methods". With the influence of the green revolution, the element of efficiency has come to the fore in this concept.

Van den Ban and Hawkins [31] define it as "an education system for the planned use of information communication methods to help farmers form ideas and make the right decisions on every subject". In 1996, the communication element of agricultural extension became decisive.

UN Commission; he thinks that the agenda of the 21st century will be to achieve the desired production increase by reducing negative environmental conditions. "This can only be possible by applying sustainable methods and permanent solutions in agriculture," he says. The aim of the United Nations Environment and Development Commission here is undoubtedly to make available to future generations the elements that ensure the continuity of life, such as a clean

environment, clean soil and clean water, and to ensure their continuity. According to an article in Tarlasera magazine, the European Union is working on making a series of new decisions in order to protect food security and increase the health of the soil, which is negatively affected by agricultural activities and climate change. If approved by the EU Agriculture Commission, it is aimed to make all soils within the EU borders healthy by 2050 [32].

Today, many different institutions and organizations such as the Ministry of Agriculture and Forestry, Chambers of Agriculture, Agricultural Cooperatives, and Continuous Learning Directorates affiliated to the Directorate of National Education are officially responsible for farmer training. Yurttaş [33] classified the extension systems in terms of responsible institutions as public extension, farmer organization extension, private sector extension and cooperative extension. Of these, the organization that carries out the most comprehensive publication work in Turkey is the ministry.

Public extension: Ministry of Agriculture and Forestry is the main institution in extension services. The regulation of the Farmer Training Services has been prepared by the General Directorate of Agricultural Reform of the Ministry and, the services have been made official. The aim of the regulation is to inform farmers about agricultural technologies and to increase their educational and cultural levels, to regulate the issues related to educational activities. In addition, a cooperation protocol has been signed with many institutions of the Ministry of Agriculture and Forestry of the Republic of Turkey. Some of these signed protocols are as follows:

Cooperation Protocol between the General Directorate of the Turkish Employment Agency and the Ministry of Agriculture and Forestry and the Union of Chambers of Agriculture of Turkey on Active Labor Market Programs,

Cooperation Protocol between the Ministry of Agriculture and Forestry and the Central Union of Agricultural Milk Producers of Turkey in the Field of Education,

Cooperation Protocol between the Ministry of National Education General Directorate of Lifelong Learning and the Ministry of Agriculture and Forestry Education and Publication Department,

Cooperation Protocol between our Ministry and GAP Regional Development Administration in the Field of Agricultural Education and Extension in the Southeastern Anatolia Region,

Agricultural Extension and Education Cooperation Protocol between our Ministry and the Union of Chambers of Agriculture of Turkey,

Our Ministry, the Ministry of National Education, the General Directorate of State Hydraulic Works and the Konya Plain Project Regional Development Administration Agricultural Education and Extension Cooperation Protocol in the KOP Region,

Cooperation Protocol on Occupational Health and Safety in Agriculture:

According to the definition made by Özçatalbaş and Gürgen [34], agricultural extension; It is an activity or service that aims to help rural residents in an educational process. The trainings applied to farmers by the Ministry of Agriculture and Forestry are mainly carried out with traditional extension approaches. The basic idea in this approach is; that the information and technology to be offered to the farmer exists in the central government. In addition, extension agencies are usually

established under the Ministry of Agriculture, so they are increasingly responsible for carrying out all forms of official activities at the local level. According to the traditional agricultural approach, the real information is dominated by the researcher, the farmer is passive, and the initiative in the dissemination of knowledge is with the publisher. The most important criterion of development in agriculture is the increase in production, the needs of the farmer are not related to his living system, but are limited only to the results of technical research [35]. In a study conducted by Irmak [36]; it has been found that the farmer trainings carried out by public institutions differ with the training subjects needed by the farmers. For example, education on the cause and prevention of stubble fires is compulsorily included in the training subject by the ministry every year. However, it has been found that there is no stubble burning in the Thrace Region. In the research, each of the producers for Lalapaşa District was asked about the publication subject they needed with multiple choice topics. The most needed agricultural extension issues were diseases and pests with a rate of 65.39%, seeds with a rate of 62.18%, being aware of innovations with a rate of 58.33%, fertilization with 47.44%, agricultural mechanization with 41.66%, irrigation with a rate of 30.13% and other issues. However, among the training subjects required by the Ministry, which we can describe as the central government, to the provincial organization, the training subjects required by the producers are almost non-existent. This negatively affects agricultural extension and also prevents the producer from growing a productive and quality product. According to a worldwide study by Gebremedhin et al., [37] while approximately 800,000 publishers serve 1.2 billion producers, most public extension services can only serve 10% of potential beneficiaries. This research is important in terms of the lack of similar public extension studies in Turkey. Public boadcasting activities carried out in 2021, 2022 and 2023 are given in **Tables 1** and **2** [38].

Table 1. Public broadcasting activities-1.

Publication activities carried out in 2021–2022–2023		
Type of activity	**Total activity (piece)**	**Total participants (farmers)**
Farmer study tours, incentive competitions, exhibitions, conferences, panels and other similar activities	25.913	365.234
farmer courses	1.224	308.027
farmer meetings	36.548	791.994
Demonstrations	1.757	20.752
field days	319	14.862
2021 total	65.761	1.500.869
2022 total	70.078	1.261.824
2023 total	55.010	1.552.250

Table 2. Public broadcasting activities-2.

Innovation Dissemination Projects			
Publishing and broadcast activities	**Realized in 2021–2022–2023**		
	Number of activities	**Number of participants**	**Number of publications**
Opening introductory meeting	18	434	
Demonstration	72	206	
Field day	13	1062	
Farmers meeting	97	1598	
Inspection trip	26	133	
Business visit	687	687	
Fair	1	500	
In-service training	26	425	
Closing evaluation meeting	12	299	
Print publications	38	0	18743
Video broadcasts	12	0	12
2021 total	1002	5344	18755
2022 total	824	5547	8820
2023 total	537	4.285	6.472

The fact that producers do not request information about cooperatives and organization presents a negative situation in terms of cooperatives and organization. When the finding is examined in terms of traditional agricultural extension approaches; It has been found that the extension subjects given by the institutions and the extension subjects requested or needed by the manufacturer differ. This situation presents a negative situation in terms of agricultural extension, rural entrepreneurship and rural development.

Table 3. Number of documents issued as a result of training for farmers.

Performance Indicators	**Unit of Measurement**	**2020**	**2021 Planned**	**2121 Year-End Realization Forecast**	**2022 Aim**	**2023 Forecast**	**2024 Forecast**
Number of documents issued as a result of training for farmers	Number	6.725	9.000	17.890	16.500	17.500	18.500

In 2020, by the Ministry of National Education (MEB) General Directorate of Lifelong Learning and the Ministry of Agriculture and Forestry, the population is rejuvenating, herd management personnel, milk and milking hygiene, initiated irrigation systems, effective and efficient irrigation systems in order to contribute to socioeconomic developments in rural areas. trainings were organized. 6725 certificates were given to farmers within the scope of farmer courses (**Table 3**). According to TÜİK data, the number of people living in the village in 2020 is 5,878,321. According to Euronews 2021, the number of people employed in agriculture in Turkey was 4 million 974 thousand in September 2021. In other words, the trainings planned to contribute to socioeconomic developments in rural areas in 2021 correspond to only 0.18% of the total farmers [38].

Table 4. Number of courses opened in handicrafts training center directorates.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of courses opened in handicrafts training center directorates (cumulative)	Number	408	520	533	650	770	890

In the Handicrafts Training Center Directorates located in Bilecik, Düzce, Elazığ, Silifke-Mersin, Kastamonu and Sivas, wood carving, stone and silver embroidery, carpet-rug and cloth weaving and ready-made garments, etc. It is aimed to increase welfare in rural areas, increase income and employment opportunities, and diversify the economy in rural areas. For these purposes, 408 courses were opened in 2020. Although these courses aim to improve one's manual skills and provide individual benefits, they cannot be said to contribute to the village in a commercial sense (**Table 4**) [38].

Table 5. Number of agriculture-based specialized organized industrial zones in operation.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of agriculture-based specialized organized industrial zones in operation	Number	1	2	1	1	2	2

In order to contribute to the development of agricultural industry integration, it is aimed to support clustering activities and to popularize Agriculture-Based Specialized Organized Industrial Zones (ABSOIZ) and to prepare suitable and sufficiently large investment areas with completed infrastructure for investors. When ABSOIZ becomes operational; regional farmers, real investors and legal entities may be positively affected. The number of ABSOIZ's in the table is the number of ABSOIZ's that have completed their infrastructure construction and are at the stage of allocating parcels to investors, according to the General Directorate of Agricultural Reform data system. The development of industry based on agriculture and animal husbandry is very important for the country's economy (**Table 5**) [38].

Table 6. Number of projects carried out for women farmers.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of projects carried out for women farmers (cumulative)	Number	123	160	168	200	235	270

(**Table 6)** The indicator in the table expresses the number of projects that directly benefit women farmers in the provinces. When determining projects, care is taken to ensure that the project topic is innovative for women farmers and that the number of women farmers who will benefit from the project is high [38]. In these

projects whose target audience is women farmers; Subjects such as mushroom cultivation, silkworm breeding, honey production and packaging, and production of local products generally cover medium or small-scale businesses [39].

Table 7. Number of facilities established within the scope of rural development supports.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of facilities established within the scope of rural development supports	Number	1.365	1.000	2.810	2.000	2.000	2.000

The indicator given in the table above measures the number of facilities established in rural areas. Farmers and agricultural investors (real and legal entities) are the target audience of the projects. These projects aim to increase income in rural areas, financial development, employment and increase the market share of products produced through agricultural industry integration. Target figures have been updated regarding the decision to start implementing the "Expert Hands in Rural Development Project" in 81 provinces within the scope of rural development supports. The data in the table is the number of businesses established by people who are eligible to implement the project within the scope of this project (**Table 7**) [38].

Table 8. Employment provided by agricultural consultancy support.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Employment provided by agricultural consultancy support	Number	1.123	1.200	1.170	1.250	1.300	1.350

It is aimed to increase the number of agricultural consultants providing consultancy services to farmers by supporting the agricultural extension and consultancy services being implemented. Data on the subject is provided annually. The table above was created by taking into account the data entered into the Agricultural Extension Consultancy Information System by the provincial and district directorates of Agriculture and Forestry regarding the subject (**Table 8**) [38].

Table 9. Number of enterprises receiving agricultural consultancy services.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of enterprises receiving agricultural consultancy services (cumulative)	Number	126.178	196.178	194.848	271.178	356.178	451.178

The number of agricultural enterprises receiving consultancy services from authorized persons and organizations for the purpose of meeting the information needs of farmers and teaching modern agricultural techniques is given in the table above. The data in the table; it was compiled from the data created by the Department of Education and Extension within the scope of supporting agricultural

extension and consultancy services (**Table 9**) [38].

Table 10. Number of producer organizations that provide agricultural consultancy.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of producer organizations that provide agricultural consultancy	Number	371	390	388	400	420	440

In the table above; the number of producer organizations that are authorized to provide agricultural extension and consultancy services to their members and employ consultants for this purpose is given. The data in the table; it was compiled from the data created by the Department of Education and Publication within the scope of supporting agricultural extension and consultancy services (**Table 10**) [38].

Table 11. Number of TV programs with agricultural content.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of TV programs with agricultural content (cumulative)	Number	615	830	830	1.050	1.275	1.505

The number of television programs prepared with agricultural content is given in the table above. Numbers of programs in the table; It consists of internet broadcasting, news, cinemas, educational films to be broadcast on national and local channels, spot (short) films and documentaries. In programs; it includes issues related to agriculture and forestry, technological developments, and changes reflected in the agenda. It is aimed to use the programs in farmer trainings through Provincial Directorates, as well as other broadcasting channels, to inform producers and consumers. The data in the table 11; it consists of the number of television programs with agricultural content prepared in line with the requests from the Ministry's service units and affiliated and related institutions and organizations. Although these trainings are important in terms of mass education; a different product is grown in each region of Turkey. Since the system works with a one-way communication channel, it is seen that producers cannot benefit sufficiently in terms of agricultural extension (**Table 11**) [38].

Table 12. Number of women trained in agriculture and home economics.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of women trained in agriculture and home economics (cumulative)	Number	792.602	928.602	1.193.862	1.429.602	1.669.602	1.909.602

The number of women farmers who received training in education extension activities on agriculture and home economics and the number of women farmers who

received training in the programs carried out in the provinces within the scope of the "Women Farmers Agricultural Extension Project" are shown in the table above. In creating the table; the number of women farmers receiving training on agriculture and home economics from the Department of Education and Publication was taken into account (**Table 12**) [38].

Table 13. Number of people trained on hunting.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of people trained on hunting (cumulative)	1.000	164,34	174	179,97	194,97	209,97	224,97

It is aimed to determine the number of potential hunters in Turkey, to increase the number of documented hunters, to ensure that illegal hunters are registered and hunted according to the rules, and to carry out training and certification activities within a certain system. Based on the data collected for this purpose, the table above has been created according to the number of people who attended the hunter training courses opened in cooperation with the provincial organizations of the Ministry of Agriculture and Forestry and public education centers and received certificates. The data in the table; it was obtained from the General Directorate of Nature Conservation and National Parks under the Ministry of Agriculture and Forestry, the General Directorate of Lifelong Learning and the General Directorate of Private Educational Institutions under the Ministry of National Education (**Table 13**) [38].

Table 14. Number of provinces where traditional knowledge based on biodiversity has been determined.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of provinces where traditional knowledge based on biodiversity has been determined (cumulative)	Number	21	41	41	61	81	0

Within the scope of the "Recording of Traditional Knowledge Based on Biological Diversity Project", information on traditional products such as medicines, yeasts and dyes developed by the public using biological resources is compiled and recorded through field and literature studies. By compiling the information in question, patenting of products developed using traditional knowledge based on our country's biodiversity can be prevented by foreigners. Besides; it may be the subject of research and development activities aimed at the development of new products with high added value in various sectors, especially food, agriculture and pharmaceuticals. Following the completion of the "Traditional Information Management System" project, it is planned to regulate the principles of access and benefit sharing to the necessary genetic resources and related traditional knowledge. Data for the provinces where field work was completed within the scope of recording traditional knowledge based on biodiversity were taken from the General Directorate of Nature Conservation and National Parks and tabulated above. This

practice is a very important study in terms of the country's economy and recording biodiversity, and much more work needs to be done locally (**Table 14**) [38].

Table 15. Number of trainings held in schools on biodiversity.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of trainings held in schools on biodiversity (cumulative)	Number	6.602	8.052	8.373	9.873	11.423	13.023

In order to inform and raise awareness of future generations on nature conservation and biodiversity issues, nature trainings are organized for primary school students in cooperation with Provincial National Education Directorates affiliated with the Ministry of National Education. The data in the table above was taken from the database of the General Directorate of Nature Conservation and National Parks and shows the number of nature trainings organized in schools. According to the Ministry of National Education data for 2021, the total number of primary school students in Turkey is 5,328,391 [40]. Considering that the number of students planned to be educated in 2021 is 8,052, this number corresponds to 15% of the total number of students. In a world where global warming is rapidly felt, it is thought that it is necessary to bring nature awareness to all primary school students (**Table 15**) [38].

Table 16. Number of species and areas monitored according to monitoring criteria.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of species and areas monitored according to monitoring criteria (cumulative)	Number	2.220	2.984	3.058	3.908	4.768	5.638

Within the scope of the National Biological Diversity Inventory and Monitoring Project (NBDIMP), endangered species subject to monitoring and areas of importance in terms of biodiversity have been determined, and monitoring studies are carried out in the provinces where inventory studies have been completed. Species and specific areas are constantly monitored in order to protect and ensure the sustainability of our biodiversity. The data obtained as a result of the monitoring study is reported and can be shared with all public institutions/organizations, universities and NGOs that monitor biodiversity. In the table above; As a result of the field studies carried out by the General Directorate of Nature Conservation and National Parks within the scope of the NBDIMP between 2020 and 2024, the total number of species and special areas monitored by the provincial organization is given (**Table 16**) [38].

Table 17. Number of awareness raising activities on adaptation to climate change.

Performance Indicators	Unit of Measurement	2020	2021 Planned	2121 Year-End Realization Forecast	2022 Aim	2023 Forecast	2024 Forecast
Number of awareness raising activities on adaptation to climate change	Number	1	1	2	1	2	2

The table above; it shows the number of awareness activities carried out within the scope of the aim of increasing the knowledge and capacity of Ministry personnel on climate change. The data in the table was created from the number of awareness trainings conducted by the General Directorate of Agricultural Reform on adaptation to climate change. All personnel of the Ministry of Agriculture and Forestry need to be trained and raised awareness about combating climate change. It is very important that this awareness created after the training given be addressed at the farmer level with a problem-solution focus (**Table 17**) [38].

Agricultural chambers: The duties and powers of the chambers are defined in Article 3 of the Law No. 6964 on Chambers of Agriculture and the Union of Chambers of Agriculture. Article 3.d of this law states that "to carry out all kinds of training, extension, and consultancy activities for the development of agriculture and rural areas, to cooperate with relevant institutions and organizations, to make contributions and suggestions." In Turkey, the cooperation between publishing organizations and producers varies between regions. For example, in Cengiz's study [26] titled A Research on the Effectiveness of Agricultural Extension and Consultancy Services: Antalya Province Example, it was determined that more than half of the producers (51.1%) received consultancy services from chambers of agriculture on agricultural extension without paying any fee.

The most effective institution in Turkey regarding farmer education is the Ministry of Agriculture and Forestry. Training, extension and publication activities have been organized within the scope of the agricultural innovation and information system created to inform producers and other stakeholders about agricultural innovations, to strengthen research dissemination and farmer ties, and to deliver R&D results to farmers and other beneficiaries through electronic sharing systems. Within the scope of this project, new varieties registered in cooperation with agricultural research institutes and provincial directorates (wheat, corn, triticale, oats, poppy, safflower, peanut, forage plant varieties), biological control methods, planning and operation of irrigation systems, milk and milking hygiene, Publication activities were also organized on topics such as economical water use in agriculture. Although these activities are beneficial for the producers, they have been submitted to the information of the producers in line with the request of the Ministry. When the issue is considered in terms of publication, it does not cover all of the specific issues that farmers, that is, the base, need, in other words, see as a problem, but the ceiling especially introduces new varieties. In this case, it presents a negative situation in terms of the effectiveness and efficiency of agricultural extension.

In the purpose part of the Regulation on Farmer and Cooperative Promotion, Training and Rewarding Fund, "This Regulation is to provide all kinds of training of farmers through various extension methods given to the Ministry by Decree Law No.

441, for cooperatives established in accordance with the Cooperatives Law No. 1163 and specified in Article 2 of the Regulation, and their higher institutions, the introduction of cooperatives, the training of cooperative managers and partners, cooperatives, the way in their organizations. It has been prepared in order to make in-kind and cash payments such as awards and bonuses to be given to the trained farmers and cooperatives within the principles to be determined, if necessary, for the execution of services such as showing, assisting in their management and activities. With this point of view; the necessity of training cooperative partner farmers has been legalized.

According to the principle of "education, training and information", cooperatives carry out education and training activities for their partners, managers and personnel for the development of cooperatives. In addition, in order to explain the structure of the cooperative, it has to organize education and training activities for those who are not partners in the cooperative.

Private sector extension: Private sector extension can be divided into 2 groups. The first is freelance agricultural consultants. Freelance agricultural consultants continue their activities with the regulation regarding the regulation of Agricultural Extension and consultancy services. Duties of freelance agricultural consultants are mentioned below:

a) To provide agricultural business owners or other units they serve with the necessary knowledge and skills on matters related to their duties at every stage of production, and to carry out agricultural practices in accordance with the relevant legislation when necessary,

b) To ensure that all kinds of information and new technologies on sustainable production techniques for plant and animal production are delivered to the target audience,

c) To inform agricultural business owners and the target audience for the protection of the environment, natural resources and biological diversity,

c) Contributing to providing agricultural enterprises with a more competitive structure and orienting them towards the product and service market effectively,

d) To provide business economics publication/consultancy and to make necessary recommendations,

e) (Amended: OG-8/11/2012-28461) (2) Publications/publications on economic analysis of enterprises, development planning, improvement of labor and capital efficiency and problems specific to family businesses, home economics, mechanization and plant propagation materials and seed production. consultancy,

f) To provide necessary personal development and entrepreneurship training for agricultural workers to do their jobs better,

g) Participating in trainings to be organized regarding the subjects in which he/she is responsible,

ğ) To benefit from printed, audio and video mass publication tools in publishing/consultancy activities and to prepare and contribute to their preparation,

h) Collecting data and keeping records regarding agricultural extension and consultancy activities,

i) To ensure the issuance of documents that will record and control agricultural production,

i) To carry out studies on producer organization.

j) (Added: OG-8/11/2012-28461) (2) To carry out information activities regarding safe food supply,

k) (Added: OG-8/11/2012-28461) (2) To fulfill the duties assigned by the Ministry regarding the execution of agricultural consultancy services.

Cooperative extension: Law on cooperatives no. 1163, farmer and cooperative promotion, training and reward fund regulation Chapter 1, Article 1. This regulation provides for all kinds of training of farmers given to the Ministry by Decree Law No. 441 through various publication methods and established in accordance with the Cooperatives Law No. 1163. For the cooperatives and their parent organizations specified in Article 2 of the Regulation, the reward will be given to the farmers and cooperatives who are trained, if necessary, for the execution of services such as introducing cooperatives, training cooperative managers and partners, guiding cooperatives, and assisting with their management and activities, within the principles to be determined separately. It was written that 'it was prepared for the purpose of making in-kind and cash payments such as bonuses,' and the necessity of training cooperative partner farmers was legalized.

According to the principle of "education, training, and information," cooperatives carry out training and education activities for their partners, managers, and staff for the development of cooperatives. In addition, it must organize training and education activities for those who are not members of the cooperative in order to explain the cooperative structure.

With the Cooperative Training Regulation published in the Official Gazette No. 31719 of the Ministry of Commerce dated 14 January 2022, it has been made mandatory for the principal and substitute members of the Board of Directors and Supervisory Boards of Cooperatives and their Parent Organizations to receive Cooperative Training. In the survey conducted with 100 people in the Devrek District of Zonguldak Province, the rate of women who know the cooperative legislation is 16%, and the rate of men is 28%. 84% of women and 72% of men either do not know the legislation or have no idea. 24% of women and 46% of men attend cooperative meetings. 68% of women and 34% of men participate in the decisions taken in the cooperative. While 76% of women and 40% of men had positive opinions about cooperative management, 24% of men made negative evaluations, and 36% did not express an opinion [39]. In research conducted on the growth of the identity and freedoms of the people and the cooperation partners in Balıkesir, it emerges with 724 people. In the study, 55.7% of the respondents showed a positive tendency about the cooperative; it was determined that only 14.6% wanted to be a founding partner or manager of a cooperative [41]. According to the study, education or information expectations from cooperatives were found to be 36.3%. The fact that producers do not demand information about cooperatives and organization presents a negative situation in terms of cooperatives and organization. When the finding is examined in terms of traditional agricultural extension approaches, it has been found that the publication topics given by the institutions differ from the publication topics requested or needed by the manufacturer. This situation presents a negative situation in terms of agricultural extension, rural entrepreneurship, and rural development.

Although agricultural extension systems are grouped into these four groups, it is thought by some researchers that the producer can also develop a mixed system of all these institutions. Çukur and Karaturhan [42] claim that as a result of all these agricultural extension systems, the pluralistic agricultural extension system will be adopted in the future. According to researchers, the pluralistic agricultural extension system is defined as a system in which public extension services, as well as other stakeholders such as farmer organizations, non-governmental organizations, private agricultural consultancy companies, etc., take an active role in extension activities.

4. Conclusion

The concept of agricultural extension will always evolve according to developing and changing agricultural technologies, communication systems, and expectations of producers and authorities. However, the demographic structure in Turkey is aging rapidly. The next generation does not want to engage in agriculture or perceives agricultural activity as a second additional job with increasing mechanization. The number of people who have completed their agricultural activities by selling their land is also considerable. The fact that agricultural extension is carried out mainly by the central authority is far from being able to respond even unilaterally to the expectations and needs of the producers. This indicates that very negative conditions await the agricultural sector in the future.

In the past, village institutes solved the problems of producers with agricultural publishers, village institute teachers, and students, and it became a trend that swept the whole country for a while. Nowadays, it would be much better for local governments such as municipalities, non-governmental organizations, headmen's offices, farmers' organizations, producer organizations, and cooperatives to determine their common problems locally, produce solutions, and get support from the central authority in financial problems. In order to benefit more from grant support programs such as IPARD during the EU harmonization process, the central authority needs to develop policies that will provide solution-oriented technical support.

Although many public institutions and private sectors are active in agricultural extension, it is clear that the desired level has not been reached in terms of extension. If agricultural extension activities are carried out jointly by the public-private sector or separately by each of these institutions and organizations, priority should be given to issues that can bring solutions to the problems of the target audience. Taking into account the educational status of those who will participate in agricultural extension studies, not entering into too many theoretical subjects in the trainings and giving priority to the practical trainings to be held in the field will ensure that the trainings reach their purpose. Supporting extension trainings with visual materials, not only trainers taking part in applied trainings, and participating in the practices of the participants will ensure that the training is more efficient. In order to achieve success in extension trainings, importance should be given to organizations that grow and market a certain product organized in the form of cooperatives. Since the participants who grow different products with different agricultural practices in their enterprises will have high expectations from the trainings, the slope issues will also be more

than this expectation. It is important to organize the trainings on certain subjects with the idea that this will enable many subject experts to take part in the training and cause the different information given not to be assimilated by the participants. Whether the trainings have achieved their purpose should be monitored and recorded for certain periods, and the data obtained should be included in the subjects of the trainings to be organized in the future. It would not be a fanciful perspective to expect that what the Village Institutes achieved in the past, the cooperatives in the rural areas today will implement a long-term participatory plan and carry out successful practices in agricultural extension.

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Article

Neutralizing the surging environmental pollution amidst renewable energy consumption and economic growth in Ghana: Insights from ARDL and quantile regression analysis

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Abstract: This research explores the link between renewable energy consumption, economic growth, electricity accessibility, greenhouse gas emissions, and environmental degradation in Ghana from 1993 to 2020. Utilizing the autoregressive distributed lag (ARDL) model and quantile regression, it analyzes the validity of the Environmental Kuznets Curve (EKC) hypothesis. ARDL findings imply that renewable energy consumption (REC), greenhouse gas emissions (GHG), and power accessibility (ATE) have positive but statistically negligible long-term associations with CO_2 emissions. In contrast, economic growth (ECG) shows a slight negative link. This suggests that current attempts to promote renewable energy and minimize emissions may only partially lower CO_2 levels. Quantile regression demonstrates a positive correlation between REC and CO_2 emissions, counter to the idea that more renewable energy consumption decreases emissions. GHG strongly affects environmental pollution (EVP) at all levels, whereas power accessibility (ATE) has a favorable effect at lower levels but becomes negative at higher ones. Economic growth's impact on pollution is detrimental at lower and median values but needs more relevance at more significant levels. These results imply the need for stricter laws, technical breakthroughs, emission limitations, and carbon pricing to mitigate pollution coming from economic expansion.

Keywords: renewable energy; economic growth; ARDL; quantile regression; EKC theory; Ghana

1. Introduction

Environmental pollution is becoming an increasingly pressing problem globally as numerous compounds are discharged into the environment, causing threats to both ecosystems and human health [1]. Pollution may emerge in various ways, spanning chemicals, organisms, biological materials, energy, noise, radiation, and heat [2]. The worldwide concern about environmental pollution and deterioration is severe, influencing the globe. Injudicious exploitation of natural resources, such as uncontrolled burning of fossil fuels, pollution, inadequate waste management, deforestation, and overpopulation, has resulted in environmental deterioration and resource depletion [3–5]. Individuals stricken by environmental pollution and environmental harm, particularly in poor countries, have significant barriers to obtaining equitable treatment and justice within the legal framework. The cause of this

issue may be attributed to insufficient environmental laws and regulations and the need for robust and competent institutions responsible for enforcing environmental safeguards [6–8]. Environmental pollution, defined as toxic substances damaging the environment and human health, has reached worrisome levels worldwide, driven by urbanization, industrialization, and economic development [9]. Addressing global environmental pollution demands multiple solutions requiring the involvement of all countries and addressing political, social, and economic factors [10–12]. Urbanization, industrialization, and incorrect chemical use have also contributed to increasing environmental pollution and deterioration, resulting in detrimental health influences on living creatures [13–15]. The peculiar effects include greenhouse gas emissions, temperature variations, ozone depletion, loss of biodiversity, and ecosystem destruction [5]. These concerns need aggressive actions to minimize global difficulties, manage the continuing climate change disaster, and adopt conservation legislation globally.

Africa presents substantial environmental pollution and degradation issues, driven by industrialization, urbanization, and population increase, resulting in pollution from resource overexploitation and industrial waste discharge [16]. Contaminants of increasing concern (CECs), such as plastics, medicines, insecticides, and personal care items, have been detected in African terrestrial and aquatic habitats [17]. Traditional wastewater treatment systems in Africa generally fail to properly remove/degrade numerous CECs, resulting in their worrying prevalence in particular countries [18]. Climate change, pollution, and biodegradation are additional problems in Africa, especially with corporations reporting environmental consequences [19–22]. Industries in Ghana, including mining, agriculture, manufacturing, and construction, have contributed to environmental deterioration via air, water, and land pollution [23]. Mining has severe implications, including land degradation, environmental pollution, and socioeconomic concerns in communities involved in small-scale mining [24]. Nevertheless, traditional and cultural techniques have been shown to help environmental conservation in particular communities, demonstrating their potential for minimizing illicit mining and controlling environmental deterioration [25]. Amid requests for environmental policy reforms, notably within the mining industry, changes towards environmental governance and increasing laws are needed to maintain the environment [26,27]. Environmental challenges in Africa bear worldwide repercussions owing to the utilization of global resources, with environmental degradation in one nation possibly influencing others [28]. Despite attempts to monitor and manage pollutants, emerging environmental contaminants offer new issues [29,30]. Additionally, pollution damages animal and wildlife health and raises public health risks via contamination of the human food chain. Addressing pollution challenges is vital for ecosystems and human populations' long-term health and sustainability.

This study analyzes how renewable energy consumption, economic growth, access to electricity, and greenhouse gas emissions affect environmental pollution reduction in Africa, emphasizing Ghana. Renewable energy plays a vital part in avoiding pollution. This study provides a novel empirical analysis by applying both ARDL and quantile regression approaches to assess the Environmental Kuznets Curve

(EKC) hypothesis in the context of Ghana. Unlike previous research that often treats renewable energy consumption and environmental pollution in isolation, this paper integrates multiple factors within a unified framework, such as access to electricity, greenhouse gas emissions, and economic growth covering the period. Furthermore, the inclusion of quantile regression offers a nuanced understanding of the varying effects of these factors across different levels of environmental pollution, thus filling existing gaps in the literature. While initially raising CO_2 emissions, research suggests renewable energy offers long-term advantages in lowering emissions and environmental deterioration [31,32]. Access to energy also greatly assists pollution management via technology that may purify waste and minimize emissions [2,25]. Economic expansion initially increases pollution levels, but the Environmental Kuznets Curve theory implies an inverted U-shaped connection ultimately arises between growth and pollution [33]. Promoting renewable energy, balanced urban-rural development, and clean production may decrease pollution while preserving economic growth. The food system is a substantial greenhouse gas emitter needing extensive reduction throughout the supply chain [4]. Efforts are ongoing to transition to a sustainable, carbon-neutral economy via emission reduction and offsetting [5]. By investigating the connection between Ghana's renewable energy consumption, economic development, and environmental pollution, this research informs policies and initiatives for environmental conservation, particularly in African countries. Employing ARDL and quantile regression models, it explores the Environmental Kuznets Curve hypothesis in the Ghanaian setting and analyzes the temporal dynamics using robust econometric approaches. The work comprises a literature review, methodology, data, empirical model, results, and discussion with policy implications.

2. Literature review

This portion of the study looks at the body of research that has already been done on the subject. More so, this section looks at earlier studies that looked at the connections between several essential variables, including the use of renewable energy consumption (REC), Economic growth (ECG), access to electricity (ATE), greenhouse gas emissions (GHG), and the effects these have on environmental pollution (EVP).

2.1. Nexus between renewable energy consumption and environmental pollution

Research has demonstrated that increasing renewable energy consumption may decrease carbon emissions and environmental pollution [34–36]. While renewable energy initially raises CO_2 emissions in the short term, it has a favorable influence on lowering emissions over the long run [37]. Renewable energy is crucial for closing the gap between production and consumption-based carbon emissions, especially in net emission-exporting countries [38]. The carbon reduction advantages of renewable energy are most evident in low-income countries, followed by lower-middle and upper-middle-income nations. In contrast, higher-income countries get the most minor benefits [39]. Trade openness, innovation, and technical advancement promote emission reductions, but tourism causes environmental damage. However, the

ecological implications of renewable energy in Africa exhibit diverse outcomes across socioeconomic classes and geographies [40]. In rising Asian nations, renewable energy considerably cuts long-term carbon emissions [41]. For OECD nations, economic development adversely affects the environment when renewable consumption is below a threshold but favorably when above it [42]. A nonlinear connection exists between renewable consumption and CO_2, with larger renewable shares permitting more accurate emission estimates [43]. These studies underscore the need to increase renewable energy usage and sustainable practices to minimize pollution and meet long-term environmental and development objectives.

2.2. Nexus between ATE and EVP

Access to electricity is a crucial development aspect and impacts environmental pollution. In Nigeria, the reliance on generators due to poor electricity generation and distribution has led to high levels of environmental pollution and adverse health impacts [44]. In developing countries, increasing access to grid connections and reliable electricity can alleviate poverty and promote economic growth, while transitioning to low-carbon energy sources can have positive health and social benefits and reduce environmental damage [45]. In India, the evolution from dirty to unpolluted energy is hindered by the country's energy-intensive and carbon-intensive industrialized economy and the socio-cultural tradition of using multiple fuels, filthy fuels, at the household level [46]. Studies have revealed that airborne particle pollution tends to increase power consumption levels while reducing the electricity generated from distributed solar panel installations. This issue disproportionately affects disadvantaged people since lower-income neighborhoods and ethnic minority groups incur a higher cost from the consequences of particle air pollution on both increased energy consumption and decreased solar power production capabilities [47]. Limited access to electricity in Sub-Saharan Africa is influenced by income per capita, transmission and distribution losses, rural population proportion, population density, dependency ratio, savings, and government effectiveness [48–50]. Access to electricity and environmental pollution are interconnected. Electricity access has numerous benefits, including reducing reliance on unsustainable wood fuels and promoting low-carbon energy sources [51]. However, the transition to cleaner energy is hindered by the link between economic development and energy-related greenhouse gas emissions [52,53]. Poor electricity generation and distribution lead to high reliance on generators, resulting in environmental pollution and adverse health impacts. Additionally, particulate air pollution has indirect co-damages on human behaviors and technologies, such as increasing electricity consumption and reducing the efficiency of distributed solar panels [54]. While the impact of pollutants on avian influenza virus infection risk is poorly understood, anthropogenic pollution may disrupt wildlife immune function and increase susceptibility to infection [55]. The interplay between access to electricity and environmental pollution highlights the need for sustainable energy solutions that minimize negative environmental and health impacts.

2.3. Nexus between ECG and EVP

There is an unambiguous connection between economic expansion and pollution of the environment, as examined by several research across different nations. According to research on African countries, economic expansion is a significant factor in rising pollution levels [56]. Factors like food costs, money, and foreign direct investment encourage pollution, whereas agricultural output and labor diminish it. For Brazil, [57] gives data supporting the Environmental Kuznets Curve hypothesis, demonstrating that pollution initially increases with economic expansion but falls beyond a certain point. Examining China, it was discovered that economic expansion may accelerate and limit pollution emissions depending on the area's development state [58]. Much research has been done on the connection between economic expansion and carbon emissions. In nations like Uruguay, a positive statistically significant correlation exists between the two [59]. However, this connection is variable between areas and countries. Some research implies a bi-directional connection in economies in transition, a uni-directional link in emerging nations, and no relevant association in developed and least developed countries [60]. Additionally, the impact of financial development on carbon emissions is inconclusive, with some studies finding a negative effect [61]. Recommend reevaluating international trade regulations and strengthening export limitations for goods with high pollution levels [62]. Policymakers should also design appropriate policies to decarbonize energy consumption and promote renewable energy use without affecting economic growth [63]. Therefore, these studies highlight the need for sustainable development and environmental governance to control pollution while promoting economic growth.

2.4. Nexus between total greenhouse gas emissions and environmental pollution

Total greenhouse gas emissions have been proven to have a substantial connection with environmental contamination [64]. Numerous studies across areas and nations continuously reveal that pollution, particularly in CO_2 emissions, substantially contributes to environmental deterioration [65–68]. Economic expansion, energy usage, and urban agglomerations are fundamental causes of increased greenhouse gas emissions and accompanying environmental deterioration [69]. Bidirectional causation occurs between greenhouse gas emissions, energy consumption, and pollution, where increased energy usage leads to more emissions, further worsening pollution. These results underline the necessity for sustainable development plans, strong environmental laws, and adopting eco-friendly technology to alleviate pollution and limit emissions. In Canada, an inverted U-shaped connection was identified between carbon intensity (GHGs/Energy) and emissions, showing emissions first increase but gradually drop over time [70]. For South Africa, improved energy intensity and cumulative energy savings were connected to energy efficiency and low-carbon goods [71]. In Central and Eastern Europe, CO_2 emissions and energy usage showed no long-term influence on economic growth, while financial development displayed bidirectional causation with emissions [72]. Asian countries exhibited cointegration between carbon emissions, urbanization, energy usage, and economic development, with comparatively high short-term emission levels [73]. The

causal relationship between total greenhouse gases and carbon emissions is complicated and impacted by variables including energy efficiency, economic growth, and financial development.

2.5. Research gap and contributions

The previous sections have evaluated current research on environmental pollution (EVP) factors. Despite the quantity of material analyzed, it is evident that there are distinct gaps and shortcomings in this domain. Therefore, more empirical research is essential to uncover the characteristics that minimize EVP successfully. The literature review also shows that no previous studies, especially those that focused on African economies like Ghana, have thoroughly investigated the relationship between access to electricity (ATE), greenhouse gas emissions (GHG), economic growth (ENG), renewable energy consumption (REC), and EVP within a single research framework. This research consequently fills a significant hole by being the first to analyze these factors together in the context of developing economies. Additionally, there is a distinct lack of contemporary research exploring the drivers of EVP, especially within African countries, in the environmental literature. Therefore, the duration of this research, stretching from 1993 to 2020, gives a new and original viewpoint on this problem. Furthermore, there remains a considerable methodological vacuum regarding quantile regression. This study intends to overcome this gap by applying the quantile regression and ARDL framework, offering a more contextually relevant and complete knowledge of the numerous elements driving the environmental pollution landscape in a growing African country.

3. Theoretical framework and empirical modeling

3.1. Theoretical framework—Environmental Kuznets Curve (EKC)

The EKC theory was established by [36] to highlight the link between economic development and environmental degradation. It suggests a curved link where environmental damage first increases throughout early economic growth stages but diminishes after reaching a particular economic threshold [74]. Since the 1990s, substantial research has been undertaken on the EKC theory. Studies have highlighted significant EKC-related issues, including economic growth, CO_2 emissions, energy consumption, renewable energy, and financial development [75]. The theory has attracted substantial interest, leading to multiple study communities concentrating on different times and issues within the EKC literature [76]. The EKC phenomena have been noticed in the E-7 economies (Brazil, China, India, Indonesia, Russia, Mexico, and Turkey), with technology developments assisting in reducing pollution [77]. In selected growing Asian nations, the N-shaped EKC theory has been verified, with increasing renewable energy consumption considerably lowering long-term carbon emissions [78,79]. Furthermore, empirical studies suggest a bidirectional link between renewable energy use and economic development, indicating a feedback loop [80,81]; promoting renewable energy consumption is a realistic method to promote energy security, cut carbon emissions, and stimulate future economic development in these countries. In this paper, we claim that the transition to renewable energy consumption,

increased energy access, and economic development via strategic planning may successfully affect the amount of environmental pollution (EVP) in Ghana. Thus, we predict a negative association between renewable energy consumption (REC) and EVP. Access to electricity (ATE) and economic development (ECG) may aggravate pollution via increasing mobility, production, energy consumption, housing, urbanization, and industrial activity, leading to environmental deterioration. Given their significant contributions to EVP, we predict ATE, ECG, and greenhouse gas emissions (GHG) processes to encompass crucial concerns such as industrial and agricultural waste, heightened energy use, emissions from transportation, and home waste.

3.2. Explanation of variables

3.2.1. Dependent variable

The outcome variable, EVP, refers to introducing harmful substances stuck on the environment through social activities, leading to carbon accumulation on Earth. This carbon can be found in various forms, such as (CO_2) emissions, urban garbage, aquatic weeds, agricultural refuse, and other wastes [25,27]. Using CO_2 emissions as a proxy allows for analyzing trends and patterns in environmental pollution over time and across different regions. It is a commonly used indicator to assess the impact of human activity on the environment, particularly on economic development and urbanization [82,83]. The emissions of CO_2 from road vehicles, for example, contribute significantly to overall CO_2 emissions and are highly concentrated in urban areas. The link between CO_2 emissions and various factors, such as population density and financial development, has been studied to understand the drivers of environmental pollution

3.2.2. Independent variables

The study analyzed four predictor variables: economic growth, renewable energy usage, access to electricity, and overall greenhouse gas emissions. Economic growth (ECG) was calculated using GDP per capita, which offers a monetary value for all final products and services generated. GDP per capita enables cross-country comparisons of living standards by accounting for cost of living and inflation disparities. Renewable energy consumption (REC) was proxied by the proportion of total final energy consumption from renewable sources. This comprehensive statistic assesses total energy use and the renewable share, allowing the study of renewable energy integration and energy mix adjustments. Access to electricity (ATE) measures dependable and inexpensive access to electricity and cooking facilities, which are vital for economic growth, industrialization, productivity, and UN Sustainable Growth Goals. While power supply may harm the environment, efficiency advances give the potential for further environmental regulations. Emissions of greenhouse gases (GHGs) include sulfur hexafluoride, hydrofluorocarbons, methane, nitrous oxide, and carbon dioxide. These gases contribute to global warming and climate change. CO_2 from fuel burning provides the bulk of anthropogenic GHG emissions; however, agricultural operations also create considerable methane and nitrous oxide emissions. Mitigating these emissions through better practices and moving to biofuels is vital for tackling climate change. Countries and organizations must measure and cut GHG emissions to

effectively confront global warming. A summary description of the measurement for all the series has been presented in **Table 1.**

Table 1. Variable description.

Variable	Symbol	Details of Variables	Source
Carbon emission	EVP	CO_2 (metric tons per capita)	WDI
Economic Growth	ECG	Per Capita (constant 2015 US$)	WDI
Renewable energy consumption	REC	% of total final energy consumption	WDI
Access to electricity	ATE	% of population	WDI
Total greenhouse gas emissions	GHG	kt of CO_2 equivalent	WDI

3.3. Source of data and measurement unit

The World Bank indicator database included the time series data for greenhouse gas emissions (GHG), access to electricity (ATE), renewable energy consumption (REC), economic growth (ECG), and environmental pollution (EVP). **Table 1** includes information on the unit of measurement, signs, and data source for the chosen variables.

3.4. Quantile plots

See **Figure 1**. Quantile plots for the variables under consideration.

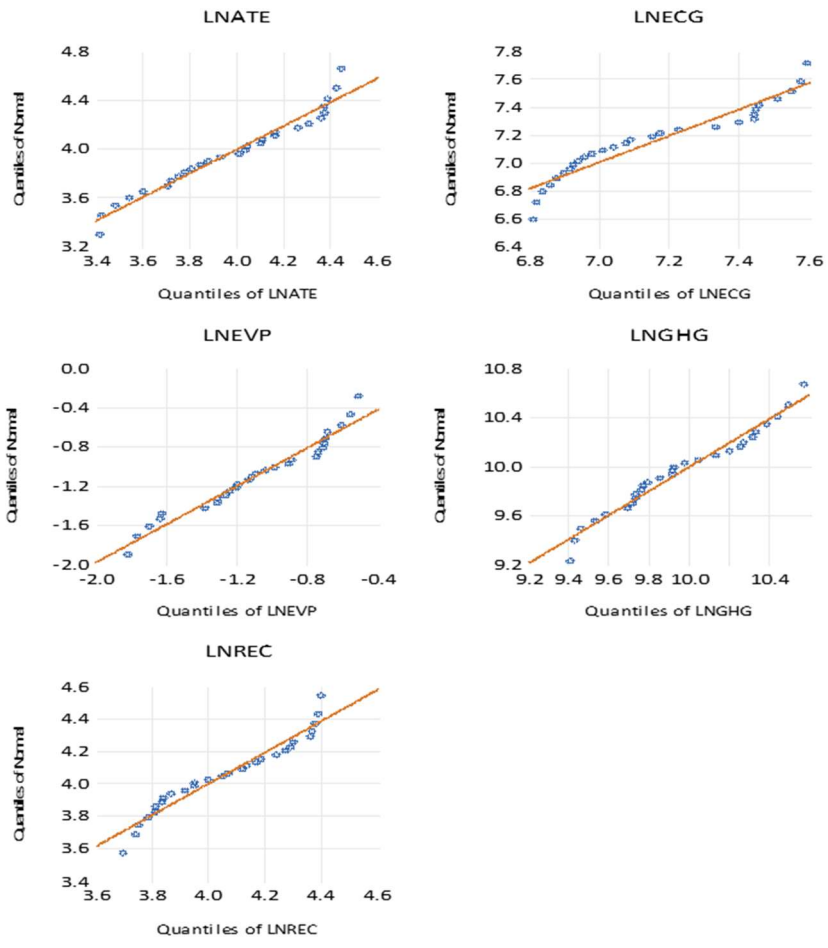


Figure 1. Quantile plots of variables.

3.5. Econometrics estimation approach

Drawing on the theoretical framework of the Environmental Kuznets Curve (EKC) hypothesis and the results of past academic research undertaken by [84–87]. This study adopts the ARDL and Quantile regression econometrics approach to examine the relationship between renewable energy consumption (REC), Economic growth (ECG), access to electricity (ATE), Greenhouse gas emissions (GHG), and Environmental pollution (EVP). ARDL (Autoregressive Distributed and Lag) is a method used in econometrics to analyze the relationship between variables over time, allowing both short-term and long-term dynamics to be captured. ARDL assumes stationarity and cointegration among the variables, making it suitable for modeling non-stationary time series data [88]. On the other hand, Quantile regression is a robust regression technique that estimates the conditional quantiles of the response variable, providing a more all-inclusive understanding of the relationship between interpreters and the reaction. Unlike traditional regression, Quantile regression does not rely on distributional assumptions and can handle heteroscedasticity effectively [84,86,89,90]. ARDL and Quantile Regression offer valuable insights into different aspects of data analysis, with ARDL focusing on time series dynamics and cointegration. In contrast, Quantile regression provides a robust alternative to traditional mean regression methods.

$$\mathrm{EVP_t} = f(\mathrm{ECG_t}, \mathrm{ATE_t}, \mathrm{GHG_t}, \mathrm{REC_t}) \tag{1}$$

To eliminate skewness problems, the data variables were transformed into natural logs.

Therefore, we may represent the equation above in the following form.

$$\ln\mathrm{EVP}_t = \beta_0 + \beta_1 \ln\mathrm{ECG_t} + \beta_2 \ln\mathrm{ATE_t} + \beta_3 GHG_t + \beta_4 REC_t + \varepsilon_t \tag{2}$$

where ε_t —represents the error term, t represents time dimensions, β_0 shows the constant term, and β_1 to β_4—are coefficients variables.

ARDL estimation model was applied as shown mathematically in Equation (3).

$$\Delta\ln\mathrm{EVP}_t = \alpha_{01} + \sum_{i=1}^{p} \alpha_{1\mathrm{i}} \Delta\ln\mathrm{EVP}_{t-\mathrm{i}} + \sum_{i=0}^{w} \alpha_{2i} \Delta\ln\mathrm{ECG}_{t-i} + \sum_{i=0}^{w} \alpha_{3i} \Delta\ln\mathrm{ATE}_{t-i} + \sum_{i=0}^{w} \alpha_{4i} \Delta\ln\mathrm{GHG}_{t-i} + \sum_{i=0}^{w} \alpha_{5i} \Delta\ln\mathrm{REC}_{t-i} + \varepsilon_{1t} \tag{3}$$

To check for causality association error correction term Equation (4).

$$\Delta\ln\mathrm{EVP}_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta\ln\mathrm{EVP}_{t-i} + \sum_{i=0}^{w} \alpha_{2i} \Delta\ln\mathrm{ECG}_{t-i} + \sum_{i=0}^{w} \alpha_{3i} \Delta lnATE_{t-i} + \sum_{i=0}^{w} \alpha_{4i} \Delta\ln\mathrm{GHG}_{t-i} + \sum_{i=0}^{w} \alpha_{5i} \Delta lnREC_{t-i} + \emptyset_1 ECT_{t-1} + \varepsilon_{1t} \tag{4}$$

In Equation (4), the delayed error correction term, abbreviated as ECT_{t-1}, assesses the pace at which the system adjusts towards long-term equilibrium. ECT_{t-1} Denotes the error correction component.

3.6. Causality test

The research evaluated the causation between the variables using the paired Granger causality analysis [35]. Causality is a statistical measure of causation based on prediction that this study uses because of its many advantages over other techniques

of analyzing time-series data. Presume that the future behavior of a separate time series *X* can be predicted using a time series *Y*. We term it "Y Granger-causing *X*." Regular least squares (OLS) regression is used to estimate coefficients. Nonetheless, granger causality between components *X* and *Y* is found using F-tests. Representing their values at time t, the notations X_t and Y_t denote the temporal sequence of the two variables. X_t and Y_t bivariate autoregressive model representation follows.

$$X_t = \beta_1 + \sum_{i=1}^{w} \alpha_i Y_{t-i} + \sum_{i=1}^{w} \mu_i X_{t-i} + \varepsilon_t$$
$$Y_t = \beta_2 + \sum_{i=1}^{w} \Omega_i Y_{t-i} + \sum_{i=1}^{w} \infty_i X_{t-i} + \mu_t \quad (5)$$

The assessment of "n" embodies the lag length, while the parameters β_2,β_1,α_i, Ω_i , μ_i and are active for estimation purposes. Likewise, the terms ε_t and μ_t exemplify the stochastic error terms or residuals.

3.7. Quantile regression estimation

Quantile regression offers numerous benefits over traditional mean regression methods. It provides a more all-inclusive understanding of how exposure affects the entire outcome distribution, making it valuable when outcomes have non-linear relationships [91]. Quantile regression outperforms linear regression owing to its greater robustness to outliers and poorly characterized error distributions, enabling a more complete statistical modeling method [92]. Unlike binary logistic regression, quantile regression does not require dichotomizing quantitative variables, thus retaining more information and providing trustworthy estimates. Additionally, applying deep learning to quantile regression allows for interpretable results and statistical inference, combining the flexibility of deep learning with the advantages of quantile regression [93]. These combined strengths make quantile regression a powerful tool in various fields, including economics, epidemiology, finance, and health psychology. Quantile regression can be defined as in Equation (5) [94]

$$y_i = x'\beta_q + e_i \quad (6)$$

In Equation (6), βq signifies the collection of undetermined parameters associated with the *q*-th percentile. The OLS reduces the model prediction error's sum of squares. e_i ($\sum_i e_i^2$), whereas the most minor absolute deviation (LAD) regression, referred to as the median regression, minimizes $\sum_i$ | e_i |. For a given total, the Quantile regression handles asymmetric penalties (1−*q*) $|e_i|$ for over-prediction and q|e_i| for under-prediction (Baum et al., 2013). The goal function is minimized using the quantile regression estimator for quantile q. [95]

$$Q(\beta_q) = \sum_{i:yi \geq x_i'\beta}^{N} q|y_i - x_i'\beta_q| + \sum_{i:yi < x_i'\beta}^{N} (1-q)|y_i - x_i'\beta_q| \quad (7)$$

where 0 < *q* < 1. The conditional quantile of y_i given x_i is as follows

$$Q_q\left(\frac{y_i}{e_i}\right) = x_i'\beta_q \quad (8)$$

According to [28] there is often a significant disparity between the median and mean values of variables such as carbon dioxide emissions, gross domestic product, and energy usage. According to [33] quantile regression, which utilizes the absolute

values of regression residuals, produces more resilient outcomes than the conventional ordinary least squares (OLS) model when the error terms deviate from a normal distribution and encompass outlier values. The sentence essentially emphasizes that there might be substantial divergence between the median and the mean for specific variables. Additionally, it is shown that quantile regression exhibits more excellent reliability compared to ordinary least squares (OLS) regression in cases where the data deviates from the assumption of normality and includes outliers that may disproportionately affect the outcomes.

4. Empirical findings and discussion

Table 2 offers a statistical descriptive overview of Ghana from 1993 to 2020. The table covers numerous statistical measurements such as the mean, median, standard deviation, etc. The five variables under analysis in this study are as follows: access to electricity (percentage of the population), total greenhouse gas emissions (metric tons of CO_2 equivalent), GDP per capita (constant US$), and renewable energy consumption (percentage of total final energy consumption). The dependent variable is carbon dioxide emissions (metric tons per capita). The four independent variables are renewable energy consumption and total greenhouse gas emissions. Data is accessible for each variable for the full-time without any missing values. All five variables indicate positive mean values. In contrast to the independent variable (CO_2 emissions), which has a relatively small standard deviation and values closely clustered around the average, the other independent variables (total greenhouse gas emissions and GDP per capita) show relatively extreme dispersions from their mean values. The distribution of all five variables is symmetric around the mean, indicating a normal distribution. The positive kurtosis values for all variables are less than three, suggesting a platykurtic character, meaning fewer extreme values are below the sample mean.

Table 2. Descriptive and correlation matrix.

	LNATE	**LNECG**	**LNEVP**	**LNGHG**	**LNREC**
Mean	3.979078	7.154889	−1.090355	9.950875	4.059188
Median	4.021724	7.082838	−1.101047	9.91655	4.059525
Maximum	4.447821	7.591667	−0.506025	10.57312	4.398146
Minimum	3.413436	6.810359	−1.820073	9.403576	3.69511
Std. Dev.	0.324279	0.266925	0.385475	0.341993	0.231525
Skewness	−0.193872	0.309378	−0.318313	0.15407	0.040268
Kurtosis	1.870166	1.577266	2.072281	1.924554	1.595774
Jarque-Bera	1.664684	2.808201	1.476949	1.460122	2.30806
Probability	0.435029	0.245588	0.477842	0.48188	0.315363
Sum	111.4142	200.3369	−30.52994	278.6245	113.6573
Correlation					
Matrix	LNATE	LNECG	LNEVP	LNGHG	LNREC
LNATE	0.101401				
	1				

Table 2. (*Continued*).

	LNATE	LNECG	LNEVP	LNGHG	LNREC
LNECG	0.079151	0.068704			
	0.948292	1			
LNEVP	0.116299	0.093866	0.143284		
	0.964835	0.946061	1		
LNGHG	0.103193	0.086611	0.124257	0.112782	
LNREC	−0.069925	−0.05829	−0.083155	−0.074675	0.05169
	−0.965843	−0.978131	−0.966245	−0.978038	1

The correlation coefficient values are shown for each of the five examined variables. It is significant to notice that the Spearman and pairwise correlation values are equal owing to the lack of missing data in the sample. Furthermore, all associations are statistically significant at varying degrees of significance. Except for renewable energy use, all variables indicate a substantial positive association with each other. There is a substantial negative connotation between CO_2 emanations and renewable energy use, which accords with economic and theoretical assumptions. It is natural to predict that as society shifts towards higher usage of renewable energy, CO_2 emissions will decrease. Conversely, total greenhouse emissions, access to power, and economic development indicate a highly positive connotation with CO_2 releases, suggesting that a rise in any of these factors would lead to a comparable increase in CO_2 emissions. This finding is compatible with economic theory.

4.1. Unit root test

The ADF (augmented Dickey-Fuller) and PP (Phillips Perron) tests were used to evaluate the degree of integration between the variables. The ADF test implies that error terms are statistically independent and homogenous, whereas the PP test assumes weak dependency and heterogeneity in the error terms. The data relating to stationarity are given in **Table 3**. Both tests demonstrate that all variables are stable on level, meaning they are integrated in order (0). As a result, it is appropriate to use the Johansen cointegration test to look for possible cointegration between the variables.

Table 3. Unit root test.

Augmented Dicky Fuller			**Phillips Perron**	
Variables	Constant-Trend	Without constant	Constant-Trend	Without constant
lnCO_2	−3.818***	−2.542***	−3.366***	−2.801***
lnREC	−2.425**	−5.324***	−4.065***	−5.371***
lnGHG	−2.096**	3.870***	−2.416**	4.840***
lnATE	−3.628***	2.905***	−4.5558***	2.672***
lnECG	−2.133**	2.196**	−1.966**	5.140***

** = significant at 5%, *** = significant at 1%.

The natural logarithmic form is applied to all variables, indicated by the letter "ln" before each variable name. GDP stands for gross domestic product per capita in constant 2015 US dollars, ATE stands for access to electricity as a percentage of the

population, GHG stands for total greenhouse gas emissions measured in metric tons of CO_2 equivalent, CO_2 stands for CO_2 emissions per capita, and REC stands for renewable energy consumption as a percentage of total final energy consumption. The Augmented Dickey-Fuller and Phillips-Perron tests were run to check for unit roots in the data to avoid false regression. The findings from both tests indicated all variables are stationary at level, suggesting they are integrated of order zero (0). The Johansen cointegration test was applied to evaluate possible long-run correlations among the variables and test the Environmental Kuznets Curve hypothesis. The appropriate lag duration was set to a maximum of 4 lags. An unconstrained error correction model was then generated to test for long-run connections between the associated variables. The proper ARDL (3, 3, 1, 3, 2) model was chosen, and diagnostic tests shown in **Table 4** verified no concerns with autocorrelation or heteroscedasticity, and the error terms were usually distributed. Analysis of the ARDL model coefficients found that renewable energy consumption (lnREC) had a positive long-run connection with CO_2 emissions, with a coefficient of 2.183268. However, this was statistically insignificant (p-value = 0.421). Similarly, greenhouse gas emissions (lnGHG) revealed a positive coefficient of 2.682888, showing a positive long-run association with CO_2 emissions, but again statistically insignificant (p-value = 0.349). Access to electricity (lnATE) exhibited a positive correlation of 0.2964714, showing a positive long-run link with CO_2 emissions, while statistically insignificant (p-value = 0.819). Conversely, economic growth (lnECG) revealed a negative coefficient of −0.6738055, demonstrating a negative long-run association with CO_2 emissions, albeit statistically insignificant (p-value = 0.763). The negligible coefficients for renewable energy consumption (lnREC) and greenhouse gas emissions (lnGHG) show that present policies targeting these sectors may not successfully lower CO_2 emissions in the long term. Policymakers may need to examine and expand renewable energy policies, emissions laws, and investment strategies to achieve more substantial emission reductions. Similarly, the cheerful but small coefficient for access to electricity (lnATE) shows that initiatives oriented primarily at boosting electricity availability may not directly contribute to CO_2 emissions reduction in the long term. However, electrification may still be crucial in enabling the transition to renewable energy and boosting energy efficiency, indirectly affecting emissions. The opposing but negligible coefficient for economic growth (lnECG) contradicts the traditional notion of a positive link between economic growth and CO_2 emissions in the long term. Policymakers should study measures to divorce economic development from environmental deterioration, stressing sustainable industrial practices, clean technology uptake, and circular economy concepts.

Table 4. Diagnostic test.

Dependent Variable	Model ARDL	B-G serial correlation LM test	ARCH LM test	Jarque-Bera normality test	Ramsey-Reset Test	CUSUM test	CUSUM of Squares test
lnCO_2	(3, 3, 1, 3, 2)	0.3085	0.4921	0.5567	0.1846	Stable	Stable

The derived F statistic value for the suitable ARDL model falls below the upper limit of the critical value table supplied by Pesaran et al. (2001). Consequently, the null hypothesis (H0) showing no long-term link between the series is accepted. This

suggests that the existing data does not give sufficient evidence to reject the null hypothesis, showing a lack of persistent link among the variables in the model. The error correction model and long-term coefficients of the specified ARDL model are detailed in **Table 5**. Therefore, no statistically significant long-run association is identified between CO_2 emissions or environmental pollution, renewable energy use, access to power, and greenhouse gas emissions. Thus, it may be argued that the reverse U-shaped Environmental Kuznets Curve hypothesis holds from 1993 to 2020. These data show that the interactions between these characteristics and environmental contaminants may develop over time, needing lengthy observation and study to comprehend their implications thoroughly. Regular monitoring and continuing study of these elements are vital for guiding policy revisions and guaranteeing the success of adopted initiatives.

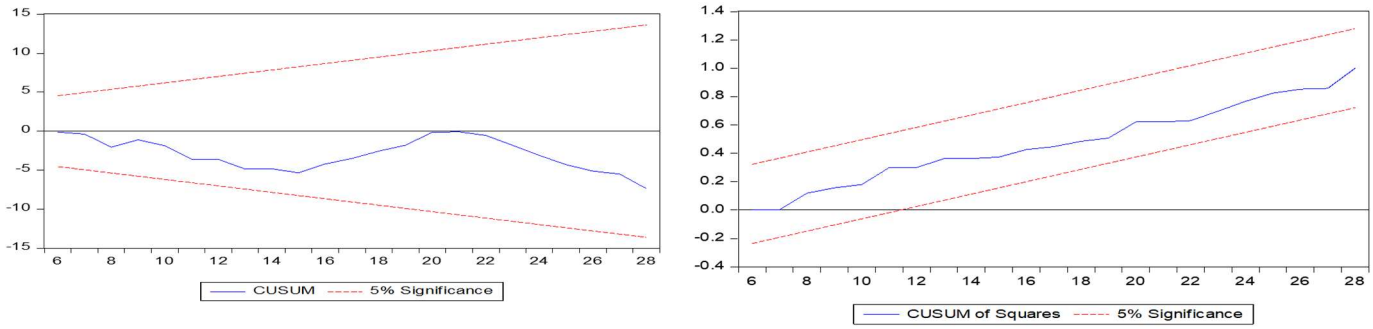
Table 5. ARDL estimation.

The dependent variable EVP				
Independent variable	Coefficients	Std. error	t statistics	Probability
lnREC	2.183268	2.571757	0.85	0.421
lnGHG	2.682888	2.697513	0.99	0.349
lnATE	0.2964714	1.250384	0.24	0.819
lnECG	−0.6738055	2.154979	−0.31	0.763

Upon evaluating the OLS and quantile regression findings reported in **Table 5**, it becomes evident that the OLS results closely reflect those obtained from the ARDL study. According to the OLS test findings, the effect of access to electricity (ATE), renewable energy consumption (REC), total greenhouse gas emissions (GHG), and economic development (ECG) on the environment in Ghana is judged statistically significant. However, quantile regression results give a more thorough view of the correlations between the independent variables and environmental contaminants. The effects of renewable energy consumption (REC), economic growth (ECG), and access to electricity (ATE) on environmental pollution (EVP) demonstrate variation throughout the range, with more apparent consequences reported at lower percentiles. In contrast, greenhouse gas emissions (GHG) consistently and substantially influence all quantiles' environmental pollution.

The CUSUM (Cumulative Sum of Recursive Residuals) and CUSUMSQ (CUSUM of Squares) tests at the 5% significance level are used to analyze the stability of the short-run and long-run coefficients in the model. Since the model's residuals stay within the critical limits, the model is stable and has no evident structural break. The CUSUM and CUSUMSQ test results imply that the regression model employed in this research is stable over the sample period under consideration. This stability suggests that the model's coefficients (parameters) and variance do not display substantial structural alterations or instability over time. In other words, the correlations between the independent factors (renewable energy consumption, greenhouse gas emissions, access to power, and economic development) and the dependent variable (environmental pollution) stay stable throughout the sample period. The steady CUSUM and CUSUMSQ charts offer confidence in the reliability and

robustness of the regression results, including the quantile regression findings mentioned previously. The model's stability demonstrates that the relationships between the independent and dependent variables are stable and may be evaluated with a high degree of confidence. These tests reveal that the regression model adopted in the research is stable, with its coefficients and variance not demonstrating significant changes or instability across the sample period, which is a critical assumption for the validity of the regression analysis. This consistency strengthens trust in the regression findings and their inferences (see **Figure 2a,b**).



(a) **(b)**

Figure 2. Model Stability Graph **(a)** CUSUM (Cumulative Sum of Recursive Residuals); **(b)** CUSUMSQ (CUSUM of Squares).

4.2. Causality test

The Granger causality test results reveal complex interconnections between environmental, economic, and energy variables, as shown in **Table 6**. Several crucial relationships emerge at a 5% significance: greenhouse gas emissions and renewable energy consumption. Both Granger causes access to electricity, suggesting these factors precede changes in electricity accessibility. Economic growth appears to be a significant driver, Granger causing both CO_2 and greenhouse gas emissions, highlighting the environmental challenges of development. Renewable energy consumption causes economic growth, indicating that sustainable energy adoption may support economic development. At a 10% significance level, additional relationships emerge, including a bidirectional relationship between economic growth and electricity access, suggesting a feedback loop between economic development and energy accessibility. Similarly, carbon emissions and electricity access are bidirectional, while renewable energy consumption shows a weak causal relationship with CO_2 emissions. These findings reveal where economic growth drives emissions, but renewable energy adoption could mitigate these environmental impacts while supporting economic development and electricity access. The relationships between greenhouse gas emissions and CO_2 per capita highlight the interconnected nature of different emission metrics.

Table 6. Causality test.

Pairwise Granger Causality Tests			
Null Hypothesis:	Obs	F-Statistic	Prob.
LNECG does not Granger Cause LNATE	26	2.688	0.0913
LNATE does not Granger Cause LNECG		2.66787	0.0928
LNEVP does not Granger Cause LNATE	26	2.62193	0.0963
LNATE does not Granger Cause LNEVP		3.4242	0.0516
LNGHG does not Granger Cause LNATE	26	5.41022	0.0127
LNATE does not Granger Cause LNGHG		0.7406	0.4889
LNREC does not Granger Cause LNATE	26	4.50222	0.0236
LNATE does not Granger Cause LNREC		1.01397	0.3799
LNEVP does not Granger Cause LNECG	26	0.34617	0.7114
LNECG does not Granger Cause LNEVP		4.83548	0.0187
LNGHG does not Granger Cause LNECG	26	0.13947	0.8706
LNECG does not Granger Cause LNGHG		4.05311	0.0325
LNREC does not Granger Cause LNECG	26	4.39926	0.0254
LNECG does not Granger Cause LNREC		2.65288	0.0939
LNGHG does not Granger Cause LNEVP	26	5.5193	0.0119
LNEVP does not Granger Cause LNGHG		2.49588	0.1065
LNREC does not Granger Cause LNEVP	26	2.87057	0.0791
LNEVP does not Granger Cause LNREC		0.06375	0.9384
LNREC does not Granger Cause LNGHG	26	0.97393	0.394
LNGHG does not Granger Cause LNREC		0.1659	0.8482

The quantile regression findings in **Figure 3** and **Table 7** give full and nuanced knowledge of the links between the independent variables and environmental contaminants, offering a more sophisticated viewpoint than the OLS regression study. To elucidate the connection between renewable energy consumption (RNE), economic growth (ECG), access to electricity (ATE), greenhouse gas emissions (GHG), and Environmental pollution (EVP). **Table 7** presents the quantile regression coefficient results with their respective *p*-values, and **Figure 3** provides the quantile regression diagram, which is duly discussed after that.

Table 7. OLS and quantile regression.

VARIABLES	**OLS**	**Q (0.05)**	**Q (0.10)**	**Q (0.20)**	**Q (0.25)**	**Q (0.50)**	**Q (0.75)**	**Q (0.90)**	**Q (0.95)**
lnREC	−0.657*	−0.567	−0.567	−0.789**	−0.740	−0.433	−0.665	−0.347	−0.347
	(0.334)	(0.421)	(0.425)	(0.379)	(0.444)	(0.525)	(0.533)	(0.520)	(0.581)
lnGHG	1.231***	0.679*	0.679*	0.943***	1.015**	0.879*	1.643**	2.381***	2.381***
	(0.259)	(0.342)	(0.340)	(0.302)	(0.386)	(0.466)	(0.650)	(0.635)	(0.536)
lnATE	0.210	0.460***	0.460***	0.362**	0.332	0.467	−0.089	−0.189	−0.189
	(0.171)	(0.130)	(0.095)	(0.139)	(0.252)	(0.352)	(0.453)	(0.388)	(0.287)
lnECG	−0.984***	−0.459	−0.459	−0.886***	−0.886***	−0.633	−1.032*	−1.634***	−1.634***
	(0.309)	(0.379)	(0.368)	(0.242)	(0.288)	(0.488)	(0.588)	(0.468)	(0.417)

Table 7. (*Continued*).

VARIABLES	OLS	Q (0.05)	Q (0.10)	Q (0.20)	Q (0.25)	Q (0.50)	Q (0.75)	Q (0.90)	Q (0.95)
Constant	−4.468	−4.166	−4.166	−2.421	−3.216	−5.428	−6.955	−10.845*	−10.845*
	(3.205)	(4.007)	(4.093)	(3.604)	(3.878)	(4.253)	(4.760)	(5.425)	(5.933)
Observations	28	28	28	28	28	28	28	28	28
R-squared	0.974								

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

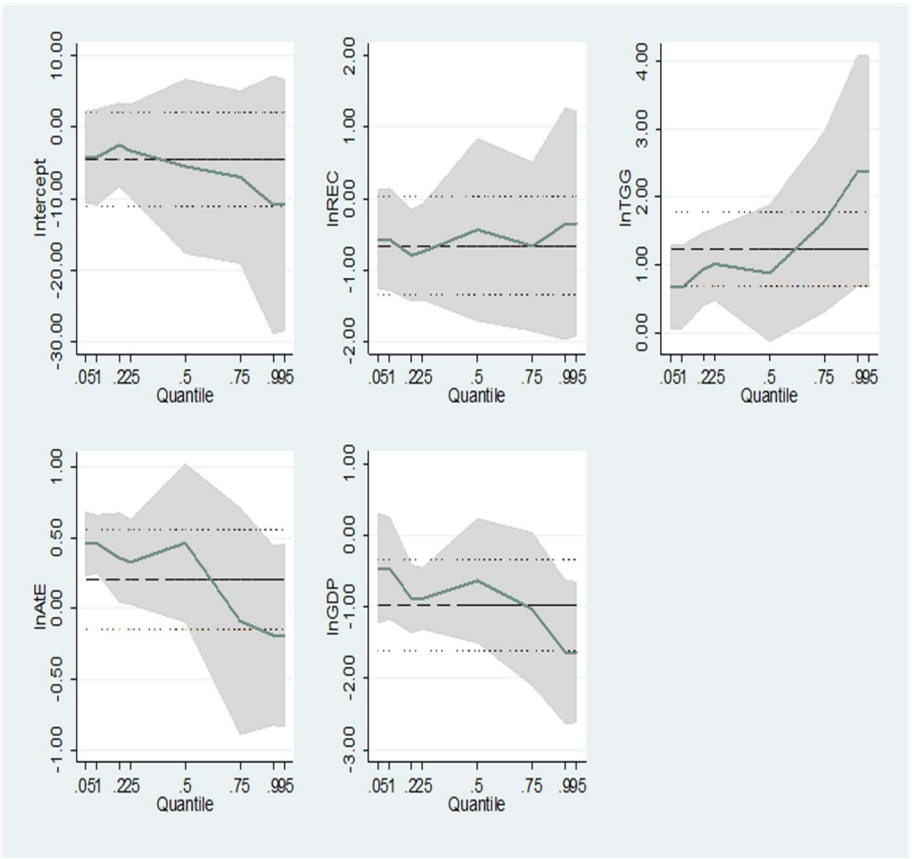


Figure 3. Quantile regression.

From the OLS and Quantile regression conclusions, renewable energy consumption (REC) has a statistically substantial deleterious bearing on EVP, as demonstrated by the OLS model aligning with the findings of [61–62,96–98]. The quantile regression results provide a more sophisticated view of this relationship. At the lower quantile (20th), REC shows a negative and statistically significant effect on EVP, indicating that in locations with lower levels of environmental pollution, increases in REC are associated with more significant decreases in pollution. The effect of REC on EVP is undesirable at the median (50th quantile) and higher quantiles. However, it is not statistically significant, indicating that the influence of REC on pollution reduction is less prominent in locations with greater environmental pollution levels. This shows that the influence of REC on lowering environmental pollution is more pronounced in places with lower pollution levels, as indicated by the lower quantiles. The OLS regression yields an average effect but does not adequately reflect

this variability across the distribution. The OLS regression shows that ECG has a deleterious and statistically momentous effect on EVP [32,99–100]. The quantile regression results provide more insights. At the lower quantiles (20th and 25th), ECG shows a negative and statistically significant effect on EVP, indicating that in locations with lower levels of environmental pollution, increases in ECG are associated with higher decreases in pollution [30–33,101]. The upshot of ECG on EVP is statistically significant and negative at the median (50th quantile) and higher quantiles, indicating that the influence of ECG on pollution reduction is more pronounced in locations with higher levels of environmental pollution. The quantile regression results demonstrate that the influence of ECG on lowering environmental pollution is more pronounced in locations with higher pollution levels, as indicated by the higher quantiles. The OLS regression does not fully capture this nuance.

Economic growth gains are associated with pollution reductions at lower levels of environmental contamination (represented by the lower quantiles). This is compatible with the downward-sloping aspect of the EKC theory [75,78,102]. At more significant levels of environmental contamination (represented by the median and upper quantiles), the negative effect of economic expansion on pollution becomes more pronounced and statistically significant. This also coincides with the EKC theory, where increased economic development reduces environmental damage. The quantile regression approach provides a more detailed view of the ECG-EVP relationship than the OLS regression, which only displays the average effect. The quantile results indicate the diverse nature of this relationship over the distribution of environmental contamination levels, validating the EKC theory in Ghana. The quantile regression results in this study are primarily compatible with the expectations of the EKC hypothesis, as they reveal that the link between economic growth and environmental pollution changes over the spectrum of pollution levels. This shows that the EKC hypothesis may be a binding framework for analyzing the ECG-EVP link in Ghana.

Secondly, the OLS analysis demonstrates that access to electricity (ATE) has a positive but statistically negligible influence on environmental pollution (EVP). The quantile regression findings give more information than sophisticated ones. ATE has a positive and substantial effect on EVP at lower quantiles (5th, 10th, 20th), indicating that in locations with lower pollution levels, ATE increases relate to higher pollution increases [19]. At the median and higher quantiles, the effect of ATE on EVP is negative but negligible, suggesting ATE's impact on pollution is less evident in places with greater pollution levels [82]. Furthermore, the OLS demonstrates that greenhouse gas emissions (GHG) positively and statistically significantly influence EVP [47–50]. From the quantile regression, GHG demonstrates a positive and substantial influence on EVP across all quantiles, demonstrating that increases in GHG are related to immense pollution rises throughout the whole distribution [18–20,103–107]. The quantile regression provides complete knowledge of the interactions between the independent variables and environmental pollutants. The impacts of renewable energy consumption (REC), economic growth (ECG), and ATE on EVP vary throughout the distribution, with more apparent effects at lower quantiles. In contrast, GHG consistently has a favorable and substantial influence on EVP across all quantiles. Compared to OLS, quantile regression shows diverse effects that are not represented

by the average impact reported in the OLS model. This method shows complex effects that change throughout the conditional distribution of the dependent variable.

5. Conclusions and policy implications

5.1. Conclusion

This study provides valuable insights into Ghana's intricate relationship between renewable energy consumption, economic growth, and environmental pollution. The findings from the ARDL and quantile regression analyses offer important policy implications for Ghana's pursuit of sustainable development and environmental sustainability. The primary driver of carbon emissions is energy usage, which leads to global ecological degradation and challenges that nations face. Firstly, the quantile regression results reveal that the influence of renewable energy consumption on environmental pollution varies across different pollution levels in Ghana. While increased renewable energy consumption effectively reduces pollution in lower pollution levels, its impact is less pronounced in areas with higher pollution intensities. This highlights the need for a targeted approach, where renewable energy policies and investments are strategically focused on sectors or regions contributing significantly to Ghana's overall pollution levels. Secondly, the positive and significant relationship between greenhouse gas emissions and environmental pollution across most quantiles underscores the urgency for Ghana to adopt comprehensive mitigation strategies. Reducing greenhouse gas emissions from various sectors, such as energy, transportation, and industry, should be a top priority to combat environmental degradation effectively. Furthermore, the study also reveals an interesting pattern regarding the role of economic growth in environmental pollution. While economic growth tends to reduce pollution in regions or sectors with lower pollution levels, it may exacerbate pollution in areas with already high pollution intensities. This finding emphasizes the importance of striking an elusive balance between Ghana's economic development and environmental sustainability. When viewed through the EKC framework, the quantile regression results suggest that economic growth's impression on Ghana's environmental pollution follows an inverted U-shaped pattern. Economic growth in regions or sectors with lower pollution levels initially increases pollution. However, beyond a particular turning point, further growth is associated with a decline in pollution levels. This pattern aligns with the EKC theory, which posits that environmental degradation increases in the early stages of economic development but decreases after a certain income level is attained as societies prioritize environmental quality and adopt cleaner technologies. Policymakers should prioritize the implementation of cleaner production technologies, stricter environmental regulations, and incentives for industries to adopt eco-friendly practices, particularly in areas with high pollution levels. Notably, the ARDL long-run coefficients indicate that none of the variables (renewable energy consumption, greenhouse gas releases, access to electricity, or economic growth) has a statistically significant impact on CO_2 emanations in the long run. This suggests that the relationships between these factors and environmental pollution may evolve, and more extended periods may be required to capture their full effects. Continuous monitoring and analysis of these variables are

crucial to inform policy adjustments and ensure the effectiveness of implemented strategies. Lastly, this study accentuates the necessity for a multifaceted approach to address environmental pollution in Ghana. Policymakers should prioritize promoting renewable energy sources, particularly in sectors or regions with high pollution levels, while simultaneously implementing effective greenhouse gas emission reduction strategies. Sustainable economic growth should be pursued by balancing development and environmental protection, adopting cleaner technologies, and encouraging eco-friendly practices across all sectors.

5.2. Policy recommendations

Clear policy implications exist for Ghana to consider based on the analytical results given. Initially, it will be critical for the government to prioritize cooperative relationships with businesses in the private sector, offer enticing tax breaks and subsidies to support renewable energy initiatives and create a welcoming regulatory framework that stimulates investment in hydropower, solar, and wind energy solutions. These steps will be vital for boosting the acceptance and expansion of renewable energy in Ghana. Harnessing Ghana's vast renewable energy potential can significantly reduce the region's reliance on fossil fuels and mitigate greenhouse gas emissions, contributing to global efforts in combating climate change. Implement carbon pricing mechanisms and emissions trading systems tailored to the Ghanaian context. By introducing market-based instruments such as carbon taxes or emissions trading systems, industries and businesses across the continent will be incentivized to reduce their carbon footprint and adopt cleaner technologies. These mechanisms can generate revenue streams for the government, which can be reinvested in renewable energy projects, energy efficiency initiatives, and environmental protection programs, fostering a sustainable development pathway. Strengthen regional cooperation and knowledge sharing among African nations. Sub-Saharan countries like Rwanda have taken more aggressive steps with environmental regulations. Environmental challenges transcend national boundaries, and regional collaboration is crucial for effective mitigation and adaptation strategies. African countries should collaborate to set ambitious regional emissions targets, share best practices, and develop joint initiatives promoting sustainable development. Rwanda's National Environment and Climate Change Policy emphasizes strict enforcement of emission standards and comprehensive urban planning, contributing to lower pollution levels. Ghana could benefit from strengthening enforcement mechanisms and integrating carbon pricing and emission trading systems to create more accountability in environmental governance. Establishing platforms for knowledge sharing and technology transfer can accelerate the adoption of clean energy solutions and drive progress toward a greener Africa. Invest in sustainable urbanization and green infrastructure to accommodate the rapid urban growth in Africa. This includes developing efficient public transportation systems, constructing energy-efficient buildings, implementing robust waste management facilities, and incorporating green spaces into urban planning. Sustainable urbanization can significantly reduce the environmental impact of cities and improve the quality of life for urban residents, aligning with global goals for sustainable development. Enhance ecological education and public awareness

campaigns across African communities. Raising awareness about environmental protection and the benefits of renewable energy is crucial for driving behavioral changes and fostering societal support for sustainable policies. Governments should invest in environmental education programs, public awareness campaigns, and community engagement initiatives to promote eco-friendly practices and sustainable lifestyles, empowering citizens to be agents of change. Actively align African policies with global climate change mitigation efforts and international agreements. African countries should actively participate in global climate change negotiations and ensure their policies are aligned with international frameworks, such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs). This collaboration can facilitate access to global financing, technology transfer, and capacity-building support, accelerating Africa's transition towards a more sustainable future. Promote sustainable agriculture and forestry practices to address the significant contributions of these sectors to greenhouse gas emissions and environmental degradation in Africa. Governments should incentivize conservation agriculture, agroforestry, precision farming, forest conservation, reforestation efforts, and sustainable forest management practices. By prioritizing these sustainable practices, Africa can protect its natural resources, improve food security, and contribute to global efforts to mitigate climate change. By implementing these personalized strategic and practical policy recommendations, Ghana and African nations can leverage the potential of renewable energy and sustainable economic growth to address environmental pollution challenges while actively contributing to global efforts in combating climate change and achieving sustainable development goals for a greener and more prosperous future.

5.3. Limitations and suggestions for future research

This study has a few limitations. First, it focuses only on Ghana, which may limit the applicability of findings to other African nations. Future research should expand the analysis to multiple countries for broader insights. Second, using national-level data might overlook regional differences. Future studies could use more localized data to capture variations between rural and urban areas. Third, while ARDL and quantile regression were effective, other models, like non-linear or machine learning techniques, could better explore complex relationships. Finally, additional factors like industrialization and trade openness should be considered in future analyses.

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Article

Sustainable development goals through participatory video and digital storytelling

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Abstract: This study focuses on a training experience that took place in the academic year 2021–2022 at Gadjah Mada University in Indonesia. A hands-on workshop on ICTeEfS focusing on Participatory Video (PV) and Digital Storytelling (DST) involved 210 teachers in the creation of videos with a two-fold objective: 1) embedding SDGs in school curricula enabled by PV/DST methodologies and 2) innovating teaching methodologies by merging digital and green skills. The process of creating PV/DST videos included a 15-step methodology integrated into four interacting phases starting from planning, moving to production, and then utilization/dissemination. The PV/DST applications produced could be used as learning resources to enrich the school curricula. Uploading PV/DST to school or social media accounts was a good method to get the message out to a wider audience while empowering teachers to address SDGs. The results can be used as guiding principles for teacher educators and teachers as well as for policymakers to integrate PV/DST in teaching, learning, and curricula addressing SDGs.

Keywords: SDGs'; sustainable development goals; participatory video; digital storytelling; ICTs; education for sustainability; green skills; digital skills; teacher training

1. Introduction

Southeast Asian countries are currently facing thesignificant impact of the sustainability crisis caused largely by unsustainable modes of production and consumption [1,2]. Research shows thatIndonesia's wealth of natural resources is being highly exploited to serve economic growth, while environmental awareness and knowledge among the populace are limited [3]. To achieve the transformational shift towards a more sustainable and just society there is a need for more equitable and responsive relationships between humans and nature. Currently, society is undergoing an increased digital transformation across all societal and economic sectors [4–7] and education should not be left behind. Education for sustainability becomes an important research area for embedding SDGs in school curricula [8] which could lead to a low-carbon sustainable development [9] and reduction of the negative impact of resource exploitation and environmental pollution [10].

The calls for taking action communicated through global initiatives such as the European Green Deal [11] and the UN 2030 Agenda for Sustainable Development

[12], and in particular the 17 Sustainable Development Goals (SDGs) which have launched the transition to a greener economy and society. Indonesia is one of the largest countries in the world and the largest among the Association of Southeast Asian Nations (ASEAN) in terms of population, Gross Domestic Product, and a fast-growing digital market that demands digital skills to accelerate the pace of its digital transformation and overcome the existing digital divide [13–15]. Recent policies in Indonesia prioritized the greening of the economy through the implementation of SDGs supported by digital transformation [16–18]. The Indonesian government has paid due attention to the transformative power of the creative and circular economy and has undertaken various initiatives to stimulate sustainable growth in this domain [19,20]. Indonesia's efforts toward digitalization generated through favorable policies and incentives have increased attention both locally and globally [21]. Green and digital skills are crucial for climate neutrality as well as for employability and entrepreneurship [22,23]. On the one hand, essential digital skills, such as being able to handle digital devices, find, adapt, and modify digital learning objects on the Web, as well as understanding ethics, risks, and opportunities are challenging all education levels. On the other hand, green skills such as possessing knowledge, values, attitudes, and action competencies needed to live together sustainably are equally positioned as necessary constituencies across all education levels.

Indeed, in an era where digital transformation and environmental sustainability meet together, Indonesia and humanity, in general, are faced with one of the most warning challenges in history to face the convergence of green and digital education. In particular, the critical role of digital technologies in addressing environmental challenges, such as consumer behaviors as a means of mitigating the effects of climate change is highly acknowledged [24,25]. The role of education, starting from pre-service teachers at Faculties of Education and continuing with in-service teachers at the primary and secondary school levels, is of critical importance. In particular, the growing importance of soft or transversal skills such as the 4Cs (Communication, Collaboration, Critical thinking, and Creativity) [26] and its extension to 10Cs [27], adding Critical reflection, Critical consciousness, Connectivity, Co-responsibility, Constructing knowledge and Cross-cultural understanding lies at the heart of converging green education with digital education. These skills are necessary to unlock human agency and equip the next generation of changemakers. However, it has to be stressed that despite growing up in a digital and hyper-connected world, not all of today's students have the digital skills required to use technology effectively, especially in the context of real-life issues that can be visible across the 17 SDGs [28,29]. The digital divide is not only situated with accessibility to the Internet but also about the existing awareness-knowledge-action gap for living together sustainably [30,31]. Addressing these gaps can help support the UN Sustainable Development Goals (SDGs), including Goal 4 (providing equitable access to quality education) and Goal 13 (climate action).

Thus, education at all levels should play a key role in developing digital skills for all students. The rapid growth of digital education in the post-COVID era paves the way for innovative practices towards merging with green skills enabled by innovative approaches to teaching, learning, and curriculum reconstruction. This

convergence can enable young Indonesian people who represent almost half of the population to manage their carbon footprint, preserve biodiversity, and promote sustainable development more effectively [19]. An issue brief for the Government of Indonesia states that if current trends persist, by 2030 more than 60% of young people may lack the skills required to thrive in the green economy [32]. Green skills will allow young people to be better prepared to act as catalysts and lead the transition to a greener future [22,33]. Research shows that Participatory Video (PV) and Digital Storytelling (DST) can be seen both as teaching methods and learning resources that can promote the merging of green education and digital education at all education levels [34,35].

The merging of green and digital skills connected with local issues elicited from the 17 SDGs enabled by PV/DST methodologies and tools was one of the key areas that the ICTeEfS (ICT-enabled Education for Sustainability) in-service teacher capacity building program funded by the European Commission. The program targeted teachers in Indonesia to get a deeper insight into the country's efforts for green and digital transformation and the role education can play in this effect. The training was designed to involve in-service teachers in learning and practicing digital tools and innovative pedagogical strategies to embed education for sustainability and in particular SDGs into teaching, learning, and curricula. It was envisaged that ICTeEfS focusing on PV/DST would unlock opportunities for revising teaching methods and curricula and turn teachers into active players in developing learners' green and digital skills. Thus, the research questions addressed in this study include the following: What are the most frequent subjects infused with SDGs? What is the preferred length of the PV/DST applications? Which SDGs are more attractive to get infused in the PV/DST applications? What lessons can be learned through the contextualization of SDGs with digital skills generated through the development of PV/DST? What kind of green skills can be inferred through the infused SDGs? How do the PV/DST activities connect with the Indonesian policies and practices for implementing the UN Agenda for SDG?

2. Materials and methods

Participatory video (PV) and digital storytelling (DST) can be merged to provide a methodology in which a group creates their own video usually to advocate their concerns and explore possible solutions to an issue that they are concerned about [36]. Thus, PV and DST bring together interested stakeholders to tell their stories to the wider community, a process that can activate self-reflection, empowerment, and action [37–39]. The PV/DST methodology is characterized by a horizontal decision-making process, collaboration, dialogue, and co-construction of knowledge to serve various purposes [40,41]. Using a PV/DST methodology unlocks the opportunity for those involved to communicate their ideas, perspectives, world views, and experiences to the broader community, and other stakeholders [42–45]. It is driven by a critical-reflective attitude and an emancipatory perspective leading those involved to learn to transform themselves and society. In other words, the PV/DST process leads to empowerment, critical reflection, community service, and giving voice to those who could otherwise not be heard [46–48]. The process of

creating PV/DST includes some procedures, starting with planning, production, utilization, and dissemination. The PV/DST methodology applied here was based on Makrakis and Kostoulas-Makrakis [49] 15 steps structured on four interlinked stages, named the PV/DST4Ps: 1) pre-planning (Steps 1–4), 2) planning (Steps 5–9), 3) production (Step 10–13), and 4) publication (Steps 14–15). In the pre-planning stage, each group started with an idea referring to a sustainability issue as part of the capacity-building program, and continued with searching PV/DST examples from the Web, preferably dealing with education for sustainability issues (Step 1). Based on the search results, participants proceed to a thorough analysis of the inherent goals, objectives, and messages conveyed (Step 2). After getting a thorough knowledge of what exists in this field, the leaders of the teacher training program developed an example to be used as a model for trainees and organized the groups to be involved in the PV/DST process (Step 3). In forming the groups, particular emphasis was placed on group communication through (Step 4): 1) creating friendly, trustful, and egalitarian relationships among the people involved in the project and 2) sensitizing the group members to the issue and tasks as well the potential for transforming their teaching and learning practices.

During the planning stage, that is, the most critical step to producing a successful and meaningful PV/DST application, the starting point includes the setting of goals, objectives, and strategies (Step 5), conducive to the PV/DST application to be developed, following up by deepening the inquiry (Step 6) for specific resources focusing on the content issue or theme and scheduling (Step 7) and to establish a realistic timeline for the entire PV/DST project. Upon that, participants in each group are in a position to proceed with scriptwriting/revising the PV/DST script (Step 8). Scripting is a process that generates the development of the storyboard that provides the plotting, that is, the sequence or the roadmap of the events taking place in the plot. The visualization and dramatization what is referred to as the process of storyboarding (Step 9) graphically describes the action that will take place in each scene of the PV/DST application.

In the production phase, starting with the editing process (Step 10) one of the most demanding tasks that requires special care and skills, including the refining of titles, text, and credits (Step 11): Although this may be part of the editing step, this can also be done as a separate step. This process continues with logging and capturing footage (Step 12), using the appropriate software tools. Formative Assessment (Step 13) focuses is testing and validation that culminates with the publication phase, including the uploading to a media platform (Step 14), usually on the web (YouTube), ending with publication and dissemination (Step 15) to interested stakeholders and the wider public.

The PV/DST methodology was part of the ICTeEfS capacity-building program at the University Gadjah Mada (UGM) in Indonesia. The training was organized in three consequent cohorts. It started with a train-the-trainer session (1st cohort) from the University of Gadjah Mada (UGM), continued with the in-house training of in-service teachers (2nd cohort), and culminated with a follow-up training for all subject teachers (3rd cohort). All the training sessions were highly supported by local educational authorities. In these workshops, particular emphasis was given to

the participatory and negotiated curriculum development approaches [50,51], the six pillars of learning (learning to know, learning to be, learning to do, learning to live together sustainably, learning to give/share, and learning to transform oneself and society), as well as the 10Cs of transversal skills needed for 21st-century education [27,52]. The epicenter of the training was the merging of all these innovations with the embedment of SDGs in school curricula enabled by PV/DST methodologies and digital tools.

3. Results and discussion

3.1. Pre-planning PV/DST

Starting from the train-the-trainer workshop at the University of Gadjah Mada (UGM), 15 teacher trainers (8 female and 7 male) were trained to lead the in-house training of teachers. In total 210 teachers from the province of Yogyakarta in Indonesia, 72% of whom were women were trained to lead further training sessions within their schools and educational districts from November 2021 to January 2022. The ICTeEFS in-service teacher training participants are teaching a wide array of courses reaching up to 33 (**Figure 1**).

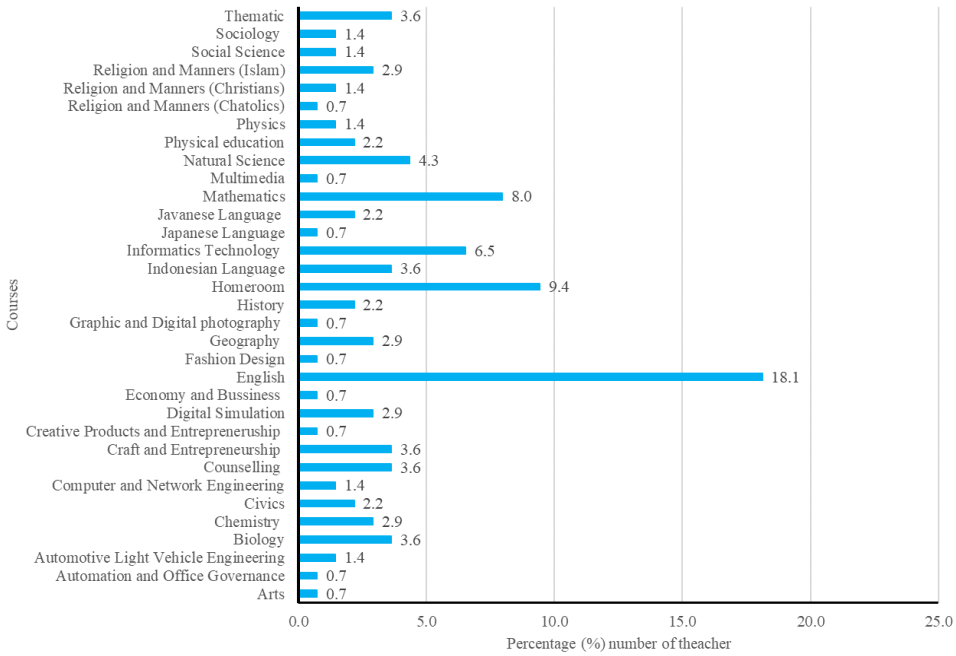

Figure 1. Subject taught by teacher trainees.

The trained teachers represented the three levels of school education, namely: primary, junior high school, and senior high school in the Special Region of Yogyakarta, an area of 3186 km^2, with 3.7 million population and 3042 schools at the primary to secondary level [53–55]. Although the majority of the teachers were working in urban schools, a significant part was also from rural schools. **Figure 2** shows the spread of the trainees' schools in the Special Region of Yogyakarta. The mandatory schooling in Indonesia lasts for nine years, consisting of elementary (6 years) and junior high school (3 years). There are two different types of high school, which are regular high school and vocational ones. These two types of schools have

quite distinct learning environments. While the vocational ones will prepare students to enter the workforce, the regular high schools will focus more on preparing students for the next level of education (college).

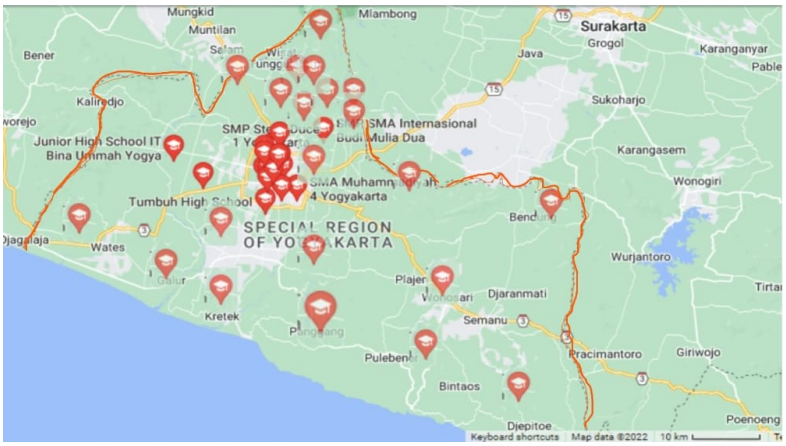

Figure 2. Geographical distribution of schools.

During the pre-planning phase, teacher trainers and facilitators introduced the concept of PV/DST and how it will be operationalized in merging green education and digital education in the context of SDGs. Trainees were given examples of PV/DST and they were asked to do their searching on the Web to identify PV/DST applications, preferably dealing with education for sustainability issues. Our experience through the ICTeEfS training sessions showed that as a starting point, trainees searched for a local sustainability issue that has drawn attention to the local society in connection with SDGs and at the same time reflected on their previous experiences in the field. Teacher trainers also developed an example to be used as a model for trainees. Through these pre-planning activities, teacher trainers aimed to sensitize teacher trainees to real-life issues that could be transformed into teaching and learning materials. Throughout the pre-planning phase, trainees were engaged in conceptualizing what should be developed and why as well as identifying what digital and green skills were lacking to be addressed in the training sessions. Our experiences show that what was mostly lacking was the skill of how to merge green and digital skills through engagement in developing PV/DST infused with SDGs. Creating a dynamic, interactional, and transformative dialogue about the significance of the PV/DST application was perceived as a critical strategy in providing teacher trainees with the knowledge and skill to be actively involved in the subsequent planning phase. As teacher trainers, we realized that PV/DST integration is complex, and trainees lacked the pedagogical knowledge necessary to integrate digital tools effectively in their everyday teaching work.

3.2. Planning PV/DST

Within the context of the ICTeEfS teacher training program, digital and green literacy were seen as a prerequisite to turning PV/DST planning into a meaningful process and learning activity. In the planning phase, teacher trainees were required to organize the PV/DST projects requiring them to design and compose digital multimodal texts in line with the objectives set and the SDG themes (**Figure 3**) they

identified as the most suitable ones in the local context. They were asked to reflect on the process and consider the advantages of integrating PV/DST in their classroom teaching and the school curricula. Our experiences as teacher trainers show that teacher trainees were not used before in PV/DST scripting and the related skills using multimodal resources in developing learning objects with the support of ICTS. Efforts were directed toward communicating the message that the script should be perceived as a process and not as a product. The storyboarding process was highly facilitated by a storyboard template used as a graphic organizer. The collection of the PV/DST multimodal elements such as images, text, music, and animated features were chosen in line with written scripts to allow trainees to proceed with the production processes.

Figure 3. SDGs adapted from UN https://sdgs.un.org/goals.

3.3. Production of PV/DST

At the end of the training, 132 PV/DST applications had been developed representing 104 primary, junior secondary, and senior secondary schools (**Figure 4**). **Table 1** summarizes the results of these applications. It has been revealed that the majority of the produced PV/DST applications are mostly found in the subjects of Sciences/Mathematics and Civics followed by Languages. It is worth pointing out that these three subjects are also more frequently represented with school grades than the other subjects. Surprisingly, the least represented subject is Natural Studies, although it is the one that shows the highest infusion of SDGs in the produced PV/DST applications. It is also surprising that Religion is a subject that shows a high infusion of SDGs compared to other school subjects. In terms of the length of PV/DST applications, the majority (N = 58) exceeds 11+ minutes, followed by less than 5'. The allocated amount of time/learning unit in Indonesia is regulated by a Decree from the Minister of Education, Culture, Research, and Technology No. 16 referring to the Standardized Process of Education for Kindergarten, Pre-School, Elementary School, Junior High School, Regular High School, Vocational High School, and Equivalent level of schooling [56]. It has been revealed that only three SDGs, namely SDG 11 (Sustainable Cities and Communities), SDG 14 (Life Below Water) and SDG 17 (Partnerships for SDGs) are missing from those infused in the content of PV/DST applications. The results show that the most frequently infused

SDGs were those of SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), SDG5 (Gender Equality), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action). It has been also revealed that teacher trainees from grades 7th and 3rd are the ones where most of the PV/DST applications have been produced.

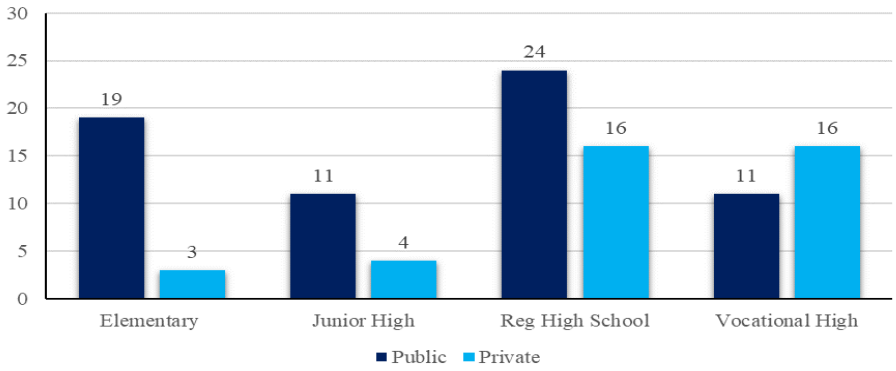

Figure 4. School level and number of participating schools.

Table 1. Distribution of PV/DST applications by subject areas, grade school level, length, and SDGs infused.

Subject areas	Grade	School level	PV/DST length in minutes				SDGs (1–17) infused in PV/DST
			0–5	6–10	+11'	Total	
Natural Studies	7	Junior Secondary			1 video	1	3, 4, 5, 7, 9, 10, 13
Sciences/Math	1, 2, 7	Primary & Junior Secondary	11 videos	8 videos	22 videos	41	1, 2, 4, 12, 16
Social Studies	5	Primary	8 videos	3 videos	5 videos	16	7, 8
Arts & Culture	3, 7	Primary & Junior Secondary	5 videos	1 video	5 videos	11	5, 8
Languages	7, 10	Junior and Senior Secondary	7 videos	9 videos	14 videos	30	3, 10, 13
Health & Sport	4, 6	Primary	1 video	2 videos	3 videos	6	1, 3, 4
Religion	7, 11	Primary & Senior Secondary	5 videos	1 video	1 video	7	3, 5, 6, 13, 15
Civics/Pancasila	3, 4, 7	Primary & Junior Secondary	1 video	1 video	2 videos	4	2, 4, 5, 16
Cross-thematic	3, 6	Primary	7 videos	4 videos	5 videos	16	7, 15
Total			45	29	58	132	1, 2, 3.4, 5, 6, 7, 8, 9, 10, 12, 13, 15, 16

3.4. Publication/Dissemination

One of the key strategies applied concerns the dissemination of the PV/DST applications which reflects the motto "Sharing is caring". Participants were encouraged to share what they had produced and learned during the training period not only within the groups but also between the schools and beyond to the wider teaching community and public. This was achieved through the use of various social media platforms such as YouTube. A total of 2305 people were reached (**Figure 5**).

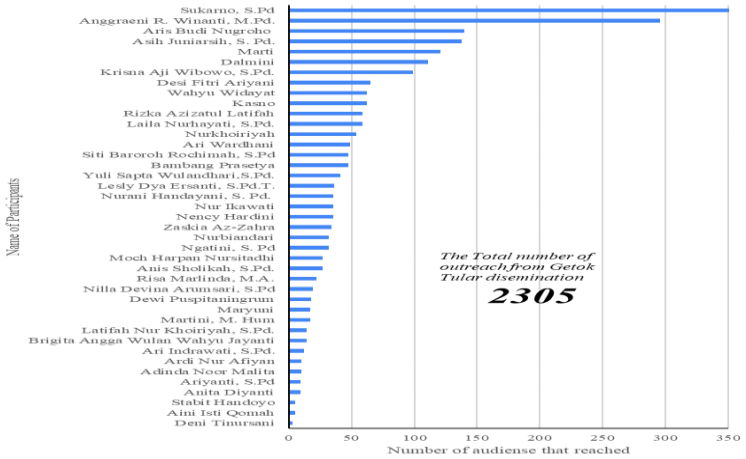

Figure 5. PV/DSTdissemination results.

4. Discussion

Our purpose in this study was to enable both teacher educators and in-service teachers how they can foster the development of digital and green skills needed for quality education (SDG 4). By digital skills, we referred to both the technical and creative skills involved in using digital media tools to develop PV/DST applications for teaching and learning as well as for enriching the school curricula. In the ICTeEfS teacher training program, digital and green skill-building was both a key objective and a byproduct of the PV/DST training activity. Several studies have shown that PV/DST is not only an effective pedagogical tool but also a tool that can empower participants to rethink teaching, learning, and curriculum perspectives as well as their roles as teacher educators and in-service teachers [55–57]. Our PV/DST methodology differs from previous similar ones in four ways: 1) attempts to contextualize green skills with digital skills; 2) integrates cross-cutting sustainability issues largely elicited from the 17 SDGs; 3) provides an inquiry-based approach that is driven by transformational teaching and learning principles and 4) helps to cultivate a participatory and digital storytelling culture for empowering teachers to address SDGs in multiple school subjects.

Among the key questions posed besides the ones that were explored in the result section were: What lessons can be learned through the contextualization of SDGs with digital skills generated through the development of PV/DST? What kind of green skills can be inferred through the infused SDGs? How do the PV/DST activities connect with the Indonesian policies and practices for implementing the UN Agenda for SDGs? Based on the results presented in **Table 1** and our reflections and discussions with teacher trainees during the training sessions the following lessons can be learned.

- ICTs and digital resources are essential means of training, acquiring, and co-constructing new knowledge that can generate new pedagogical practices.
- Using PV/DST as a teaching and curriculum development methodology offers teachers the opportunity to deal with local real-life issues with particular reference to SDGs.

- The teacher's role is fundamental to the infusion of SDGs in course curricula by employing PV/DST as innovative teaching methodologies, and content that is driven by real-life issues.
- PV/DST focusing on green issues generates many digital skills that help reflect on teacher trainees' personal theories and practices.
- Education leadership plays a key role in the implementation of SDGs and the PV/DST integration in teaching, learning, and curriculum enrichment.
- Interpreting the high outcome of viewing the PV/DST applications, it can be assumed that sharing PV/DST not only serves to "raise awareness" on real-life issues but also by turning teacher trainees "becoming visible" through the dissemination of their work can lead to an empowering and multiplier effect.
- Working closely with in-service teachers facing various challenges in their teaching practices taught us that what actually may matter more is how to bring the school to society and vice versa.
- By using PV/DST methodologies to merge and enhance green and digital skills, the ICTeEfS project opened spaces for the in-service teachers to reflect, learn, and talk about a wide array of sustainability issues elicited from SDGs that are not usually discussed in their classes.
- The convergence of digital technology and education for sustainability is one of the most significant pathways for creating meaningful synergies where digital technologies meet with the greening of teaching, learning, and curricula.
- The themes integrated or infused within the PV/DST learning products may serve as a means to raise teacher trainees' critical consciousness on SDGs issues, reflect on previous teaching practices, and consider changing personal theories on teaching, learning, and curricula,
- For us as teacher trainers, it was critical to create an open dialogue, ensure trust, share knowledge and experiences, discuss challenging issues, and question dominant ways of teaching, learning, and being.

All these assumptions and interpretations derived from the study results have strong support in previous research. It has been also shown that digital teaching and learning across all education levels can significantly contribute to learning to transform oneself and society [58,59]. Developing, producing, using, and disseminating digital applications contextualized with sustainability issues can significantly contribute to changing unsustainable actions that have led to the current climate crisis [60]. Teacher education and in-service training play a crucial role in building the capacity of future and current teachers to contextualize green education with digital education [61,62]. Teaching quality spelled out in SDG4 requires a more systematic integration of Education for Sustainability (EfS) across all education levels in Southeast Asia, starting from primary and secondary school education to teacher education [63]. Teachers are the key drivers in embedding the UN 2030 agenda for SDGs in teaching, learning, and curricula [64]. However, the teacher- and system-level barriers should be given special attention for a successful infusion of SDGs in education [65]. PV/DST both as teaching methods and as supplements to classroom-based activities are conducive to education for sustainability and digital literacy [66], merge several media such as image, video, sound, and music to

contextualize a story that may convey messages cutting across the four pillars of sustainable development [67]. The use of digital technologies in education can address sustainability issues largely elicited from SDGs and provide students with an interactive and engaging learning experience, unlocking opportunities for creative real-world problem-solving [68,69].

The research results also show that the most frequently infused SDGs refer to SDG3 (Good Health and Well-being; SDG4 (Quality Education); SDG5 (Gender Equality); SDG7 (Affordable and Clean Energy), and SDG13 **(**Climate Action). Good Health and Well-being' has unsurprisingly received attention from teacher trainees. This may be explained by the fact that the training was implemented by the end of the COVID-19 pandemic and the health crisis seemed to present an opportunity for Indonesian teachers to address this SDG in teaching, learning, and curriculum development through PV/DST. The situation during the pandemic revealed that Indonesian teachers as in many other countries were not ready to tackle the problems caused by the pandemic. Indonesia is also the world's fourth-largest populated country with unique socio-cultural and multi-ethnic characteristics, as well as a rising economic power that makes critical healthcare a hot issue, related to Indonesian wellbeing [70].

It was also unsurprisingly that gender issues appeared to be highly preferred as core themes in the PV/DST applications developed by teacher trainees. Perhaps, the reason for choosing gender issues among the teacher trainees is that Indonesia experiences more gender inequality than other neighboring countries taking into consideration its level of economic development [71], despite the enaction of legislation governing the rights of women [72]. It is worth pointing out that Indonesia's female labor force participation rate is comparatively low compared to the region, and has remained unchanged over the last two decades despite structural changes to the economy and higher female education performance in school subjects [73–75]. In connection to the quality of education that is highly debated, traditional modes of teaching and learning still predominate in its education system [76]. It is hoped that the various capacity-building initiatives such as the ICTeEfS program supported by the European Commission will contribute to shifting transmissive teaching and learning to constructivist and transformative alternatives that are more suitable to meeting the demands for merging green and digital skills addressing SDGs. Indeed, one of the most recurring strengths attributed to the development of PV/DST applications as part of the training process was its potential to enable reflection and rethinking of dominant perceptions of teaching, learning, and curriculum development. Such an assumption seems to be supported by previous research showing that PV/DST helps to cultivate a participatory culture of a group of people that can ultimately generate positive changes related to quality education [77–79]. It is also worth pointing out that the length of the PV/DST applications does play a critical role in their integration into teaching, learning, and the school curriculum. Taking into consideration the structure of the Indonesian school system, the most suitable PV/DST applications that could be used in offline learning were the ones that have short to medium lengths of time (5–30 minutes). Video with short-medium lengths are more suitable to Indonesia's study timeframe study unit which is

35 minutes for elementary school, 40 minutes for junior high school, and 45 minutes for senior high school and vocational high school.

5. Conclusion

This project challenged teacher educators and teachers to design and create PV/DST as part of a capacity-building program and of teaching, learning, and curriculum enrichment. A participatory video is a useful tool for promoting SDGs and the principles of Education for Sustainable Development. As it has been argued in the discussion section, digital technologies can support the greening of pedagogy and curricula which in turn unlocks opportunities for transformational teaching and learning. Teacher capacity-building programs should play a critical role in merging digital education and green education through which teachers can be involved in participatory and collaborative efforts of designing and making digital artifacts such as PVs. Through this experience, we have learned that learning should be 1) anchored on and driven by participants' interests, 2) powered by collaborative efforts, and 3) oriented toward real-life experiences.

Exploring the dynamic nature of PV/DST in the context of green education and in particular with SDGs is essential for bridging the awareness-attitudes-knowledge-action gaps and helping in merging digital and green skills. Therefore, this project aimed to bridge these significant gaps through a capacity-building program in the Yogyakarta periphery led by the University of Gadjah Mada. This endeavor is not only pertinent to teacher educators and teachers but also to educational policymakers and stakeholders within Indonesia. In this perspective, we also aim to draw lessons and inspiration for innovative teaching and learning practices that can be applied in various local, regional, and global contexts. As green education enabled by digital technologies continues to reshape education structures, teaching, and learning processes, education locally and globally is confronted with the imperative task of shifting from transmissive to constructivist and ultimately transformative pedagogies.

The present study has some limitations that need to be addressed in future research. First, there is a need to measure the learning outcomes of such PV/DST methodologies and practices in classrooms on sustainability behaviors. Further, the study was exploratory in nature, aimed at integrating a PV/DST methodology as part of a teacher capacity-building program to embed sustainability and SDGs in teaching, learning, and curricula. When conducting similar interventions in the future, it is suggested to complement with a follow-up investigation of possible learners' experiences during the use of PVs/DST in class. It is also important to connect the SDG themes with the school curriculum applying inter/cross-disciplinary teaching methodologies. Such a connection could help to find which lesson unit and subject PV/DST fits better. Despite these shortcomings, digital and green education, PV/DST, and ICTs are essential components of the implementation of the UN Agenda for SDGs and the European Commission Green Deal, both in terms of strategic innovation, pedagogy renewal, teacher training, and inclusive school development.

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Article

Shifting towards renewable energy: A sustainable solution to pollution

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Abstract: The 21st century poses unprecedented challenges in addressing climate change and environmental degradation, largely driven by the reliance on fossil fuels such as coal, oil, and natural gas. These energy sources contribute significantly to greenhouse gas emissions and air pollution, resulting in detrimental effects on human health and ecosystems. This paper explores the urgent need to transition to renewable energy technologies—including solar, wind, hydroelectric, geothermal, and biomass—as a sustainable alternative. It highlights the economic viability of renewable energy, emphasizing job creation, reduced energy costs, and enhanced energy security. Effective policy frameworks are crucial for fostering the adoption of renewables and phasing out fossil fuel subsidies, thereby mitigating the adverse impacts of climate change and promoting public health. Ultimately, the integration of renewable energy into global energy portfolios is essential for achieving sustainable development and a cleaner future.

Keywords: renewable energy; climate change; sustainable development; fossil fuel alternatives

1. Introduction

The 21st century presents a crucial moment for humanity as we face the urgent need to tackle climate change and environmental degradation, largely caused by the heavy reliance on fossil fuels [1]. Coal, oil, and natural gas have historically been the mainstays of global energy production; however, their combustion releases harmful pollutants such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM) [2]. These pollutants significantly contribute to global warming, climate change, and declining air quality, posing serious threats to human health and ecosystems [3]. In light of these environmental challenges, renewable energy technologies present a viable solution. Sources like solar, wind, hydroelectric, geothermal, and biomass utilize natural processes to produce electricity and heat with significantly lower environmental impacts and greenhouse gas emissions [4]. Transitioning from fossil fuels to renewable energy is not only an environmental necessity but also economically advantageous, supported by substantial empirical evidence and practical applications [5].

Renewable energy technologies provide numerous benefits over fossil fuels in terms of sustainability and environmental protection. For example, solar energy employs photovoltaic panels or concentrated solar power systems to convert sunlight into electricity, resulting in minimal environmental impact throughout its lifecycle [6]. Wind energy captures the kinetic energy of wind through turbines, generating clean electricity

without greenhouse gas emissions or pollutants during operation [7]. Hydroelectric power utilizes the gravitational force of flowing water, delivering a reliable energy source while maintaining a low carbon footprint [8]. Geothermal energy extracts natural heat from beneath the Earth's surface, providing a continuous energy supply with negligible greenhouse gas emissions [9]. Biomass energy employs organic materials like wood and agricultural residues to produce heat and electricity, serving as a renewable alternative to fossil fuels while potentially achieving carbon neutrality [10].

The feasibility and economic benefits of transitioning to renewable energy are becoming increasingly clear. A multitude of studies and real-world examples illustrate that investments in renewable energy infrastructure can lower energy costs, enhance energy security, and stimulate economic growth through job creation and technological advancement [11]. Regions that have adopted renewable energy strategies have reaped substantial rewards, including decreased reliance on imported fossil fuels and improved resilience to fluctuations in energy prices [12]. The declining costs associated with renewable energy technologies, alongside supportive policies and technological innovations, continue to propel the global transition toward a sustainable energy future [13].

Effective policy frameworks and international collaboration are essential for accelerating the adoption of renewable energy technologies and phasing out fossil fuel subsidies. Initiatives such as carbon pricing, feed-in tariffs, renewable portfolio standards, and tax incentives are crucial for promoting investments in renewable energy and fostering an environment conducive to sustainable development [14]. By prioritizing the deployment of renewable energy and creating a supportive regulatory framework, global communities can mitigate the adverse effects of climate change, enhance public health, and protect ecosystems for future generations [15].

2. Methodology

This study employs a mixed-methods approach to examine the role of renewable energy technologies in mitigating climate change and environmental degradation. It begins with a systematic literature review of peer-reviewed articles and reports from 2010 to 2023, synthesizing findings on the effectiveness of various renewable sources. Quantitative analysis assesses the cost-effectiveness and economic benefits of these technologies, utilizing data on installation and operational costs, job creation, and technological advancements, with comparative statistical methods. Qualitative case studies from diverse regions highlight implementation challenges and successes through semi-structured interviews with stakeholders and site observations. A comparative regional analysis explores variations in the renewable energy transition across developed and developing countries, integrating all findings to provide comprehensive insights and policy recommendations for enhancing renewable energy adoption.

3. Current pollution crisis

The burning of fossil fuels is a major source of air pollution, as outlined in **Table 1**.

In urban and industrial areas, emissions from vehicles, power plants, and factories release a complex mix of pollutants into the air, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and particulate matter (PM) [16]. These pollutants degrade local air quality and contribute to regional and global smog, acid rain, and ground-level ozone, severely impacting human health [17].

Table 1. Impact of conventional energy.

Source of Energy	Description	Impact	Effect on Plants and Animals
Coal	A fossil fuel formed from ancient plant matter, burned for electricity and heat.	High greenhouse gas emissions Air pollution leading to health issues	Acid rain harming forests and aquatic ecosystems
Oil	A liquid fossil fuel used for transportation and heating.	Significant carbon emissions Oil spills causing habitat destruction	Oil spills harming marine life Disruption of food chains
Natural Gas	A fossil fuel primarily composed of methane, used for heating and electricity generation.	Lower emissions than coal and oil, but still significant	Methane leaks contribute to climate change Potential harm to wildlife
Nuclear	Energy produced through nuclear fission; non-renewable due to uranium supply.	Risk of radioactive waste and accidents	Low greenhouse gas emissions during operation Habitat impact from mining uranium
Peat	An accumulation of decayed vegetation, used as a fuel source in some regions.	Emits significant CO_2 when burned	Loss of biodiversity in peatland ecosystems

Exposure to these pollutants is linked to serious health problems, including respiratory diseases like asthma and chronic obstructive pulmonary disease (COPD), cardiovascular issues, and an elevated risk of premature death [17]. Vulnerable groups, including children, the elderly, and those with pre-existing health conditions, face heightened risks [18]. Moreover, the deposition of these pollutants into water bodies and soil leads to environmental harm, biodiversity loss, and disruption of ecosystems [19]. For instance, acid rain adversely affects aquatic ecosystems and damages forests and agricultural crops.

Addressing the pollution crisis requires a comprehensive strategy that integrates the deployment of renewable energy, energy efficiency measures, sustainable transportation systems, and advanced pollution control technologies [20]. Transitioning to renewable energy sources such as solar, wind, hydroelectric, geothermal, and biomass can significantly cut emissions of greenhouse gases and air pollutants [21]. These technologies utilize natural processes to generate electricity and heat with minimal environmental consequences, contributing to climate change mitigation [22,23].

Additionally, policy frameworks that incentivize investments in renewable energy, promote cleaner technologies, and eliminate fossil fuel subsidies are vital. Mechanisms like carbon pricing, feed-in tariffs, and emissions trading systems are critical for hastening the shift to a low-carbon economy and ensuring sustainable development [24]. International collaboration and commitment to these objectives are essential for meeting global targets related to greenhouse gas emissions and air quality improvements [25].

4. Renewable energy technologies

Renewable energy technologies encompass a range of methods for energy generation and use:

- Solar Energy: Solar technologies, such as photovoltaic (PV) cells, directly convert sunlight into electricity, while concentrated solar power (CSP) systems use mirrors or lenses to focus solar energy for electricity or heat production [26].
- Wind Energy: Wind turbines capture wind's kinetic energy to generate electricity. Onshore and offshore installations are increasingly common, contributing to sustainable energy production [27].
- Hydroelectric Power: Hydroelectric dams and run-of-river systems harness flowing water to generate electricity, providing a consistent power supply with minimal greenhouse gas emissions [28].
- Geothermal Energy: Geothermal power plants extract heat from beneath the Earth's surface, generating electricity and providing direct heating and cooling. This form of energy is considered reliable due to its consistent availability [29].
- Biomass Energy: Biomass includes organic materials such as wood, agricultural residues, and organic waste. It can be converted into biofuels or directly burned for heat and electricity, serving as a renewable alternative to fossil fuels [30].

Each renewable technology presents unique advantages and challenges influenced by geographic location, resource availability, and technological maturity. Advances in technology and economies of scale have significantly lowered the costs of renewable energy generation, enhancing their competitiveness against traditional fossil fuels in many regions [31].

Globally, renewable energy deployment has been rising steadily, driven by environmental concerns, energy security needs, and economic advantages. Solar and wind power have particularly experienced rapid growth due to declining costs and supportive government policies [32]. Hydroelectric power continues to play a significant role in global electricity generation, especially in areas with abundant water resources [33]. Geothermal projects are expanding in regions with suitable geological conditions, offering sustainable energy solutions in both developed and developing nations [34]. Biomass energy, while more localized, is vital for decentralized energy production and rural development [35].

Diversifying energy sources through renewable technologies is essential for addressing climate change, reducing reliance on fossil fuels, and promoting sustainable global development. Ongoing investments in research, development, and infrastructure are crucial for advancing renewable energy deployment and realizing a clean energy future.

5. Role of renewable energy in pollution mitigation

Renewable energy is essential in combating pollution and minimizing greenhouse gas emissions worldwide:

Greenhouse Gas Reductions: By displacing fossil fuel-based electricity generation, renewable sources significantly reduce carbon dioxide (CO_2) and other greenhouse gas emissions. This reduction is critical for addressing climate change and meeting international climate goals [36].

Air Quality Improvement: The shift to renewable energy technologies leads to notable enhancements in air quality. Reducing emissions of pollutants like sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), and volatile organic compounds (VOCs) helps lessen respiratory and cardiovascular diseases linked to poor air quality [37].

Water and Soil Protection: Unlike fossil fuel extraction and combustion, renewable energy technologies have minimal direct effects on water resources and soil quality. This characteristic is vital for preserving ecosystems, maintaining biodiversity, and supporting sustainable land use practices [38].

The environmental and public health benefits of renewable energy are evidenced by various case studies. For instance, Germany's Energiewende initiative has successfully reduced the country's carbon footprint while boosting economic growth and enhancing energy security through significant investments in renewable infrastructure [39]. Likewise, Costa Rica has made remarkable progress toward achieving nearly 100% renewable electricity generation, demonstrating the feasibility of ambitious renewable energy targets in smaller and developing countries [40].

Integrating renewable energy into national energy portfolios not only diversifies energy sources but also strengthens energy resilience and decreases dependence on imported fossil fuels. Nations prioritizing renewable energy deployment gain enhanced energy security, reduced environmental impacts, and improved public health outcomes [10].

The broad adoption of renewable energy technologies is crucial for achieving sustainable development goals, combating climate change, and protecting public health. Continued investments in renewable energy research, development, and deployment are essential for facilitating the global transition to a low-carbon economy and ensuring a cleaner, more resilient future for generations to come.

6. Economic and environmental benefits

Transitioning to renewable energy brings substantial economic and environmental benefits at local, national, and global levels:

Job Creation: The renewable energy sector is a significant source of employment, providing opportunities for skilled workers in areas like manufacturing, installation, maintenance, and research and development. Expanding renewable energy infrastructure drives economic growth and job creation in both urban and rural settings [11].

Cost Competitiveness: Advances in renewable energy technologies, alongside economies of scale and decreasing production costs, have made these energy sources increasingly competitive with traditional fossil fuels. Solar and wind energy, in particular, have reached grid parity in many regions, making them appealing investments for utilities, businesses, and consumers [12].

Energy Security: Renewable energy diversifies energy sources and reduces dependence on imported fossil fuels, enhancing energy security and resilience to geopolitical instability and price volatility. Countries investing in renewable energy infrastructure gain greater energy independence and reduced vulnerability to supply disruptions [13].

Environmental Conservation: Renewable energy technologies generally have less environmental impact compared to fossil fuel extraction and use. By cutting greenhouse gas emissions, air and water pollution, and habitat destruction, renewable energy aids in biodiversity conservation and ecosystem resilience [14].

Public Health Benefits: Adopting renewable energy improves public health outcomes by lowering exposure to air pollutants and alleviating the health impacts of climate change on vulnerable populations. Communities with cleaner air quality and reduced pollution levels often see lower rates of respiratory diseases, cardiovascular issues, and premature mortality [15].

These advantages underscore the multifaceted benefits of transitioning to renewable energy, not only in terms of economic prosperity and energy security but also in fostering environmental sustainability and public health on a global scale.

7. Environmental impact of different energy sources

The main environmental impact of thermal power plants is air pollution through different polluting gases and particulate matter emitted from the burning of fossil fuels in boilers. Additionally, fly ash collected from electrostatic precipitators (ESPs) and bed ash collected from the boiler firing bed contribute to environmental impacts. Boilers emit a variety of polluting gases and particulate matter through stacks. In addition to this, bed ashes and fly ashes are also generated in solid fuel-fired boilers along with particulate matter and pollutant gases. The main gaseous pollutants include carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), formaldehyde, polynuclear aromatic hydrocarbons (PAHs), lead, hydrogen chloride (HCl), cadmium, mercury, dioxins/furans, and other toxic chemicals). These pollutants have varying impacts on the environment and human health. Major environmental impacts include climate change, acid rain, and the greenhouse effect. In terms of safety, thermal power plants present significant risks. There have been numerous instances worldwide of boiler explosions, resulting in substantial loss of life and property damage. The main environmental impact of DG power is air pollution through different polluting gases and particulate matters emitted from the burning of diesel in diesel engine. This is having a very similar kind of pollution impact as automobiles.

DG sets emit a variety of polluting gases and very less quantity of particulate matters through stacks. The main gaseous pollutants are Carbon dioxide (CO_2), Nitrogen oxides (NOx), Sulfur dioxide (SO_2), Carbon monoxide (CO), etc. These pollutants have different impacts on environment and on human health. The major impact on environment is climate change, acid rain and greenhouse effect etc. When we think about the Safety impact of DG sets there is no any significant risk during power plant operations.

Solar power generation system is having very low environmental impact. Total carbon foot print is verylow compared to conventional power generation system. Health and safety impact are also low compared to conventional power generation system.

Similarly, the wind power generation system is also having very low environmental impact like solar power generation system. Health and safety impact are also low compared to conventional power generation systems. Different types of particulate matter and gaseous emission is given in **Table 2**. The environmental impact also given in **Figure 1** to get better idea by visual comparison where GRID power is having highest environmental impact and the solar power is having lowest impact.

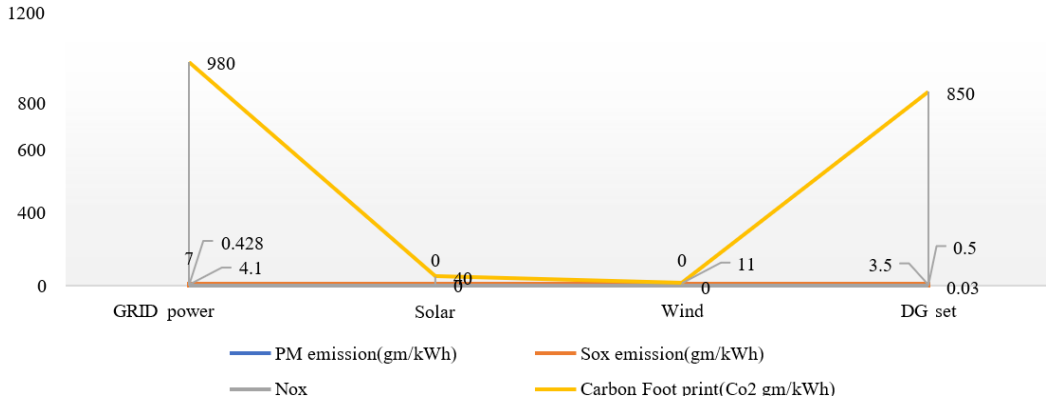

Figure 1. Environmental impact of different energy sources.

Table 2. Environmental impact of different energy generation systems.

Fuel	PM emission(gm/kWh)	Sox emission(gm/kWh)	NOx Emission(gm/kWh)	Carbon Foot print (CO_2 gm/kWh)	Impact index
GRID power (Coal)	4.1	7	0.428	980	4
Solar	0	0	0	40	1
Wind	0	0	0	11	1
DG set	0.03	3.5	0.5	850	2

8. Generation efficiency of different energy sources

If we keep aside the factory efficiency which will be same for any type of energy supply the main efficiency to be considered that is losses from input to output. When we consider the GRID power which is mainly generated from the solar power plants there are many losses which to be discussed. Generation losses, transmission losses and distribution losses.

If we keep aside the factory efficiency which will be same for any type of energy supply the main efficiency to be considered that is losses from input to output. When we consider the DG power whichis mainly generated from the combustion of diesel there are many losses which to be discussed. Mainly Generation losses is there apart from that transmission losses and distribution losses are very negligible because the power supposed to be generated in the same premises of factory where the DG power is intended

to be use.

The efficiency of solar power generation currently ranges from approximately 10% to 20% [40]. Advancements in technology are continually being made, and it is anticipated that the efficiency of solar power panels will improve further in the near future. In contrast, wind power generation typically achieves efficiencies between 20% and 40% [41]. The power generation efficiency is also expected to improve further like solar power generation system with new developments in this field. Though solar power generation efficiency is lower but it is considered as 100% as it has no any physical input supplied by the user. Different energy sources having different generation efficiency is given in **Figure 2**.

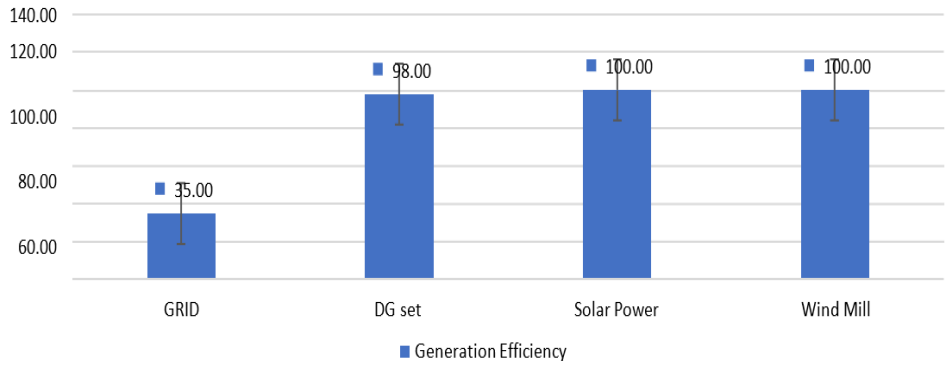

Figure 2. Generation efficiency of different energy sources.

9. Economic impact of different energy sources

The power is being generated by burning the fossil fuel, transmitted and finally distributed to the point of use. The cost of electricity is around 6 Rupees per unit. The power is being generated by burning the Diesel hence the cost of generation is much higher compared to other power generation system. The cost of electricity generated from DG set is around 24 to 30 Rupees per unit in India now a days.

Since solar power requires no input material for its operation and converts solar energy into electrical energy, the power generation cost is very low which is on account of its installation and operation cost only.

Like solar power generation wind power requires no input material for its operation and it convertswind energy into electrical energy, the power generation cost is very low which is on account of its installation and operation cost only. Economic impact of different energy sources is given in **Figure 3**.

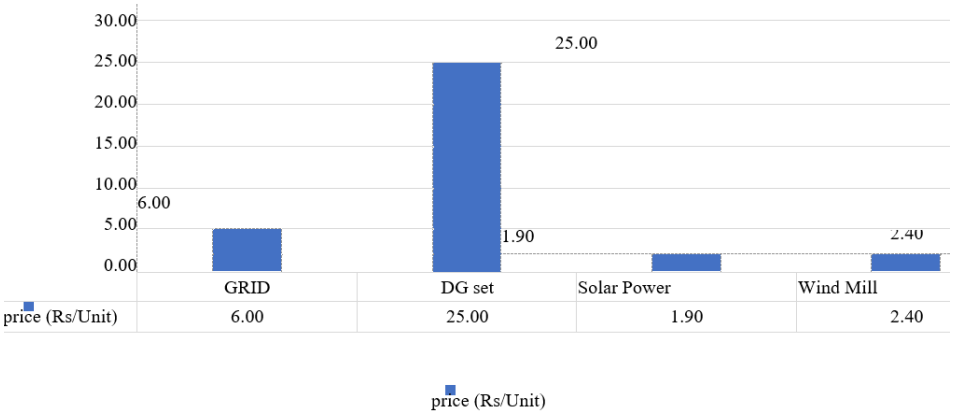

Figure 3. Economic impact of different energy sources.

10. EEE impact factor analysis of different energy sources

When we combine all the impacts i.e., environmental impact, generation efficiency impact and economicfactor impact that is known as EEE impact EEE factor, as introduced by Jena et al. [42] according to which the study was conducted for evaluation of available alternate energy sources. It is calculated and given in **Table 3** and the values are plotted in a graph given in **Figure 4**.

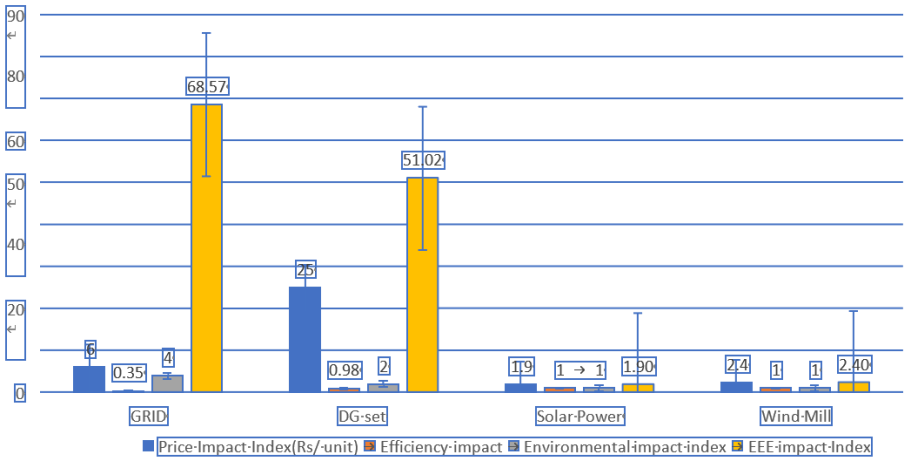

Figure 4. EEE impact factor energy source.

Table 3. EEE impact of different energy sources.

Fuel	GRID	DG set	Solar Power	Wind Mill
Price Impact Index (Rs/unit)	6.00	25.00	1.90	2.40
Efficiency impact	0.35	0.98	1	1
Environmental impact index	4	2	1	1
EEE impact Index	24.00	50.00	1.90	2.40

11. Observation and discussion

The comparison of conventional and renewable energy sources reveals significant differences in environmental impact, generation efficiency, and economic viability. Conventional energy sources, such as coal, oil, and natural gas, are major contributors to greenhouse gas emissions, air pollution, and habitat destruction, as shown in **Table 1**. These impacts include high carbon emissions, acid rain, and toxic spills that adversely affect both plants and animals. In contrast, renewable energy technologies—like solar, wind, and hydroelectric power—exhibit markedly lower environmental footprints. They not only reduce greenhouse gas emissions but also improve air quality by eliminating harmful pollutants. The observed data indicate that while coal generates substantial emissions, solar and wind energy produce negligible to zero emissions during operation.

The efficiency of energy generation also varies widely among these sources. While fossil fuel power plants suffer from significant generation and transmission losses, solar and wind energy systems, despite having lower maximum efficiencies (10%–20% for solar and 20%–40% for wind), are inherently more efficient due to the absence of fuel input costs. Economically, renewable sources present compelling advantages: the cost of electricity from solar and wind is significantly lower than from diesel generators and conventional fossil fuels, as highlighted in **Figure 3**. This transition to renewable energy not only promises reduced costs but also fosters job creation in growing sectors.

Overall, the findings support the argument for a shift toward renewable energy as a means to combat climate change, enhance energy security, and promote sustainable development. The Environmental, Economic, and Efficiency (EEE) impact analysis in **Table 3** underscores that renewable sources like solar and wind yield the most favorable EEE indices, reinforcing their potential as critical components in the global energy transition. Continued investment and innovation in these technologies are essential for maximizing their benefits and achieving a sustainable energy future.

12. Policy recommendations

Robust policy frameworks and regulatory mechanisms are crucial for facilitating the transition to renewable energy and meeting sustainable development goals, as summarized in **Table 4**:

- Renewable Energy Targets: Governments should set ambitious renewable energy deployment targets, backed by clear timelines, incentives, and regulatory frameworks. Renewable portfolio standards, feed-in tariffs, and competitive procurement processes can drive investments in renewable energy projects and facilitate market integration [16].
- Carbon Pricing: Implementing carbon pricing mechanisms, such as carbon taxes or emissions trading systems, incentivizes emissions reductions and encourages investment in low-carbon technologies. Revenue generated can be reinvested into renewable energy research, development, and infrastructure, further accelerating the transition to a low-carbon economy [17].

- Fossil Fuel Subsidy Reform: Eliminating subsidies for fossil fuels and reallocating financial resources toward renewable energy investments can create a level playing field and foster market competitiveness. Governments should prioritize the removal of environmentally harmful subsidies and adopt transparent fiscal policies that support sustainable energy transitions [18].
- Research and Innovation: Ongoing investments in renewable energy research, development, and innovation are vital for advancing technological breakthroughs, enhancing energy efficiency, and reducing renewable energy generation costs. Public-private partnerships and international collaboration can expedite the commercialization and deployment of innovative renewable technologies [19].
- Capacity Building and Education: Fostering renewable energy literacy and capacity building among policymakers, businesses, and communities encourages informed decision-making and boosts public support for sustainable energy transitions. Educational initiatives, training programs, and knowledge-sharing platforms can empower stakeholders to actively participate in shaping a clean energy future [20].

These policy measures are essential for creating an enabling environment for renewable energy adoption, fostering innovation, and driving sustainable development across economies worldwide.

Table 4. Summary of policy impact.

Policy Recommendation	Description	Potential Impact
Emissions Regulations	Implement strict emissions standards for coal, oil, and natural gas industries.	Reduction in greenhouse gas emissions Improved air quality and public health
Incentives for Clean Technology	Provide tax credits and subsidies for technologies that reduce emissions from conventional energy.	Encouragement of innovation and investment Transition towards cleaner energy solutions
Transition Plans for Coal Workers	Develop retraining programs for workers in declining coal industries.	Support for affected communities Facilitation of workforce transition to renewable sectors
Investment in Carbon Capture and Storage (CCS)	Fund research and deployment of CCS technologies in fossil fuel plants.	Mitigation of carbon emissions from conventional energy Extended operational life of existing energy infrastructure
Energy Efficiency Standards	Establish and enforce energy efficiency standards for conventional energy production.	Reduction in overall energy consumption Lower energy costs for consumers
Public Awareness Campaigns	Launch initiatives to inform the public about the environmental impacts of conventional energy.	Increased public support for cleaner energy policies Greater accountability for energy producers
Diversification of Energy Sources	Encourage a mix of energy sources to reduce reliance on any single conventional source.	Enhanced energy security Resilience to market fluctuations

13. Conclusion

The transition from conventional fossil fuels to renewable energy sources is not merely an environmental necessity but a strategic imperative for economic growth and public health. The current pollution crisis underscores the urgent need for action, as the health impacts of air pollutants and greenhouse gas emissions continue to threaten vulnerable populations and ecosystems. Renewable energy technologies present a viable pathway to mitigate these impacts, providing cleaner alternatives that enhance air quality and promote sustainable development.

The implementation of robust policy measures—such as emissions regulations, incentives for clean technologies, and the establishment of renewable energy targets—will be pivotal in accelerating this transition. Additionally, fostering public awareness and education will strengthen community support for sustainable practices. As countries and regions increasingly invest in renewable energy infrastructure, they will not only achieve substantial environmental benefits but also bolster their economic resilience and energy independence.

Moving forward, a coordinated global effort is essential to ensure that the shift towards renewable energy is inclusive and equitable, paving the way for a sustainable and resilient future for all.

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Article

Industry-university partnership governance base on new technologies emergence

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Abstract: Governance plays a critical role in advancing Industry 4.0 technologies by enhancing collaboration between industry and academia. This joint relationship significantly accelerates the development of artificial intelligence (AI) technologies, improves research quality, and strengthens scientific and technical capabilities. The primary objective of this research is to investigate the impact of advancements in AI technologies on strengthening the relationships between industry and universities. By conducting a qualitative analysis of governance practices in technology development across various countries, this study delves deeply into the dynamics of this relationship. The findings indicate that AI serves a pivotal role in enhancing research capabilities, introducing innovative technologies, promoting collaboration, facilitating technology transfer, and driving innovation, competitive advantage, and sustainable progress in industries. Furthermore, the study focuses on governance strategies related to AI within the context of industry-academia collaboration, including the formation of joint committees, initiation of collaborative research projects, facilitation of technology transfer, and establishment of shared platforms for education and research in AI and related fields. These aspects are meticulously examined within the framework of human capital development and knowledge-based economic growth, underscoring the importance of effective governance structures in leveraging AI advancements to strengthen industry-academia partnerships and stimulate technological innovation.

Keywords: AI technology; technology integration; industry-university cooperation

1. Introduction

Artificial intelligence (AI) significantly influences a wide range of industries by enhancing research capabilities and providing efficient solutions to complex challenges. The evolution of AI, shaped by effective governance, not only introduces innovative technologies but also bolsters market competitiveness. Moreover, AI promotes collaboration between industry and academia, creating an environment that nurtures innovation. The advancement of artificial intelligence under robust governance empowers both universities and industry stakeholders with the necessary tools to accelerate technology development and transfer, ultimately facilitating sustainable growth and development [1].

Artificial intelligence is a concept with varied interpretations [2], that often encompasses technologies like machine learning, neural networks, and various automated systems. It is occasionally presented as a versatile technology [3] due to its increasingly widespread use across different domains. This extensive application results in practical uncertainties, particularly in the realms of policymaking and regulation [4]. Nations such as the United States, China, and Russia aim to exploit artificial intelligence to shift the power dynamics in their favor [5], while other global

actors may employ artificial intelligence differently based on their own interests, objectives, and domains [6].

The swift expansion of artificial intelligence technologies and their transformative influence on a wide array of issues have presented fresh challenges for policymakers and other stakeholders on a global scale. Many endeavors associated with the advancement of artificial intelligence technologies are overseen by governments, yet international bodies have exhibited a notable capacity in addressing policies related to artificial intelligence. Despite artificial intelligence being an innovative technology that falls outside the scope of current legal or regulatory frameworks [7], there is a trend towards addressing new obstacles within existing structures [8].

Countries across the globe have implemented a variety of strategies to facilitate the advancement of artificial intelligence technologies. These strategies exhibit a range of objectives and methodologies. For instance, certain nations, particularly those in East Asia, place a strong emphasis on "development" by involving the government significantly in fostering artificial intelligence innovation [9]. Conversely, countries within the European Union concentrate on "control", emphasizing the implementation of regulations governing artificial intelligence [10]. In contrast, nations like the United Kingdom, the United States, and Ireland prioritize "promotion" policies with intricate governance structures and a predominant role assigned to the private sector [11]. The primary aim of these strategies is to modernize societies and integrate artificial intelligence technologies into various aspects of human life. Recognizing the significance of contemporary information and communication technologies, including artificial intelligence, these strategies necessitate comprehensive approaches that encompass experts, technological capabilities, financial resources, and legal frameworks. In essence, these strategies demonstrate an acknowledgment of the significance of artificial intelligence and the necessity for targeted integration of resources [12].

The governance strategies related to the advancement of artificial intelligence (AI) technologies within the context of industry-academia collaboration involve a diverse array of stakeholders, including private enterprises, industry associations, universities, professional organizations, government bodies, international organizations, and civil society. These stakeholders advocate for various norms and mechanisms to regulate AI, including ethical guidelines, national policies, and formal regulations [13]. While private companies are instrumental in guiding AI initiatives, their primary focus on profitability and market demands can sometimes conflict with the broader public interest. Therefore, there is a critical need for external government oversight to ensure that the wider implications of AI are adequately considered [14]. This scholarly investigation examines the experiences of different countries in implementing AI within the industry-academia dynamic and assesses the outcomes of these initiatives.

2. Theoretical foundations of research

2.1. Industry-university government cooperation

Artificial intelligence (AI) has become a catalyst for significant transformations across various sectors of society, empowering mankind to approach management in a more methodical and strategic manner. The pivotal role of AI is evident in its ability to serve as a vital link between the realms of academia and industry, facilitating knowledge exchange and collaboration. The ascendancy of the industry in AI research is steadily increasing, primarily due to its command over computational capabilities, vast pools of data, and a talent pool rich in skilled researchers. This transition towards industry dominance is manifested in the generation of impactful research outcomes, including scholarly publications, cutting-edge models, and essential performance indicators that shape the landscape of artificial intelligence [15].

The domain of artificial intelligence (AI) is increasingly recognized within the field of international relations as a landscape marked by competition and potential conflicts, driven by uncertainties regarding the relinquishment of control over technology and oversight of human intervention. Russian President Vladimir Putin's statement in 2017 resonates with a commonly held perspective in global discussions, as he famously asserted, "Whoever becomes the leader in artificial intelligence will rule the world" [16]. In this context, numerous government and private entities have expressed their viewpoints on the societal implications of AI, particularly from a governance perspective, focusing on critical areas such as infrastructure development, military applications, and the effects on employment and human relations. While some of these viewpoints have proposed comprehensive strategies to address the challenges posed by AI, a majority have embraced principled stances aimed at mitigating the risks associated with disruptive AI technologies. By 2020, over 30 nations had initiated discussions on developing national strategies for AI, with 17 countries actively implementing these strategies [17].

The exploration and discussion of national strategies for artificial intelligence governance within the industry-university domain originated during a pivotal research session held at a Dartmouth workshop in 1956, marking the inception of a groundbreaking field of study. Since that momentous occasion, the realm of AI development has transitioned into the hands of the private sector, embarking on a transformative journey across diverse sectors such as industrial robotics, data mining, and the integration of AI-driven leadership roles. This evolution witnessed a pattern where these innovations first gained traction within the tech industry, gradually earning societal approval through early triumphs and practical applications. Over the course of subsequent years, a new wave of sophisticated AI technologies emerged, encompassing advanced AI systems, deep learning algorithms, cutting-edge voice and image recognition software, as well as state-of-the-art data analytics tools. These technological marvels have found widespread application in sectors such as banking, e-learning platforms, medical diagnostics, smart transportation systems, and beyond, revolutionizing the way we interact with and harness the power of AI in our daily lives [18].

In the contemporary landscape, nations at the forefront of technological innovation and home to the most prominent industrial players in the AI sector have assumed a leading role in shaping the trajectory of global AI development for the coming decade. Meanwhile, numerous other countries, particularly those in the developing world, are engaged in ongoing deliberations and knowledge-sharing

initiatives to define their respective national priorities and chart a course for future AI frameworks that align with their unique socio-economic landscapes and aspirations [19].

2.2. Industry-university governance based on artificial intelligence based on justice and ethics

The European Union, recognizing its internal disparities, holds the belief that artificial intelligence has the potential to support the green deal [3] and is committed to promoting "human-centric artificial intelligence". Consequently, artificial intelligence is seen as a means to advance social justice and reduce inequality, empowering even the most marginalized individuals. The European Union endorses the principles of "ethics by design" and "security by design" in research and technology development [3]. A specific category of "high-risk artificial intelligence" has been established by the European Union, subject to special regulatory and oversight measures [3].

The United Nations, the European Union, and the World Economic Forum concur that governance frameworks must be adaptable to keep pace with innovation and harmonize regulations across various stakeholders. Regulatory sandboxes are referred to by the European Union and the United Nations. A comprehensive governance framework is essential to mitigate the risks of artificial intelligence technologies and ensure their safe and ethical use, safeguarding privacy, fundamental rights, and benefiting the most vulnerable individuals.

Furthermore, the United Nations, the European Union, and the World Economic Forum advocate for interdisciplinary research to guide the applications of artificial intelligence towards sustainable and socially just foundations [17]. Collaboration among diverse stakeholders, including universities, civil society, citizens, and the private sector, is deemed necessary to harness artificial intelligence effectively and ensure its sustainability. This collaboration is essential for enhancing understanding of artificial intelligence, reducing discrimination and biases [3], and ensuring that the impact of artificial intelligence is positive for the majority while facilitating data access. Private companies and universities contribute skills and expertise, while the public sector provides appropriate legislation, funding, and support. Citizens and users should engage in acquiring digital and technical skills. Transparency and explainability are crucial to ensure informed consent and trust.

The United Nations promotes the concept of data altruism for justice in industry-university governance, emphasizing data sharing by the private sector to complement public sector data for the benefit of disadvantaged individuals. Gender-disaggregated information and improved data accessibility in developing countries are also endorsed by the United Nations to be more beneficial for vulnerable populations. Computational capacities should be enhanced to facilitate artificial intelligence training [20].

Ethics and justice are crucial in the development of tripartite relationships among academia, industry, and government for several reasons [21]. Firstly, ethical considerations ensure the responsible and sustainable use of resources and technologies, promoting transparency and accountability in decision-making processes [13]. Secondly, a focus on justice helps to address power differentials and

ensure fair and equitable distribution of benefits and opportunities among stakeholders. Lastly, an ethical and just approach fosters trust and collaboration among academia, industry, and government, leading to more effective and impactful partnerships that contribute to societal well-being and progress.

3. Research background

3.1. Industry-university governance based on AI in China

China's approach to advancing artificial intelligence (AI) technologies is diverse. The nation is in the process of modernizing its military systems, increasingly integrating AI and associated technologies into areas such as information, command and control, logistics, and weapon systems. Efforts are underway to establish a regulatory framework for AI, including laws, ethical standards, and policy guidelines by 2025. China has emerged as a global frontrunner in AI research, innovation, and implementation, demonstrating significant progress in these areas. Moreover, the country has witnessed substantial growth in AI patent citations, particularly in key regions like the Yangtze River Delta, Pearl River Delta, and Bohai Rim. These developments underscore China's dedication to AI advancement and its commitment to fostering an environment conducive to innovation and technological progress.

3.2. Industry-university governance based on AI in Netherlands

Artificial intelligence (AI) is a rapidly growing technology field that can have a significant impact on Dutch society and all its economic elements. To strengthen the Netherlands' position and maximize opportunities, a long-term program called AiNed has been designed by the Dutch AI Coalition and a consortium of over 400 public and private organizations. The development and utilization of AI aim to enable the Netherlands to benefit from the economic and social advantages of AI and synchronize with other leading countries.

According to the Dutch government's governance forecast, this approach could potentially generate a 1.6% growth in the country's Gross Domestic Product (GDP) based on the development of AI technologies. This serves as a catalyst for strong growth in the number of companies investing in and utilizing AI. The Netherlands also promotes the beneficial social impacts of AI by employing responsible and human-centric AI programs that align fully with European objectives. The National Growth Fund has allocated 204.5 million euros for the initial phase of the AiNed program.

Examples of AI applications currently employed and supported under these approaches in the Netherlands include: Improving medical diagnoses and treatments, reducing pesticide use, energy savings, personalized education, more effective crime fighting, cost-effective repair and maintenance of roads, bridges, and railways, more efficient production and transportation of goods, long-term customer relationships in the service and retail sectors, as well as autonomous robots, vehicles, and unmanned aircraft.

Maximizing participation and seizing major opportunities for the Netherlands, the availability of extensive data, affordable computing power, and new generations of AI methods are rapidly advancing artificial intelligence. Despite a strong starting

position in terms of AI knowledge, digital infrastructure, and overall use of digital technology in the Netherlands, there is a need for stronger development and a risk of falling behind [22].

The Dutch experience in supporting the development of AI technologies includes aligning Dutch business goals and policies in AI development. The Dutch government has established a new research consortium called CVON-AI to facilitate the development and use of AI solutions in medical research. The goal of this consortium is to create a cloud-based platform accessible to researchers, demonstrate the clinical applications of AI, optimize analytical methods, and enhance AI awareness through education [23].

3.3. Industry-university governance based on AI in Canada

Canada is actively promoting the advancement of artificial intelligence (AI) technologies. In 2017, the Canadian government introduced the "national strategy for artificial intelligence", aiming to position Canada as a global frontrunner in AI innovation. The government sponsors workshops on AI and its societal impacts, convening experts, influencers, and community representatives to explore the ethical and social dimensions of AI across various sectors like healthcare, education, and the workplace. However, there are concerns regarding the inclusiveness of these workshops, potentially excluding ordinary citizens and average consumers from engaging with the technology. Gender diversity in AI-related activities in Canada remains understudied, highlighting the need for legislative measures to support women in the AI industry and ensure equity and gender parity. In summary, Canada's efforts to advance AI technologies encompass strategic planning, educational initiatives, and a call for greater gender inclusivity and representation.

3.4. Industry-university governance based on AI in United Kingdom

The United Kingdom is actively promoting the advancement of artificial intelligence (AI) technologies. The National Health Service (NHS) is striving to establish itself as a global leader in AI applications in healthcare and is dedicated to training and involving medical professionals in AI initiatives. The integration of AI into healthcare presents regulatory challenges and necessitates a delicate balance between the advantages of ongoing enhancements and the assurance of safety protocols [24]. Within the field of dermatology, there is growing interest in utilizing AI for evaluating the risk associated with skin lesions; however, there is a notable absence of ethical guidelines and standardized regulations in this area. Recent legal competitions in the UK have underscored the imperative need for robust AI policies and the significance of incorporating legal considerations into AI governance and decision-making processes [25]. Aspiring physicians in the UK acknowledge the positive influence of AI technologies on their clinical training, yet they express apprehensions regarding the potential impact on clinical judgment and practical competencies.

3.5. Industry-university governance based on AI in Brazil

Brazil has a rich history of formulating digital advancement strategies,

encompassing endeavors in research and development, as well as the integration of AI-driven technologies across industry and governmental sectors. The government has prioritized enhancing criminal investigation techniques and public safety measures through the utilization of AI solutions. In light of the global health crisis caused by the COVID-19 pandemic, Brazil introduced a remote healthcare platform powered by artificial intelligence to enhance the accessibility of medical services [15]. Recent research underscores the necessity of establishing a public policy framework to foster the acceptance of AI technologies in Brazil, as delays in this regard could exacerbate disparities among nations. In summary, Brazil's approach entails a diverse array of policies and programs designed to bolster the advancement and implementation of AI technologies in key domains such as digital innovation, law enforcement practices, and healthcare services [26].

4. Research methodology

The current research methodology utilized in this study employs a meta-study approach known as Systematic Literature Review (SLR), focusing on analyzing the policies and developmental materials of chosen nations in the realm of artificial intelligence technology advancement. Systematic literature review involves the systematic exploration, assessment, synthesis, and interpretation of quantitative or qualitative research within a specific field [21]. Following the methodology proposed by Sandelowski and Barroso [27], the research process in this study unfolded through seven distinct stages, encompassing: Articulating the research objectives and formulating research inquiries, systematically scrutinizing texts and research backgrounds, identifying and selecting pertinent documents, extracting relevant data, analyzing and synthesizing study outcomes, ensuring quality control, and presenting the research findings. The tasks undertaken at each stage are detailed as follows:

4.1. Stage 1—Clarifying research objectives and inquiries

The primary aim of this study is to address the following queries through a comprehensive review of literature, documents, and policy frameworks concerning artificial intelligence technology development in selected countries: 1) To what degree is the advancement of artificial intelligence technologies prioritized in the governance strategies of chosen nations with regards to industry-academic partnerships? 2) What key initiatives and tactics are adopted by selected countries in fostering the growth of artificial intelligence technologies? 3) How do the primary strategies of selected countries in advancing artificial intelligence technologies align with industry-academic governance dimensions?

4.2. Stage 2—Thorough review of background information

This segment involves conducting library research and meticulously examining reputable documents and articles to identify the initiatives and policies of selected countries in the realm of artificial intelligence technology development.

4.3. Stage 3—Criteria for selecting study subjects

The choice of countries for analyzing developmental documents was based on three key factors: 1) Availability of information; 2) global rankings and achievements in artificial intelligence; and 3) alignment with the unique context of Iran's ecosystem. Following rigorous evaluation and assessment by researchers, the countries selected for examination were China, England, Canada, Brazil, and the Netherlands. Subsequently, the primary industry-academic governance policies and developmental materials from these nations were reviewed and assessed.

4.4. Stage 4—Data extraction

During this phase, comprehensive examination and supplementary research were conducted, leading to the initial (open) and axial coding of the documents.

4.5. Stage 5—Information analysis and synthesis

This stage involved breaking down and analyzing the coded data to identify key concepts and themes using the content analysis technique. Systematic Literature Review (SLR) offers a range of methodologies for synthesizing data, including content analysis, theory-driven analysis, thematic synthesis, qualitative comparative analysis, and framework analysis [28]. The deductive content analysis approach was utilized to develop a central theory, model, or conceptual framework. Thus, the research employed open coding, axial coding, and selective coding techniques to achieve its objectives.

5. Findings

The integration of artificial intelligence (AI) technology into partnerships between universities and industries significantly enhances educational innovation by aligning specialized environments, educational content, teaching methodologies, and learning platforms with real-world industry practices and demands. As academia transitions into a digitally immersive era propelled by AI, it is crucial for researchers and professors to adapt to effectively engage with AI technologies to shape the future of education. AI is fundamentally transforming the interaction dynamics between academia and industry, with the latter increasingly contributing to AI research and its myriad applications across various sectors.

This study investigates the governance aspects of industry-university collaboration in advancing AI technologies and examines the experiences of selected countries. Notably, the research highlights three governance models: Control, Develop, and Promote, which provide a framework that resonates with both theoretical insights and practical experiences. The absence of these models in subsequent discussions is noted and could be beneficial for the literature review protocol and selection of case studies.

The innovations and strategies outlined in four key AI applications are as follows: (1) Enhanced data collection and analysis to facilitate knowledge acquisition, drive scientific breakthroughs, spur industrial advancements, and support informed decision-making; (2) Increased automation across sectors such as transportation and manufacturing; (3) Improved productivity regarding individual consumption, energy

utilization, and resource management; (4) Promotion of equality and poverty alleviation through AI interventions.

These points, while reasonable, could be perceived as stemming from a deductive approach, with limited reference to how they were synthesized. Enhanced data gathering and analytic capabilities enabled by AI are evident in various studies indicating its effectiveness in uncovering insights and trends within extensive datasets, which can lead to scientific discoveries and enhanced understanding of complex global issues. AI tools empower quicker and more informed decision-making processes, employing technologies such as machine learning, smart sensors, remote sensing, the Internet of Things, computer vision, and drones for comprehensive data analysis. These applications span monitoring diverse phenomena, including weather patterns, species migration, forest health, public transport efficiency, and energy consumption.

Moreover, research showcases the proficiency of AI in predictive analytics, such as forecasting future energy demands, carbon emissions, and climate change consequences. The United Nations Digital Cooperation Roadmap emphasizes the necessity of utilizing big data and AI to derive actionable insights that can effectively address public health challenges, including disease outbreaks and their implications for vulnerable communities [16].

The World Economic Forum, along with the United Nations and the European Union, advocates for the utilization of artificial intelligence technologies to tackle challenges posed by climate change and environmental shifts. These technologies leverage big data to identify patterns that enhance decision-making processes and improve forecasting accuracy [16]. Within the realm of industry-university governance centered on artificial intelligence, it is anticipated that advancements in democratic systems and responsible economic models will be fostered. This will be achieved through improved information accessibility, enhanced communication channels, and more efficient monitoring of inefficiencies [1]. Artificial intelligence plays a crucial role in bolstering cybersecurity measures, enabling the tracking and analysis of intricate criminal networks, and streamlining migration and asylum procedures. The growing adoption of automation [4] is another key aspect highlighted in studies on industry-university governance driven by artificial intelligence. Automation, facilitated by technologies like robotics and autonomous vehicles [5], liberates individuals from mundane tasks, allowing them to focus on more creative endeavors. This shift not only enhances human well-being by freeing up time for innovation but also contributes to more effective industry-university governance by redirecting attention towards creative and impactful tasks. In work environments, automation enhances operational efficiency and organizational performance by minimizing errors and production fluctuations on assembly lines. The implementation of autonomous vehicles and intelligent systems through automation aids in reducing accidents and improving overall road safety. By integrating automation and artificial intelligence technologies, individuals can allocate more time to strategic and creative pursuits, alleviating them from repetitive and exhausting tasks. This transition ultimately leads to the enhancement of industry-university governance and the promotion of human welfare.

6. Enhanced efficiency and environmental sustainability

Automation plays a pivotal role in reducing redundancy, energy wastage, and unnecessary emissions. Research indicates that artificial intelligence contributes significantly to advancing sustainable production practices, particularly in the realm of agricultural progress. Within agriculture, the integration of artificial intelligence technologies aids in minimizing pesticide and fertilizer usage, optimizing water resources, controlling weed proliferation, promoting animal well-being, and swiftly identifying crop diseases. Furthermore, applications extend to streamlining transportation systems, managing energy distribution effectively, optimizing waste disposal methods, and implementing energy-efficient solutions like smart homes that align with residents' daily routines. Smart grids further enhance energy management by integrating various renewable energy sources. The European Union highlights the potential of "smart thermostats, which analyze user behavior and adjust temperatures accordingly, leading to potential energy savings of up to 25%" [3].

Advancement in social equity and poverty alleviation. In the discourse surrounding sustainable development, artificial intelligence is anticipated to play a crucial role in fostering gender equality. Emphasis is placed on creating new employment opportunities, particularly for women, through artificial intelligence interventions. Given the competitive edge in artificial intelligence development held by major economies like China, the United States, and the European Union, the United Nations has devised an "internal strategy to bolster AI-driven empowerment, with a specific focus on supporting developing nations and millions of vulnerable individuals" [20]. Reports from the Global Pulse initiative underscore the positive impact of artificial intelligence technologies in aiding populations in developing countries, particularly in areas such as women's workforce participation, monitoring gender-based violence, mapping unsafe regions, and more.

7. Conclusion and insights

The collaboration among academia, industry, and society forms the foundation of artificial intelligence (AI) governance. Active involvement from AI developers, professional bodies, and educational institutions shapes the norms governing AI development and deployment. Despite technology companies espousing ethical standards for AI utilization, the pursuit of financial gains and market pressures can sometimes impede their alignment Enhanced efficiency and environmental with public interests. Reflecting on the broader spectrum of intelligence encompassing both artificial and natural information flows is essential to understanding the societal and environmental impacts of AI. The deployment of AI systems presents unique legal complexities, necessitating global harmonization of laws and regulations. While AI has revolutionized the public relations domain and offers avenues for enhancement, it also raises pertinent concerns that demand attention from researchers and experts.

The formulation of policies governing the collaboration between academia and industry in the domain of artificial intelligence holds significant importance due to the myriad benefits it offers to nations. Given the swift evolution of AI technologies, countries must adapt their policies promptly to keep pace with advancements and leverage the opportunities presented by these technologies. The provided **Table 1**

delineates key strategies for managing industry-academia relationships in the development of AI technology in five specific countries. These strategies, derived from a comprehensive document review, are segmented into four categories: Data-driven decision-making, automation-centric industry-academia governance, productivity-oriented industry-academia governance, and proactive industry-academia governance aimed at fostering greater equality and reducing poverty.

The utilization of AI in policymaking presents governments with valuable prospects. For instance, AI enables governments to prioritize issues according to public preferences and formulate evidence-based policies. Moreover, it facilitates real-time policy assessment and feedback on their efficacy. Additionally, the integration of AI technologies in industry-academia governance promotes collaboration between stakeholders and policymakers, enhancing legitimacy. As indicated in the literature, AI can streamline policy decisions, resulting in greater efficiency, enhanced service delivery, and the generation of public value. Nevertheless, the implementation of AI policies in policymaking encounters a range of challenges that necessitate scrutiny. Key challenges encompass data management, ethical considerations, organizational structure, accountability, and ethical responsibilities. Addressing ethical concerns such as data privacy and equitable AI usage is crucial in industry-academia governance and policy development.

Table 1. Key strategies for industry-university cooperation in the development of AI technology in selected countries (alphabet base).

	Enhanced decision-making through data analytics	**Automation-driven industry-university cooperation**	**Productivity-focused industry-university partnership**	**Promoting equity and poverty alleviation through industry-university cooperation**
Brazil	• Focus on research and development of artificial intelligence technologies in industry and government • Promoting economic improvement and developing innovation based on artificial intelligence • Focus on criminal investigation and population security based on artificial intelligence • Development of AI-based telehealth platform in the covid-19 pandemic.	• Improving and empowering the workforce • Supporting the workforce to develop artificial intelligence technologies and automate production processes. • Using artificial intelligence to automate processes	• Defining a public policy to promote the adoption of artificial intelligence that can reduce inequalities in the field of technology in the country.	• Smartening of public services • Resource management optimization • Real-time evaluation of policies
Canada	• Development of training programs and workforce preparation in the field of artificial intelligence • Encourage research and development in the field of artificial intelligence and big data	• Development of capabilities of intelligent and automatic devices in different economic and social sectors	• Improving the level of education and training in the field of artificial intelligence and related technologies • Promoting research and development in the field of artificial intelligence and creating connections between universities, industry and government	• Creating legal and ethical frameworks for the use of artificial intelligence and protection of privacy and data security • Creating organizational and policy frameworks to facilitate and accelerate the process of developing and deploying artificial intelligence in Canada.

Table 1. (*Continued*).

	Enhanced decision-making through data analytics	Automation-driven industry-university cooperation	Productivity-focused industry-university partnership	Promoting equity and poverty alleviation through industry-university cooperation
United Kingdom	• Development of intelligent data centers that provide the possibility of collecting and analyzing various data and information. • Encouraging research and development in the field of artificial intelligence and big data • The use of artificial intelligence in public services in various fields	• Developing research and development strategies in the field of artificial intelligence • Improving the position of artificial intelligence in terms of strategy and institutional, • Artificial intelligence support for learning and sustainable development. • Developing legal and ethical standards and frameworks • Using solutions based on artificial intelligence and data, • Creating a facilitating political environment • Establishing and developing reliable artificial intelligence systems that include competition	• Increasing awareness and transformation in the vision of senior managers towards artificial intelligence and its applications • Creating specialized and targeted networks among different actors • International networking in the field of research and development • Providing artificial intelligence knowledge and skills at all levels of education and training skilled human resources • Education and skill enhancement of the working forces in the public and private sector for labor market developments • Financing and investment	• Development and strengthening of artificial intelligence financing ecosystem in priority areas. • Encouraging private and public sectors to invest in research and development of artificial intelligence. • Facilitating sharing and access to national data
Netherlands	• Promoting research and development in the field of artificial intelligence and big data • Policymaking in the area of privacy protection in the use of data and information	• Developing research and development strategies in the field of artificial intelligence in order to strengthen the position of the Netherlands in this field. • Improving the position of artificial intelligence strategically and institutionally with the aim of maximum use of artificial intelligence technology. • Artificial intelligence support for learning and sustainable development at different economic and social levels.	• Developing legal and ethical standards and frameworks for using solutions based on artificial intelligence and data. • Creating a facilitating policy environment for the establishment and development of reliable and competitive artificial intelligence systems.	• To use responsible and human-centered AI programs that are in line with European goals, in order to create beneficial social impacts of AI. • Development and use of artificial intelligence so that it is possible to exploit its economic and social benefits and keep pace with other leading countries.

Hence, nations must incorporate AI development policies into their overarching strategies to capitalize on the benefits AI offers in policymaking. These policies should address pertinent challenges and factors to maximize the advantages of AI in enhancing governmental performance and public services. Governments should have confidence in AI's ability to optimize operations and services. Many countries have already harnessed AI, some employing it in policy formulation. Iran should similarly

embrace AI across all facets of industry-academia governance, particularly within government institutions, to unlock unprecedented opportunities and narrow the technological gap with other nations. This objective is also articulated in Iran's strategic vision for AI development, aiming to position the country among the top 10 global leaders in AI by 2031, fostering economic prosperity and societal well-being. Therefore, comparative analyses of successful nations' experiences and developing countries sharing similarities with Iran can offer valuable insights for policymakers to leverage.

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Article

Local leaders as catalysts for sustainable development: A behavioral and systemic analysis

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Abstract: This study investigates the critical role of local leadership in sustainable development, focusing on leaders' behavioral traits and their dynamic interactions with systemic factors. A mixed-methods approach was employed, combining System Dynamics Modeling with qualitative and quantitative data collection. Data were gathered through the stratified sampling of residents, focus groups with 35 participants across domains such as agriculture, education, and health, and public consultations in the Vytina Municipality Unit in Greece. Questionnaires addressed topics including sustainability principles, behaviors, cultural norms, and community goals, while focus group discussions explored sector-specific challenges and strategies. The analysis utilized thematic coding for qualitative data and sensitivity analysis for simulation outputs to evaluate leadership effectiveness. Findings highlight the significance of adaptability in dynamic environments, cultural sensitivity in overcoming resistance to change, and community engagement in fostering trust and participation. Simulation results revealed critical feedback loops, such as the reinforcement of trust through transparency and collaboration, which amplified sustainable development outcomes. This research underscores the potential of System Dynamics Modeling to integrate empirical insights and predict the long-term impacts of leadership behaviors. Key challenges include the model's reliance on simplified assumptions and its context-specific applicability. Future research should further refine the model and expand its validation in diverse communities to enhance its robustness and utility.

Keywords: sustainable development; local leadership; system dynamics; behavioral traits; community engagement

1. Introduction

Sustainable development in rural and underdeveloped regions presents unique challenges that necessitate the active involvement of local leaders as catalysts for change. These leaders possess an intimate understanding of their communities cultural, economic, and environmental contexts, enabling them to address specific needs effectively [1]. Bottom-up sustainable development initiatives emphasize grassroots participation, with local leaders playing a pivotal role in fostering collaboration, inclusivity, and long-term community resilience [2].

Despite their importance, sustainable community development efforts often face hurdles such as resource scarcity, environmental degradation, and resistance to change. Leaders who build trust, engage the community, and adapt to evolving conditions are more likely to achieve lasting development outcomes. However, the complex interplay between leadership behaviors and systemic factors, such as cultural norms and community feedback, remains underexplored [3].

While global frameworks like the United Nations' Sustainable Development Goals (SDGs) underscore the importance of local participation, there is limited

research examining how local leaders navigate the balance between short-term community needs and long-term sustainability objectives. This study addresses this gap by analyzing the role of leadership traits—including visionary thinking, adaptability, and collaboration—in fostering sustainable community development. Employing a system dynamics approach, the research investigates how these traits interact with systemic factors to influence outcomes such as community trust, system stability, and sustainability success [4].

The findings aim to enhance the understanding of effective leadership practices and offer actionable strategies for sustainable development. The study contributes to academic discourse by integrating leadership theories with sustainability frameworks and provides practical insights for local leaders and policymakers.

The Vytina Municipality Unit in Greece serves as a compelling case study, showcasing how adaptive and visionary leadership drives sustainability efforts. This community-led initiative integrates environmental stewardship, social cohesion, and economic growth through a holistic approach to well-being. The key areas of focus include:

1) Community Engagement and Visionary Leadership: Vytina's leadership employs a bottom-up approach that empowers residents to co-create a shared sustainability vision. This inclusive methodology reflects contemporary trends in governance that prioritize collaboration and active participation [5].
2) Holistic Approach to Sustainability: The initiative aligns with global frameworks like the SDGs by addressing environmental, social, and economic dimensions of sustainability. It emphasizes cultural preservation, education, and income generation to meet both immediate and long-term needs [6].
3) Strategic Partnerships and Advocacy: Vytina's leadership has formed strategic collaborations with scientific organizations and external entities, enhancing the impact of its sustainability initiatives. These partnerships demonstrate how local leaders can extend their influence through broader networks of expertise and resources [7].
4) Behavioral Challenges and Adaptive Solutions: A critical challenge in Vytina is overcoming behavioral resistance to change. By fostering a sense of community ownership through engagement and consistent feedback, the leadership exemplifies adaptive practices, remaining flexible and responsive to evolving dynamics [8].

This case study highlights the transformative potential of local leadership in driving sustainable development. Visionary leadership, long-term planning, community trust, and environmental stewardship emerge as critical factors in achieving sustainability goals. The integrated approach taken in Vytina underscores the vital role local leaders play in shaping sustainable futures and ensuring the well-being of future generations.

2. State-of-the-art review

2.1. Knowledge gap

Sustainable development research often prioritizes top-down approaches or generalized frameworks for community participation, overlooking the critical role of

local leadership in bottom-up initiatives, especially in rural and underdeveloped regions. Local leaders are uniquely positioned to drive sustainable change by leveraging their understanding of local contexts, mobilizing resources, and fostering community participation [9]. However, their effectiveness depends not only on personal traits such as visionary thinking, adaptability, and ethical integrity but also on their ability to navigate systemic factors like cultural norms, economic conditions, and political dynamics [1,10,11].

Existing methodologies largely capture static aspects of leadership, missing the evolving complexities of community systems. System Dynamics (SD) Modeling offers a valuable lens for analyzing these interactions through simulations and feedback loops, thereby bridging gaps in understanding the dynamic interplay between leadership behaviors and sustainable development outcomes [4].

2.2. Theoretical frameworks

1) Leadership Theories
   - Transformational Leadership: Inspires communities through vision and ethical integrity [5,12].
   - Adaptive Leadership: Emphasizes flexibility in navigating changing environments [8,13].
   - Collaborative Leadership: Highlights partnerships and inclusive decision-making [2].
2) Sustainable Development Frameworks
3) The United Nations' Sustainable Development Goals (SDGs) emphasize integrating environmental, social, and economic dimensions [6]. This study aligns with these principles by exploring local leadership's role in advancing these objectives [14]. System Thinking and Dynamics
   - System Thinking [10] provides a holistic lens to analyze interconnected leadership behaviors and community dynamics.
   - System Dynamics Modeling [4] utilizes tools such as Causal Loop Diagrams (CLDs) to map feedback loops, enabling researchers to visualize and simulate the impact of leadership traits on development outcomes.

2.3. Challenges in local leadership

1) Conflicting Priorities
2) Local leaders often balance immediate community needs with long-term sustainability goals, which can result in tensions among stakeholders [1].
3) Scalability of Bottom-Up Initiatives
4) Tailored local projects may face challenges in replication or expansion, risking dilution of their core vision [15,16].
5) Resource Constraints
6) Limited financial and technical resources often necessitate external collaborations, creating dependencies that can compromise local autonomy [10].
7) Behavioral Resistance
8) Resistance to change is a significant barrier, requiring leaders to employ strategies for trust-building and cultural sensitivity [3].

2.4. Advancing leadership effectiveness

Building on the case of MU Vytina, this research highlights how visionary thinking, adaptability, and collaborative leadership can transform sustainability initiatives. Effective leaders integrate environmental stewardship, community trust, and long-term planning while fostering partnerships to address resource gaps. The SD model further illuminates how leadership behaviors interact with systemic factors to influence development success, offering a replicable framework for other rural contexts.

By synthesizing these theoretical insights and addressing identified gaps, this study contributes to a deeper understanding of local leadership dynamics in sustainable development.

3. System component development (streamlined and enriched)

In bottom-up sustainable development, local leaders play a pivotal role in shaping community engagement, mobilizing resources, and achieving long-term success. This section explores the behavioral and systemic factors that define effective leadership, using system thinking to analyze their interactions and influence on development outcomes.

3.1. Leadership behavioral components

Local leaders contribute to sustainable development through specific behaviors and strategies, which interact dynamically with community systems. The following components are key:

1) Visionary Thinking

Leaders articulate long-term development goals aligned with their community's sustainability aspirations. A clear and inspiring vision fosters trust and commitment [10]. For instance, Vytina's leadership demonstrated visionary thinking by setting ambitious goals that integrated environmental, social, and economic dimensions, reflecting Kotter's [17] emphasis on transformational change.

2) Community Engagement

Open communication and empathy build trust, ensuring inclusive participation [1]. Vytina's initiative exemplified this by involving diverse stakeholders in co-creating a sustainable future, consistent with Arnstein's [18] ladder of citizen participation.

3) Collaborative Leadership

Successful leaders form partnerships and empower community members, fostering shared responsibility [2]. In Vytina, collaboration with scientific organizations and local authorities was guided by Gray's [19] principles of cooperative problem-solving.

4) Adaptability

Leaders must adjust strategies in response to challenges, such as evolving environmental or economic conditions [8]. Vytina's leadership demonstrated adaptability by refining plans to address emerging community needs.

5) Ethical Integrity

Transparency and accountability strengthen credibility and community trust [5]. Leaders in Vytina exhibited ethical leadership, advocating for justice and maintaining open communication [20].

6) Resilience and Persistence

Effective leaders remain determined despite setbacks, creatively solving problems to achieve long-term goals [21]. Vytina's leadership demonstrated resilience, overcoming financial constraints and cultural resistance.

7) Environmental Awareness

Leaders prioritize sustainability by integrating environmental considerations into decision-making [3]. Vytina's leadership emphasized energy efficiency, waste management, and preservation of natural spaces, embodying Brown's [22] concept of stewardship.

8) Cultural Sensitivity

Respecting and integrating local values into strategies enhances community acceptance [23]. Vytina's sustainability plan preserved cultural heritage alongside economic and environmental goals.

9) Proactivity

Leaders anticipate challenges and initiate change, ensuring resilience and adaptability [24]. Vytina's leadership proactively addressed risks, such as fluctuating resource availability, by implementing preventive measures.

10) Managing Resistance to Change

Addressing resistance helps secure community buy-in [25]. Vytina's leaders reduced opposition by fostering a shared vision and gradually introducing sustainable practices.

11) Long-Term Planning

Leaders balance immediate needs with future sustainability goals [10]. Vytina's comprehensive plan prioritized resilience through short-, medium-, and long-term strategies.

3.2. Systemic factors influencing leadership

Leadership effectiveness is shaped by five contextual factors:

1) Community Feedback (CF): Builds trust and engagement, allowing leaders to refine strategies based on local needs.
2) Economic Factors (EF): Resource availability determines the feasibility of sustainability goals.
3) Environmental Data (ED): Guides leaders in aligning decisions with ecological realities.
4) Cultural Norms (CN): Shapes how communities respond to change and leadership initiatives.
5) Political Components (PC): External support from governance frameworks influences the alignment of local initiatives with broader goals.

In the Vytina case, leaders skillfully integrated these factors to foster trust, stability, and sustainability.

3.3. System dynamics and variables

Using system thinking, key leadership outcomes were analyzed:

1) Community Trust (CT): Trust facilitates smoother implementation of sustainable practices.
2) System Stability (SS): Reflects the resilience of the leadership framework in managing resources and conflicts.
3) Sustainable Development Success (SDS): Balances social, economic, and environmental dimensions to ensure long-term viability.

Key input variables (e.g., CF, EF, ED) influence behavioral components like adaptability and visionary thinking, which in turn shape trust and system stability.

3.4. Data collection for system inputs

1) Community Feedback: Surveys, focus groups, and public consultations to gauge trust and engagement [3].
2) Economic Factors: Local economic reports, business surveys, and funding analyses to evaluate financial health [5].
3) Environmental Data: Monitoring systems and surveys to assess environmental conditions [16].
4) Cultural Norms: Ethnographic studies and historical data to understand community values [1].
5) Political Components: Stakeholder interviews and government reports to assess policy support [3].

Metrics such as trust, resource availability, and resistance to change are scaled to evaluate leadership dynamics.

3.5. Conclusion

This section demonstrates how leadership behaviors interact dynamically with systemic factors to drive sustainable development. By employing system thinking, the analysis provides actionable insights into improving leadership effectiveness in diverse community contexts.

4. Materials and methods

This section outlines the methods employed to examine the role of local leadership in sustainable development, emphasizing a comprehensive, mixed-methods approach.

4.1. Data collection methods

A combination of qualitative and quantitative methods was employed to capture leadership behaviors and their interaction with systemic factors.

4.1.1. Interviews

Semi-structured interviews were conducted with 15 local leaders actively involved in sustainability initiatives in the Vytina Municipality Unit. Selection criteria emphasized diversity in:

- Sectoral Focus: Agriculture, tourism, and governance.
- Demographics: Age and gender.

The interviews explored:

- Leadership traits (e.g., visionary thinking, adaptability).
- Decision-making processes.
- Challenges faced in implementing community-driven development initiatives.

4.1.2. Surveys

Structured surveys were administered to 150 community members, sampled to represent diverse demographics (age, occupation, geography). The surveys captured:

- Leadership Performance: Perceptions of community trust and engagement.
- Community Perspectives: Themes on sustainability principles, behaviors, and cultural values.
- Specific Metrics:
  - Satisfaction with infrastructure, social services, and local projects.
  - Responses to open-ended questions (e.g., "What aspects of the community should remain unchanged?").
  - Likert-scale ratings (e.g., satisfaction with health plans or tourism-related projects).

  Focus areas included health, safety, recreation, and cognitive flexibility.

4.1.3. Focus groups

Three focus groups (8–10 participants each) included [26]:

- Local business owners, farmers, and youth representatives.
- Discussions on community needs, cultural norms, and leadership behaviors.

Facilitation Techniques: Network analysis was used to ensure active and diverse participation.

4.2. Data analysis methods

4.2.1. Qualitative analysis

- Thematic Analysis: Identified patterns in leadership traits and their impact on sustainability [27–29].
- Coding: Key themes like adaptability, cultural sensitivity, and long-term planning were extracted from interview and focus group data.

4.2.2. Quantitative analysis

- Statistical Metrics: Trust levels, engagement rates, and satisfaction were measured using descriptive and inferential statistics.
- Trends Analysis: Data informed the system dynamics model, highlighting baseline community perceptions.

4.2.3. System dynamics modeling (SDM)

- SDM provided a comprehensive framework to simulate leadership behaviors and their systemic impacts.
- Tools: Causal Loop Diagrams (CLDs) were developed using VENSIM.
  - Key Inputs: Community feedback, economic factors, environmental data, cultural norms, and political components.
  - Key Outputs: Community trust, system stability, and sustainable development success (SDS).

4.3. Causal loop diagram development

The CLD visualizes relationships between leadership behaviors and systemic factors (**Figure 1**).

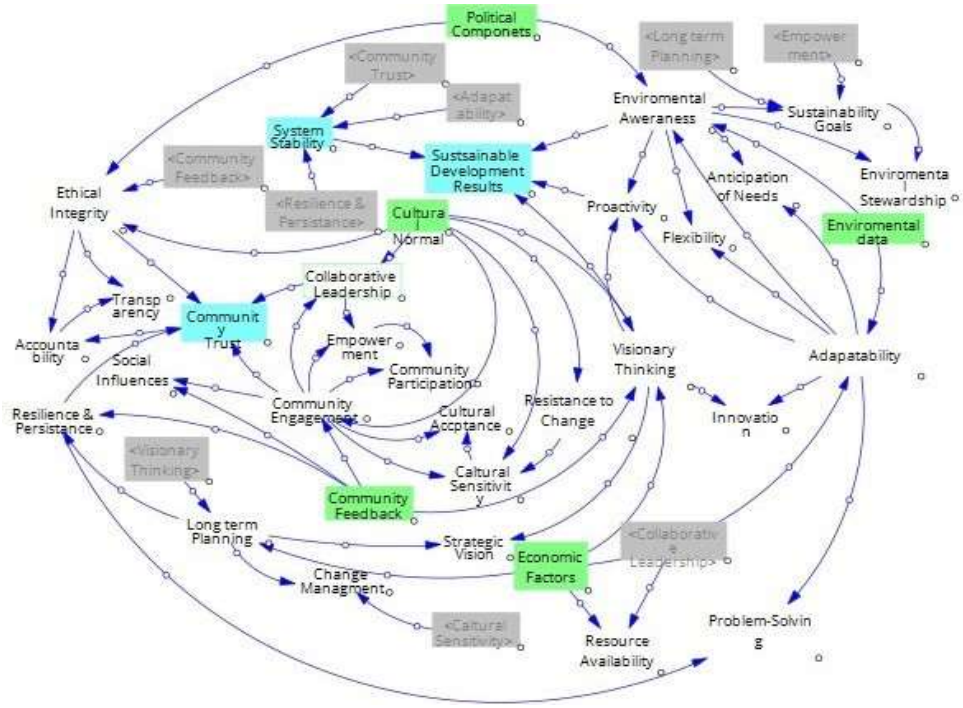

Figure 1. CLD. Visualization of relationships between leadership behaviors and systemic factors.

Variables: Inputs like cultural norms and economic factors influenced traits such as adaptability and visionary thinking.

- Feedback Loops:
  - Reinforcing Loop: Trust-building increased participation, enhancing leadership legitimacy.
  - Balancing Loop: Resistance to change hindered some initiatives, mitigated by culturally sensitive leadership.

4.4. Simulation and sensitivity analysis

1) Simulation Run: Real-world data inputs were used to model scenarios with varying leadership behaviors.
2) Sensitivity Testing: Assessed the impact of changes in input variables (e.g., economic constraints or cultural resistance) on system outcomes.
3) Key Outputs: The model predicted levels of community trust, system stability, and sustainable development success under different scenarios.

4.5. Participant selection and characteristics

1) Local Leaders

- Purposively selected for active roles in sustainability projects.
- Represented diverse sectors (e.g., agriculture, tourism).

2) Community Members

- Randomly sampled for surveys to ensure demographic representation (age, gender, socioeconomic status).

3) Focus Group Participants

- Included stakeholders directly impacted by leadership decisions (e.g., business owners, farmers, youth).

Ethical Considerations

- Informed Consent: Participants consented before data collection, ensuring confidentiality and voluntary participation.
- Ethical Approval: Obtained from the relevant institutional review board.

5. Results

This chapter presents the simulation outcomes and key findings of the leadership evaluation system. The results illustrate how input variables interact with leadership traits to influence sustainable development outcomes.

5.1. Input variables and their measurements

Input variables were measured on a 1–1000 scale, capturing the following aspects:

- Community Feedback (CF): Reflects how positively or negatively the community perceives the leader's actions. A higher score indicates greater support and approval.
- Economic Factors (EF): Represents the strength of the local economy. Higher scores mean better resource access and fewer economic barriers.
- Environmental Data (ED): Captures leader's awareness and integration of environmental factors. Higher scores denote better environmental stewardship [30].
- Cultural Norms (CN): Indicates the alignment of leadership with local cultural values. Higher scores suggest greater cultural sensitivity.
- Political Components (PC): Reflects the political context, including support or resistance from local authorities. Higher scores signify a favorable political climate.

Table 1 presents the simulation results based on weighted relationships between input and output variables.

5.2. Key system variables

- Visionary Thinking (VT): 76
- Long-Term Planning (LTP): 71.2
- Adaptability (AD): 73
- Community Engagement (CE): 65
- Collaborative Leadership (CL): 63
- Sustainable Development Success (SDS): 66.24

(Full equations are provided in **Table 1**.

Table 1. Simulation run.

Input Variables	Equation	Run Value

Community Feedback (CF)	CF = 80	80
Economic Factors (EF)	EF = 60	60
Environmental Data (ED)	ED = 70	70
Cultural Norms (CN)	CN = 50	50
Political Components (PC)	PC = 40	40
System Variables		
Visionary Thinking (VT)	VT = (0.6 × CF + 0.4 × ED)	76
Long-Term Planning (LTP)	LTP = (0.7 × VT + 0.3 × EF)	71.2
Community Engagement (CE)	CE = (0.5 × CF + 0.5 × CN)	65
Collaborative Leadership (CL)	CL = (0.6 × CE + 0.4 × EF)	63
Adaptability (AD)	AD = (0.5 × VT + 0.5 × ED)	73
Ethical Integrity (EI)	EI = (0.7 × CF + 0.3 × PC)	68
Resilience & Persistence (RP)	RP = (0.6 × LTP + 0.4 × CE)	68.72
Environmental Awareness (EA)	EA = (0.7 × ED + 0.3 × PC)	61
Cultural Sensitivity (CS)	CS = (0.6 × CN + 0.4 × CE)	56
Proactivity (P)	P = (0.6 × AD + 0.4 × RP)	71.29
Resistance to Change (RC)	RC = (0.6 × CN + 0.4 × CS)	52.4
Change Management (CM)	CM = (0.6 × LTP + 0.4 × RC)	63.68
Cultural Acceptance (CA)	CA = (0.7 × CS + 0.3 × CE)	58.7
Problem-Solving (PS)	PS = (0.6 × AD + 0.4 × RP)	71.29
Empowerment (EM)	EM = (0.7 × CE + 0.3 × CL)	64.4
Community Participation (CP)	CP = (0.6 × CE + 0.4 × EM)	64.76
Sustainability Goals (SG)	SG = (0.5 × LTP + 0.3 × AD + 0.2 × EA)	69.7
Resource Availability (RA)	RA = (0.7 × EF + 0.3 × CL)	60.9
Anticipation of Needs (AN)	AN = (0.6 × AD + 0.4 × EA)	68.2
Social Influence (SI)	SI = (0.7 × CE + 0.3 × CF)	69.5
Flexibility (FL)	FL = (0.7 × AD + 0.3 × EA)	69.4
Innovation (IN)	IN = (0.6 × VT + 0.4 × AD)	74.8
Strategic Vision (SV)	SV = (0.7 × VT + 0.3 × LTP)	74.56
Accountability (AC)	AC = (0.6 × EI + 0.4 × CT)	72.8
Environmental Stewardship (ES)	ES = (0.7 × EA + 0.3 × SG)	63.61

Table 1. (*Continued*).

Input Variables	Equation	Run Value
Transparency (TP)	TP = (0.6 × EI + 0.4 × AC)	69.92
Output variables		
Community Trust (CT)	CT = (0.2 × VT + 0.2 × LTP + 0.2 × CL + 0.2 × EI + 0.2 × CA)	68.64
System Stability (SS)	SS = (0.25 × LTP + 0.25 × RP + 0.25 × AD + 0.25 × CT)	70.96
Sustainable Development Success (SDS	SDS == (0.25 × SS + 0.25 × EA + 0.25 × RA + 0.25 × CP)	66.24

5.3. Variable weightings in calculation

Weightings for system variables were determined based on expert opinions in the absence of prior research. These weightings served as inputs for sensitivity analyses,

allowing for the examination of how variations in these assumptions impact the model's outputs. This approach ensures that critical variables are systematically tested for their influence on sustainable development outcomes.

5.3.1. Key findings by research questions

1) How do leadership behaviors influence sustainable development outcomes?
   - Visionary Thinking: Scored highest (76), highlighting its critical role in fostering community trust and aligning short-term actions with long-term goals.
   - Adaptability: Scored 73, showcasing its importance in navigating dynamic challenges such as economic fluctuations or environmental crises
   - Collaborative Leadership: Achieved a score of 63, underlining the value of partnerships in resource acquisition and community participation.
2) Which systemic factors interact most significantly with leadership behaviors?
   - Community Feedback: Strongly correlated with leadership traits such as ethical integrity (68) and cultural sensitivity (56). Effective feedback mechanisms reinforced trust (68.64).
   - Economic Factors: Directly influenced long-term planning (71.2) and resilience (68.72). Resource availability emerged as a critical enabler of sustainability initiatives.
3) What feedback loops reinforce or hinder sustainable development success?
   - Reinforcing Trust Loop: Higher community trust increased participation, which strengthened leadership legitimacy and project outcomes.
   - Resistance to Change Loop: Cultural norms and resistance (52.4) acted as barriers, but leaders with cultural sensitivity mitigated these effects effectively.

5.3.2. Detailed results and implications

1) Leadership Behaviors and Their Impact
   - Visionary Thinking: Leaders who communicated clear, long-term sustainability goals fostered greater trust and collaboration. For example, environmental preservation initiatives in Vytina demonstrated the power of a unifying vision.
   - Adaptability: Enabled leaders to maintain stability in the face of uncertainties, such as resource constraints or socio-political challenges.
   - Collaborative Leadership: Enhanced resource availability and participation through strategic partnerships.
2) Systemic Factors and Leadership Effectiveness
   - Community Feedback: Leaders who incorporated community insights built stronger trust and engagement, while those who failed to do so faced resistance.
   - Economic Factors: Limited resources hindered development efforts, even with effective leadership, emphasizing the need for external support.
3) Feedback Loops
   - Trust Loop: Highlighted the role of ethical integrity and transparency in fostering participation and project success.

- Resistance Loop: Demonstrated the need for cultural sensitivity to overcome resistance and align initiatives with local values.

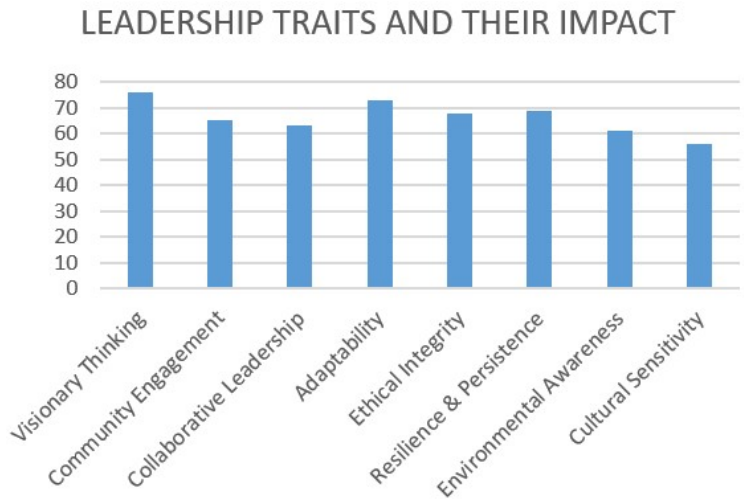

Figure 2. Leadership traits and impact on sustainable development.

A bar chart (**Figure 2**) comparing leadership traits shows that Visionary Thinking and Adaptability scored highest, while Cultural Sensitivity and Environmental Awareness scored lower, indicating areas for improvement.

5.4. In-depth analysis

The findings emphasize the interconnectedness of leadership traits and systemic factors:

- Leaders with strong visionary thinking and adaptability were most effective in fostering community trust and achieving sustainable outcomes.
- Resource availability remained a critical determinant of success, highlighting the need for leaders to secure external partnerships.
- Validation of the model included variable metrics such as community trust, participation rates, and other key indicators, which were gathered through questionnaires, interviews, discussions, and community events. The model's output was found to align closely with empirical estimations. Further research could explore ways to converge these empirical estimations with the model's outcomes to enhance accuracy.

5.5. Recommendations for future practice

- Strengthening Visionary Leadership: Offer training programs to help leaders articulate and communicate clear sustainability goals.
- Enhancing Adaptability: Use scenario-based simulations to improve leaders' ability to respond to change.
- Fostering Feedback Mechanisms: Implement structured community feedback loops to ensure continuous trust-building and engagement.

6. Discussion

This section synthesizes the findings, highlights their implications for leadership in sustainable development, and suggests practical applications and directions for future research.

6.1. Key findings

6.1.1. Critical role of leadership

The study underscores the pivotal role local leaders play in fostering sustainable development. Key traits—visionary thinking, adaptability, and collaborative leadership—emerged as essential in guiding communities toward long-term sustainability.

6.1.2. Challenges

Despite these traits, local leaders face challenges such as:

- Political Resistance: External opposition can limit initiative implementation.
- Resource Constraints: Limited access to financial and human resources often hampers progress.
- Cultural Barriers: Resistance to change rooted in cultural norms requires culturally sensitive leadership strategies [31].

6.1.3. Case insights

The Vytina case study illustrates that continuous adaptation, engagement, and trust-building are vital for overcoming these obstacles and achieving sustainable outcomes.

6.2. Linking results to theoretical frameworks

1) Leadership Theories

- Transformational Leadership: Visionary thinking aligns with transformational leadership principles, emphasizing motivation through clear, long-term goals [5]. In Vytina, leaders who articulated sustainability visions garnered trust and participation.
- Adaptive Leadership: Adaptability was critical in addressing resource scarcity and resistance to change, reflecting the principles of flexibility in dynamic environments [8].
- Collaborative Leadership: Partnerships with stakeholders, including scientific organizations, validated the importance of collaborative practices [2].

2) Sustainable Development Frameworks

- The findings align with the United Nations' SDGs, emphasizing inclusivity and grassroots participation. The positive impact of community engagement and feedback loops in this study underscores the importance of grassroots participation in achieving sustainability objectives [32].
- Resistance to change highlights the importance of localized strategies to complement global frameworks.

3) System Thinking and System Dynamics

- Trust Loop: Positive feedback loops, such as increased trust enhancing participation, validated previous applications of system thinking [10,33].

- Resistance Loop: Identified cultural norms and resistance as barriers, showcasing the utility of System Dynamics Modeling in scenario analysis [4].

New Insights:

This study's integration of leadership behaviors and systemic factors challenges the universality of leadership theories, emphasizing the need for context-specific adaptations.

6.3. Practical implications for leadership in sustainable development

1) Strategic Decision-Making

Purpose: Inform sustainable project design.

Application: Leaders can assess community feedback, cultural norms, and environmental factors to refine strategies, ensuring alignment with community needs and sustainability objectives [34].

2) Adapting to External Changes

Purpose: Enhance resilience to crises (e.g., climate change, political instability). Application: Evaluate adaptability and community trust to sustain long-term planning under shifting circumstances.

3) Enhancing Community Participation

Purpose: Strengthen collaborative leadership.

Application: Diagnose barriers like low trust or cultural insensitivity, fostering inclusive decision-making and aligning initiatives with local values.

4) Managing Resistance to Change

Purpose: Address opposition to new initiatives.

Application: Identify resistance factors and adjust strategies through cultural sensitivity and transparent communication.

5) Crisis Management

Purpose: Navigate natural disasters and economic disruptions.

Application: Assess resilience and trust, prioritizing stability and recovery while aligning with long-term goals.

6) Evaluating Policy Impact

Purpose: Assess sustainability-focused policies.

Application: Simulate policy scenarios to refine designs, anticipate community responses, and ensure alignment with leadership behaviors [35].

7) Leadership Development

Purpose: Enhance leadership skills.

Application: Use the system as a training tool to simulate leadership scenarios, identifying areas for growth and alignment with sustainability goals [36].

8) Monitoring and Evaluation

Purpose: Track project progress.

Application: Use periodic system evaluations to adjust strategies and ensure initiatives remain aligned with sustainability objectives.

9) Securing Resources and Partnerships

Purpose: Enhance resource mobilization.

Application: Leverage collaborative leadership and innovation to attract external support and strengthen development capacity [37].

6.4. Future research directions

1) Longitudinal Studies: Investigate how leadership behaviors evolve and influence sustainability over time [38].
2) Cross-Cultural Comparisons: Explore cultural sensitivity across diverse socio-economic and geographic contexts.
3) Refined System Dynamics Models: Incorporate additional variables like technological advances or climate impacts.
4) Digital Tools Integration: Examine the role of digital platforms and AI in enhancing feedback loops and decision-making.

6.5. Conclusion

The findings demonstrate that leadership traits and systemic factors are deeply interconnected, with adaptability, visionary thinking, and cultural sensitivity playing pivotal roles. Practical applications of the leadership evaluation system provide a roadmap for optimizing sustainable development initiatives, while future research directions aim to refine these insights and extend their applicability across diverse contexts.

7. Conclusion

7.1. Summary of key findings

This study underscores the critical role of local leadership behaviors in fostering sustainable development in rural communities. The key findings include:

- Visionary Leaders balance immediate needs with long-term sustainability goals significantly enhance community trust and system stability.
- Adaptability: Effective navigation of dynamic challenges, such as economic constraints and environmental changes, ensures resilience and responsive strategies.
- Collaborative Leadership: Partnerships and resource mobilization are vital for addressing the multifaceted demands of sustainable development.
- Cultural Sensitivity: Managing resistance to change and ensuring the acceptance of sustainability initiatives depends on a leader's cultural awareness.

System Dynamics Modeling provided insights into the interplay between leadership traits and systemic factors, identifying feedback loops that reinforce or hinder development outcomes.

7.2. Importance of findings

The findings offer actionable recommendations for policymakers and community leaders:

1) Leadership Development: Training programs should prioritize enhancing visionary thinking, adaptability, and cultural sensitivity to prepare leaders for complex sustainability challenges.
2) Participatory Approaches: Structured feedback mechanisms can strengthen community trust and engagement, fostering positive reinforcement loops.

3) Resource Optimization: Leaders should focus on forming partnerships and securing external support to address resource constraints and scale successful initiatives.

This study reveals the dynamic interactions between leadership behaviors and community systems, highlighting the transformative potential of local leaders as agents of change capable of driving sustainable development and long-term community resilience.

7.3. Limitations

While providing valuable insights, the study has certain limitations:

- Sample Size: The relatively small sample may limit the generalizability of the findings.
- Context-Specificity: The findings are specific to the Vytina Municipality Unit and may require adaptation to different cultural or economic contexts.
- Simplified Model: The System Dynamics Model includes assumptions and weightings that may not fully represent real-world complexities.
- Resource Constraints: Limited resources influenced the breadth of data collection and analysis.

Future research should address these limitations by increasing sample sizes, expanding to diverse settings, and refining the modeling framework for broader applicability.

7.4. Comparative insights from other initiatives

The findings from the Vytina case study [39–41] resonate with global best practices and challenges in sustainable development:

- Successful Comparisons: Initiatives like Curitiba's urban planning in Brazil and Bhutan's Gross National Happiness framework demonstrate the value of visionary leadership and cultural alignment in driving sustainability [42].
- Challenges from Unsuccessful Efforts: The struggles in projects like the Aral Sea restoration or renewable energy initiatives in Sub-Saharan Africa highlight the consequences of limited community engagement, resource mismanagement, and insufficient institutional support.

These comparisons emphasize the importance of integrating visionary leadership, community involvement, and resource optimization in fostering successful sustainable development.

7.5. Closing thoughts

This research advances the understanding of local leadership in sustainable development, while highlighting the need for context-specific exploration of challenges and opportunities. Future studies should expand the application of System Dynamics Modeling across diverse cultural and geographic settings, providing refined tools and strategies for empowering leaders to guide their communities toward sustainable futures [43].

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Article

A comprehensive education for an economically sustainable society in the Argentine Republic

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Abstract: The 2030 Agenda for Sustainable Development establishes education as a fundamental tool to raise awareness about the importance of sustainable development, highlighting the importance of aligning educational policies in Argentina with international standards. There is growing interest and some promising initiatives in sustainable education in Argentina, but significant barriers still must be overcome. Teacher training and the integration of sustainability into curricula are key aspects that need attention to move towards an educational system that fosters an active commitment to sustainable development.

Keywords: social inequality; trends in education; vulnerability; economic gap

1. Introduction

Amid the vast cultural diversity that defines in Latin America today, education is considered a complex and dialectical social phenomenon. In order to analyze it, it is primarily necessary to contextualize it at the regional, sub regional and country level. And even within each country, it is implemented differently in accordance with the conditioning factors, since education appears to be shaped by economic factors, in addition to being constrained by its inherent limitations. Factors such as poverty and exclusion and the distribution of wealth must be considered [1]. Latin America's arrival at so-called modernity, as a historical process, was aligned with its pressing demands for development and freedom, while simultaneously drawing on the historical experiences of France and the United States as points of reference. The 19th century ended with a liberal political spirit. This philosophical stance was neither assumed mechanically, nor embraced uncritically, but was adopted by each country as the foundation of a necessary process of change in education [2]. The current problem is to ensure an education with solid learning and the acquisition of tools that allow lifelong learning. It is a priority to advance in the determination of a concept of quality of education and the sustained work of all the actors in the process in quality management [3]. On the other hand, climate change, environmental degradation and pollution are reaching a global consensus and are currently discussed in the media, academic meetings and political agendas around the world [4]. Sustainability must inevitably be integral to any comprehensive response to the complexity and urgency of today's environmental challenges. The relationship between human development and environmental impact cannot be regarded as straightforward. On the one hand, people living in rich countries and with higher levels of education are more likely to lead lifestyles that leave a harmful footprint on ecosystems. This comportment has encouraged people to modify their personal attitudes and everyday behavior to support recycling, reduce waste, conserve energy and improve water sanitation [5]. It is widely

recognized that education plays a fundamental role in the search for sustainability and the achievement of sustainable societies [6]. Therefore, many countries incorporate these issues into their curricula and educational programs [7]. According to the study by Rodríguez García et al. [8], the progressive increase in publications related to sustainability in the educational field is highlighted, which indicates a growing relevance of this topic. The authors observe that sustainability should not only be understood from an environmental perspective, but should also integrate social, economic and institutional contexts. In Argentina, education has become an important pillar to achieve a sustainable economy and society. This paper presents how this evolution has occurred, showing a growing interconnection between the aforementioned elements. The concept of sustainable development should be reflected upon, moving away from mere economic growth but as an essential component to mitigate inequalities in social development.

2. Methodology: Obtaining new results

The existing body of research demonstrates the fundamental role that education plays in the life of a country, its society and its economy. Employing a methodology grounded on different principles, it aims to address research gaps in a country characterized by diverse climates, disparities in public well-being and challenges related to environmental sustainability in urban areas of Argentina. The ecologist Donella Meadows [9], best known for being the author of The Limits to Growth [10], asked her students "What would the world be like if there were no hunger?" at Dartmouth College in Hanover, New Hampshire, back in the 1970s. They found it difficult to answer, so Meadows set out to change that situation, creating a global movement, known as systems thinking. It is now considered essential to face major global challenges such as the Sustainable Development Goals. Individuals engaged in systems analysis strongly adhere to the concept of "leverage points", defined as specific locations within a complex system where even a minor change in one aspect can trigger significant alterations throughout the entire structure. Meadows initially presents her original first nine points to intervening in a system [11], subsequently offering a revised list of twelve points (**Table 1**) [12]. Systems thinking has become a fundamental approach to address the complexity of contemporary social and environmental phenomena. It is in this context that Gual [13] highlights the need to develop systems thinking skills. This understanding is crucial to promote sustainability through innovative approaches. Noboa [14] contends that comprehending social reality requires a holistic perspective that accounts for the interactions shaping it.

Table 1. 12 points for intervening in a system (in increasing order of effectiveness) [12].

12	Constants, parameters, numbers (such as subsidies, taxes, standards).
11	The sizes of buffers and other stabilizing stocks, relative to their flows.
10	The structure of material stocks and flows (such as transport networks, population age structures).
9	The lengths of delays, relative to the rate of system change
8	The strength of negative feedback loops, relative to the impacts, against, they are trying to correct.
7	The gain around driving positive feedback loops.

Table 1. (*Continued*).

6	The structure of information flows (who does and does not have access to information).
5	The rules of the system (such as incentives, punishments, constraints).
4	The power to add, change, evolve, or self-organize system structure
3	The goals of the system.
2	The mindset or paradigm out of which the system, its goals, structure, rules, delays, parameters arises.
1	The power to transcend paradigms

3. Results and discussion

3.1. Argentina in numbers

The population of the Argentine Republic as of 1 July 2022 amounts to 46,234,830 inhabitants (INDEC [15]).

According to data from the Ministry of Health of the Argentine Republic in 2022, the crude birth rate reached 10.7 per thousand and the mortality rate 8.6. Regarding the Argentine demographic evolution, an upward growth rate is recorded until 1914, mainly due to the high immigration rate, a moderate growth between 1914 and 1947, and an even slower growth rate from 1960 to 2001. This is explained by the demographic transition process and, in 2010, a slight increase is seen with an average annual growth rate of 11.4 per thousand [16]. **Table 2** presents the population data by sex and masculinity index, median age and population density, according to the province corresponding to the year 2022 [17]. To comply with the statistical quality standards required by INDEC, the category of the responses to the question on sex recorded at birth is redistributed between the categories Woman/female and Man/male.

Table 2. Population by sex and masculinity index, median age and population density, according to provinces, corresponding to the year 2022 [17].

Jurisdiction	Population			Masculinity index (1)	Median age (2)	Population density
	Total	Sex				
		Men	Women			
						hab./km^2
Total	45,892,285	22,186,791	23,705,494	93.6	32	12.5
Ciudad Autónoma de Buenos Aires	3,121,707	1,439,873	1,681,834	85.6	39	15,161.3
Buenos Aires	17,523,996	8,470,569	9,053,427	93.6	33	57.3
24 partidos del Gran Buenos Aires	10,849,299	5,226,941	5,622,358	93.0	33	2,875.3
Interior de la provincia de Buenos Aires	6,674,697	3,243,628	3,431,069	94.5	33	22.1
Catamarca	429,562	210,464	219,098	96.1	31	4.2
Chaco	1,129,606	547,655	581,951	94.1	29	11.3
Chubut	592,621	291,412	301,209	96.7	33	2.6
Córdoba	3,840,905	1,856,395	1,984,510	93.5	33	23.3
Corrientes	1,212,696	589,009	623,687	94.4	30	13.6

Table 2. (*Continued*).

Jurisdiction	Population			Masculinity index (1)	Median age (2)	Population density
	Total	Sex				
		Men	Women			
						hab./km^2
Entre Ríos	1,425,578	693,547	732,031	94.7	32	18.2
Formosa	607,419	296,810	310,609	95.6	29	8.0
Jujuy	811,611	393,590	418,021	94.2	31	15.2
La Pampa	361,859	177,858	184,001	96.7	34	2.5
La Rioja	383,865	187,348	196,517	95.3	30	4.2
Mendoza	2,043,540	989,578	1,053,962	93.9	32	13.7
Misiones	1,278,873	626,076	652,797	95.9	28	42.8
Neuquén	710,814	349,088	361,726	96.5	32	7.5
Río Negro	750,768	366,857	383,911	95.6	33	3.7
Salta	1,441,351	702,839	738,512	95.2	29	9.3
San Juan	822,853	401,201	421,652	95.1	30	9.3
San Luis	542,069	265,327	276,742	95.9	31	7.2
Santa Cruz	337,226	167,133	170,093	98.3	31	1.4
Santa Fe	3,544,908	1,710,259	1,834,649	93.2	34	26.6
Santiago del Estero	1,060,906	521,543	539,363	96.7	29	7.7
Tierra del Fuego, Antártida e Islas del Atlántico Sur	185,732	92,340	93,392	98.9	31	0.2
Tucumán	1,731,820	840,020	891,800	94.2	30	76.7

(1) Masculinity index: number of men per 100 women.
(2) Corresponds to the population in private homes.

Figure 1. The political map of the Argentine Republic, with its provinces and capitals [18].

It should be noted that the average density is 14.4 inhabitants/km^2, excluding the departments of Antarctica and the South Atlantic Islands. **Figure 1** shows the political map of the Argentine Republic, with its provinces and capitals [18].

3.2. Argentina and poverty

The goals of the 2030 Agenda are uncertain as countries struggle with inflation, climate change, and wars, among other calamities. Inflation influences energy and food prices, spreading increasing inequality in societies [19,20]. Regarding the global situation, the World Bank warned that by 2023, there would be almost 700 million people living in extreme poverty [20]. If we recall the content of the Brundtland report and its quote that "a world in which poverty is endemic will always be prone to ecological and other catastrophes" [21] then vulnerable populations are those who suffer from inclement weather such as hurricanes, storms, floods, etc. The direct consequence of this phenomenon is to increase poverty and famine [22]; for example, the current war in Ukraine fundamentally affected wheat and corn prices [23].

Poverty in Argentina has been studied from various perspectives, reflecting its complexity and multidimensionality. Before beginning the study of poverty by geographic regions in Argentina, it is necessary to remember that the poverty line considered in this case is that of the country as a whole, in order to be able to appreciate the situation including its different standards of living. Thus, it is not surprising that Patagonia has very low poverty rates (around 15%), compared to the rest of the regions. The relatively poorest region is the NEA (northeast of Argentina), presenting rates close to 50% in 2002. A notable case is that of the NOA (northwest of Argentina), since it is the only region that presents a downward trend in the poverty rate. A similar behavior is also observed in the Cuyo region [24]. Da Silva et al. [25] in their article on the social policies adopted in Argentina to combat poverty, analyze the low effectiveness of the policies applied, which do not address the structural causes of the problem. The article written by Chao [26] provides a comprehensive analysis of poverty in Argentina through an approach that integrates social and economic aspects. Poverty must be understood as a multidimensional phenomenon that not only affects individuals in terms of income, but also is related to the social capital and social networks that families possess. This suggests that public policies must consider these dynamics to be effective in reducing poverty. The use of various scales to measure poverty contribute to a deeper understanding of the situation faced by Argentine households, as no single measure accurately reflects the reality of families in vulnerable conditions [24].

Numerous works constitute an instrument for reading poverty. In this line, we can highlight numerous works by CEDLAS (Center for Distributive, Labor and Social Studies – National University of La Plata) among which we can point out the approaches of Gustavo Busso [27]. Also the work of Busso et al. [28], proposes to understand the increase in the poverty rate in Argentina between 1992 and 2002. Other works supported by the measurement problem are those of Casanova [29], on the notion of poverty traps in relation to the linearity of income. Similarly, Conconi and Ham [30], are concerned with defining a notion of poverty based on the idea of constructing multidimensional poverty measures. Meanwhile, Alejo and Garganta

[31], focus their research on the Permanent Household Survey to break down poverty into two: chronic and transitory. Poverty has been thoroughly examined; to exemplify, Sen [32], distinguished two main dilemmas which were posed either on the conundrum of the identification of the poverty spectrum or the construction of an index to evaluate the poverty of citizens. Moreover, Zhou and Liu [33], distinguished Sen's contribution on poverty nomenclature in the 'capability approach', especially on the issue of what poverty really is: 'a deprivation of basic necessities', not only a matter of low income standards. Poverty, inequality and social exclusion are therefore integral parts of the Sustainable Development Goals (SDGs: 1, 6 and 10), emphasizing the multidisciplinary nature of the above-mentioned issues. Moreover, the intrinsic elements of the 2030 Agenda and the measurement of poverty, inequality and polarization would significantly improve integrated policy pathways in national and international forums [34].

3.3. Sustainable development in Argentina

According to Rawls' concept of social justice, inequalities loom across social classes or manifest themselves in discrepancies between communities [35]. Poverty eradication is the central theme of the SDGs (UN 2016) [36]. The core SDGs for poverty and inequality are SDGs 1, 2, 3, 4, 6, 7, 10, and 11 [37–39]. Regarding poverty eradication, the most important is SDG 1. SDG 1.2 calls for halving the population below the poverty line [40]. While SDG 1.3 puts emphasis on socially excluded, vulnerable, unemployed and disabled people. However, not all notions of poverty are addressed in SDG 1. SDG 10.3 applies to reducing inequalities that focuses on people living in the bottom 50% of median income [41].

To analyze sustainable development in Argentina, it is useful to look at its current state and especially at trends in matters of conservation, energy use, consumption, public policies, etc. and other factors that reflect how the country is progressing toward ensuring its future generations access to the natural resources essential for their survival.

According to the World Wildlife Fund (WWF), Argentina is the ninth country in the world with the greatest natural wealth and biodiversity. In addition, it has one of the seven natural wonders of the world, the Iguazu Falls. Argentina has an enormous diversity of fauna and flora thanks to its size and the climatic varieties conditioned by factors as diverse as latitude, altitude, etc. In Argentina, three very different geographical areas can be distinguished: plains in the central and northern areas, regions with dense vegetation and extensive areas of palm groves and grasslands; plateaus in the southern area, plateaus and mountain ranges (Patagonia) and mountains in the western area, mountainous, hilly relief, with scarce vegetation. On the other hand, according to the Sustainable Development Goals of the Argentine Republic, by 2030 [42], the proportion of men, women and children of all ages living in poverty in all its dimensions must be reduced by at least half. In addition, implement nationally appropriate social protection systems and measures for all, including minimum levels, achieving broad coverage for the poor and vulnerable. Also, ensure that all children complete free, equitable and quality primary and secondary education, leading to relevant and effective learning outcomes. Regarding per capita economic growth in

accordance with national circumstances and, in particular, a growth of the gross domestic product of around 3% per year. It must strive for the development of reliable, sustainable, resilient and quality infrastructure, including regional and cross-border. Seeking affordable and equitable access for all. Finally, promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective institutions, such as schools that are accountable and inclusive at all levels [42].

3.4. Sustainable education in Argentina

Sustainable education in Argentina has been the subject of growing interest in recent years, reflecting a commitment to sustainable development at all educational levels. As practices and theories related to education for sustainability are explored, various initiatives and approaches have been identified that seek to integrate these concepts into the national educational system. The chapter by Hernandez et al. [43] offers a critical view on the implementation of education for sustainability in higher education institutions in Latin America. The authors highlight that, despite the growing awareness of the importance of sustainability, the effective implementation of educational strategies that include environmental considerations remains limited. This is partly attributable to the lack of specialized training, which hinders the incorporation of these topics into the curriculum. Regarding cognitively complex activities, these are generally broad, and allow the student to get closer to reality and learn more meaningfully. As a general trend, it was verified that the items with the highest specific weight are environmental issues (35%) and recycling (28%). Consequently, the educator must overcome the deficiencies that the textbook may present by fostering additional cognitively demanding activities, incorporating questions and problems that require substantial application of knowledge, and, where feasible, covering a broad range of content related to sustainability, while also incorporating a more global perspective, including human and economic considerations [44]. Koskela [45] discusses education for sustainable development, stressing the importance of aligning educational policies with international standards. For example, Barth and Michelsen [46] call for the creation of spaces for informal Education for Sustainable Development (ESD), in universities through facilitating activities such as peer discussions and voluntary work. Informal learning can also drive organizational changes towards sustainability. In fact, there has been a promising development in the private sector regarding the sustainability performance of companies, partly due to informal, non-formal and, in some cases, formal learning (**Figure 2**) [45].

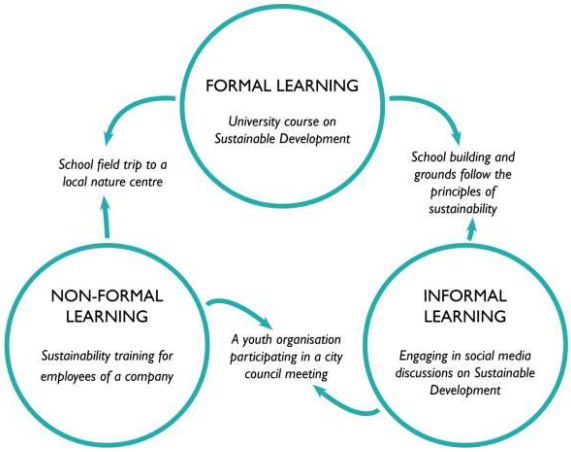

Figure 2. Examples of how learning for sustainability can take place in formal, non-formal and informal settings or in activities that blend different forms of learning [45].

In conclusion, there is a growing interest and some promising initiatives in sustainable education in Argentina, but significant barriers still must be overcome. There is a need to include specific examples in Argentine educational contexts, which could provide solutions tailored to local particularities. Teacher training and the integration of sustainability in curricula are key aspects that need attention to move towards an educational system that fosters an active commitment to sustainable development.

4. Conclusions

The need to integrate approaches that foster critical reflection and ethical commitment in the search for sustainable solutions is highlighted. Education and active participation in the construction of inclusive societies are key elements to advance towards poverty reduction, applying systemic thinking in educational, social and economic practice.

To conclude this point, I thought of Pedro Bonifacio Palacios, whose pseudonym was Almafuerte, an Argentine teacher and poet, who was born on 13 May 1854 and died on 28 February 1917, in La Plata. His work is characterized by the strength and passion in his verses, which address themes such as love, social injustice and the fight for ideals. He wrote a poem called ADIÓS A LA MAESTRA (Farewell to the Teacher) (**Figure 3**) [47]. The poem exemplifies, simply and extensively, the role of the teacher in the most vulnerable social classes. The poem is presented below:

Figure 3. The teacher in the most vulnerable social classes [47].

Sublime worker,
blessed lady:
evening has come
for you too.
The evening, which says:
rest!…the hour
of saying goodbye to the children
But do not despair, holy teacher:
not everything in the world
is gone;
you will always be
our compass,
the only dear
second mother!
As the months go by,
as the years go by,
we will be adults,
brilliant perhaps…
but never will the greatest or strangest events
completely deflower
eternal childhood!
In the midst of the faces
that lovingly preserve
the noble, the pure
filial memory,
like a solemn
vision of Minerva,
your image, lady,
will have its place.
And wherever
the law of the environment
will want to
nibble our lives,
nail our cross,
the school must rise
fantastically,
like a sumptuous
great tower of light.
Do not moan, do not cry
holy teacher:
not everything in the world
is gone;
you will always be
our compass,
the only dear
second mother!

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Article

Mobilizing local government towards sustainable development: Challenges, initiatives, and support strategies

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Abstract: This article explores the innovative sustainable development plan designed for the Municipality Unit (MU) of Vytina, a rural community in Greece. The study focuses on the experience and lessons learned over four years through educational and planning activities led by the Sustainable Development Association. The article highlights challenges, particularly the lack of direct municipal and government support, and emphasizes the necessity of financial, educational, and regulatory mechanisms to improve the effectiveness of bottom-up planning. The methodology combined qualitative and quantitative approaches, including surveys, focus groups, and participatory planning sessions. Findings reveal the importance of empowering residents to shape their sustainability goals while addressing barriers such as limited resources, resistance to change, and institutional gaps. The study proposes measures to streamline planning and align local efforts with broader frameworks like the 2030 Agenda for Sustainable Development. This research contributes to sustainable development discourse by providing a replicable model for rural communities, balancing local realities with global objectives. It highlights the pivotal role of municipalities and governments in fostering effective and inclusive sustainability initiatives.

Keywords: bottom-up planning; sustainable development; community engagement; municipal governance; rural sustainability

1. Introduction

Sustainable development has emerged as a critical global objective in response to the growing environmental, social, and economic challenges faced by societies worldwide. The pressing need to address climate change, resource depletion, and social inequality has driven the adoption of sustainable development plans at multiple governance levels, ranging from international frameworks, such as the United Nations' Sustainable Development Goals (SDGs), to localized strategies tailored to specific communities [1,2] These plans aim to achieve balanced growth by integrating environmental stewardship, social inclusivity, and economic resilience [3].

Globally, the success of these plans has been uneven, influenced by variations in governance structures, resources, and socio-political conditions [4,5]. In Europe, for instance, the European Union's Green Deal represents a comprehensive approach to achieving climate neutrality by 2050, incorporating policies across sectors such as energy, transportation, and agriculture [6]. Similarly, in Asia, countries like Japan and South Korea have adopted long-term sustainability strategies focused on technological innovation and green growth according to Organization for Economic Co-operation and Development. However, localized efforts often face significant challenges due to financial and institutional constraints, particularly in rural areas.

This study investigates the innovative sustainable development planning process in Municipality Unit (MU) Vytina, Greece. The MU of Vytina is a rural community located in the mountainous Arcadian region of Greece. Known for its dense fir forests, rich cultural heritage, and agricultural traditions, Vytina represents a unique socio-economic and environmental landscape. The community primarily relies on small-scale farming, livestock, and beekeeping, while also leveraging its natural beauty for tourism. However, like many rural areas, the community faces challenges such as population decline, resource constraints, and limited infrastructure, which necessitate sustainable development strategies tailored to its specific needs. The research focuses on how municipal authorities can support bottom-up planning initiatives and overcome barriers to effective implementation. It examines how local and central government strategies align with global sustainability objectives while addressing specific regional constraints. While global frameworks provide a valuable blueprint, their adaptation to local realities often falls short, leading to gaps in policy implementation and outcomes. By addressing the gap between global sustainability goals and local implementation challenges, this study offers a unique perspective to the field of public policy and sustainable development. It focuses on the intersection of global sustainability objectives and local implementation challenges. While there is substantial research on sustainable development at the global and national levels, there is a need for more localized studies that explore how these plans can be effectively tailored to specific contexts. This study contributes to this gap by providing insights into the local adaptation of sustainable development plans and offering practical recommendations for policymakers and practitioners.

2. Literature review

Bottom-up methodologies have long been recognized as critical to fostering community ownership and addressing local needs effectively. [7] "ladder of citizen participation" remains a foundational model for understanding the degrees of public involvement in planning processes, emphasizing that higher levels of participation yield greater empowerment and agency for communities. Similarly, [8] underscores the importance of participatory approaches in rural development, highlighting their potential to build trust, foster social cohesion, and promote locally tailored solutions.

Participatory planning processes, such as those employed in Vytina, enable local stakeholders to identify priorities and craft solutions specific to their socio-economic and environmental contexts. Reed et al. [9] argue that such approaches improve decision-making and enhance community resilience by incorporating diverse perspectives and local knowledge. However, they caution that the success of these methods is contingent upon effective facilitation and sufficient institutional support.

Despite their advantages, bottom-up methodologies face significant barriers. Political resistance, a lack of financial and human resources, and limited technical expertise often impede these processes. Frey and Stutzer [10] identify behavioral inertia and resistance to change as key challenges, particularly in communities with entrenched hierarchical governance structures. Smith [11] further notes that fostering

a shared vision among stakeholders can be particularly difficult in contexts characterized by socio-economic disparities or conflicting priorities.

Aligning local efforts with broader legislative frameworks and international goals, such as the United Nations Sustainable Development Goals (SDGs), is another critical challenge. The SDGs call for the integration of environmental, social, and economic dimensions into development strategies [3]. However, translating these global objectives into actionable local plans requires both flexibility and alignment with local realities [12]. Studies highlight the need for robust support mechanisms, including financial incentives, technical training, and clear regulatory guidelines, to ensure the successful localization of global goals [13].

This research builds on the EarthCAT methodology, a participatory framework that emphasizes sustainability through community engagement [14]. The methodology has been widely applied in various contexts to facilitate holistic planning and foster community-driven change. By adapting EarthCAT to Vytina's unique socio-economic and environmental conditions, this study contributes to the growing body of literature on the applicability of participatory frameworks in rural settings.

Furthermore, this research draws on theories of adaptive governance, which stress the need for flexibility in addressing complex socio-environmental challenges. Adaptive governance, as articulated by Gustafsson and Krantz [15] and Pereira et al. [16], advocates for iterative decision-making processes that respond dynamically to changing circumstances. These theories align closely with the Vytina case, where local stakeholders had to address evolving challenges and leverage opportunities over the course of the planning process.

In addition to governance theories, this study is informed by systems thinking, particularly the work of Meadows [17] and Senge [18] which emphasizes the interconnectedness of social, economic, and environmental systems. By treating the community as a complex system, this research integrates systems thinking with participatory methodologies to ensure that strategies address the multidimensional nature of sustainability challenges.

Lastly, recent empirical studies provide insights into the conditions necessary for successful bottom-up planning. For example, Lee and Rydin [5] highlight the importance of creating enabling environments through capacity building and institutional support, Magee et al. [19] advocate for aligning local initiatives with regional and national policies to enhance coherence and scalability. These findings underscore the critical role of municipal and central government support in overcoming barriers to participatory planning.

In summary, the literature highlights both the transformative potential and inherent challenges of bottom-up planning. By synthesizing insights from participatory frameworks, governance theories, and empirical studies, this research aims to contribute a nuanced understanding of how rural communities like Vytina can navigate the complexities of sustainable development planning.

3. Material and methods

3.1. Case study: Pioneering sustainable development in the Municipal Unit of Vytina

The MU of Vytina, situated in Greece's Arcadian mountains, initiated a bottom-up planning process to address environmental, social, and economic challenges. This initiative, driven by local citizens and coordinated through the Sustainable Development Association (SDA), aimed to address pressing environmental, economic, and social challenges. The process resulted in the creation of a comprehensive sustainability plan, setting a benchmark for similar projects globally, using the EarthCAT methodology [14,20].

3.1.1. Key objectives

The initiative was guided by the following objectives:

1) Empowering community: Engaging residents to co-create their future.
2) Preserving heritage: Safeguarding cultural and natural assets.
3) Fostering resilience: Building adaptive capacity for future uncertainties.
4) Promoting prosperity: Balancing environmental stewardship with economic growth.

3.1.2. The planning methodology

The SDA employed a modified version of *The EarthCAT Guide to Community Development* methodology, consisting of the following steps:

1) Laying the foundations: Forming representative groups, raising public awareness, and collecting community input.
2) Creating a shared vision: Involving 144 citizens in mapping out long-term aspirations across 17 sustainability sectors, such as natural areas, tourism, and education.
3) Setting goals and strategies: Defining visionary and specific goals, bridging them with actionable strategies, and linking them to United Nations Sustainable Development Goals (SDGs).
4) Monitoring and revision: Establishing sustainability indicators and conducting periodic reviews to adapt the plan.

3.1.3. Data collection

Data collection involved stratified sampling of respondents to various questionnaires. These topics included residents' beliefs, sustainability principles, behaviors, environmental concerns, economic issues, socio-cultural dynamics, goals, and strategy development. Specific questionnaire themes addressed areas like social services, health, safety, recreation programs, cultural programs, infrastructure, short-term projects, routine-seeking, and cognitive rigidity [19,21].

Example questions included:

Open/free text: "What things are worthy of the community and we do not want to change? What things need to change? How do you imagine your village 20 years from now?"

Likert Scale (1–5): "Are you satisfied with the community's provision of a family health plan?" and "Do you feel that the announced short-term project regarding the internal touristic trails in Vytina is in the right direction?"

Data from surveys, workshops, and planning sessions were utilized as follows:

- Surveys targeted a stratified sample of 200 residents, capturing quantitative data on priorities like infrastructure needs, healthcare satisfaction, and environmental concerns. For example, 68% of respondents expressed dissatisfaction with waste management, leading to the prioritization of this issue in the action plan.
- Community workshops focused on brainstorming solutions, such as ways to reduce reliance on non-renewable energy sources.
- Participatory planning sessions were structured into three phases: Identification of challenges, proposal of solutions, and voting on prioritized actions.

Focus groups with about 35 participants were organized across domains such us economy, education, agriculture, and health. Facilitation techniques such as network analysis were employed to encourage active engagement.

4. Results

4.1. Achievements

The participatory planning process in the Municipal Unit (MU) of Vytina yielded substantial achievements, demonstrating the transformative potential of bottom-up approaches:

1) Comprehensive sustainability plan: The process resulted in a well-structured sustainability plan encompassing [17]:
   - 43 visionary goals targeting long-term aspirations.
   - 85 specific goals addressing immediate needs across diverse sectors, including environment, economy, and culture.
   - 293 proposed actions and projects, providing actionable steps for achieving the identified goals.
2) Enhanced community engagement: The participatory nature of the process empowered local residents, fostering a sense of ownership and responsibility toward the community's future. Regular workshops and focus groups cultivated a collaborative atmosphere to ensure the integration of diverse perspectives into the plan [3].
3) Capacity building: Residents and local stakeholders acquired valuable skills in strategic planning, data collection, and decision-making. This capacity-building aspect laid the foundation for sustained engagement in future developmental activities.
4) Alignment with broader sustainability principles: While the goals were derived from local priorities, they were conceptually aligned with the UN SDGs, ensuring relevance to global sustainability objectives. This alignment underscores the potential replicability of the Vytina model in other rural contexts

4.2. Challenges

Despite these achievements, the process encountered significant barriers:

1) Resource limitations: The lack of dedicated funding and technical expertise posed challenges to the implementation of proposed strategies. Insufficient municipal and central government support necessitated reliance on volunteer efforts, prolonging the planning phase [10].
2) Behavioral resistance: Resistance to change among some residents slowed the adoption of sustainability principles. Misconceptions about the benefits of sustainable development and further complicated efforts to build consensus [11].
3) Institutional gaps: The absence of formalized municipal frameworks and inadequate support mechanisms from the central government highlighted systemic challenges. These gaps underscored the need for a clearer regulatory environment and streamlined administrative processes.
4) Time-intensive process: The iterative nature of the bottom-up methodology required sustained commitment from participants over extended periods. Balancing this commitment with daily responsibilities proved challenging for many stakeholders.
5) Lack of shared vision: Overcoming individualistic attitudes and limited familiarity with sustainability principles required extensive community engagement and education.

4.3. Lessons learned

The experience in MU Vytina offers several valuable lessons for advancing participatory planning in rural contexts:

1) Community ownership is critical: Active participation fosters a sense of ownership among residents, enhancing commitment to both planning and implementation phases. Early and continuous engagement is essential for maintaining momentum and trust [22].
2) Holistic approaches yield better outcomes: Addressing sustainability as a multi-dimensional issue—integrating social, economic, and environmental goals—ensures balanced and comprehensive development. The interconnectedness of strategies minimizes conflicts and amplifies synergies.
3) Capacity building is indispensable: Empowering residents with knowledge and skills is foundational to the success of participatory planning. Training in facilitation, data analysis, and strategic thinking equips stakeholders to contribute effectively.
4) Institutional support is essential: Municipal and governmental support, though absent in this case, is crucial for overcoming resource constraints and accelerating progress. Financial incentives, legislative clarity, and technical assistance can significantly enhance the efficacy of bottom-up methodologies.
5) Flexibility facilitates adaptation: Adaptive governance frameworks, characterized by iterative learning and responsiveness to emerging challenges, are vital. Flexibility allows for adjustments that address unforeseen obstacles and evolving priorities.

6) Shared vision as a unifying force: The collaborative development of a shared vision serves as a rallying point, aligning diverse stakeholders and mitigating resistance. Investing time in visioning exercises builds consensus and strengthens community bonds
7) Integrated approaches ensure balanced development across social, economic, and environmental dimensions [9].
8) Educational outreach is crucial for overcoming resistance and embedding sustainability concepts [23].

4.4. Implications for policy and practice

The results from MU Vytina highlight the potential of participatory approaches in driving sustainable development in rural settings. However, the experience underscores the necessity of creating enabling environments through:

- Financial and technical support: Addressing resource gaps to expedite planning and implementation.
- Legislative backing: Providing a clear framework to integrate local initiatives with broader national and global goals.
- Capacity building programs: Institutionalizing training for municipal authorities and community leaders.

The lessons learned offer actionable insights for policymakers and practitioners seeking to replicate the Vytina model in other rural contexts. Establishing structured support systems can bridge the gaps identified and enhance the scalability of participatory planning frameworks.

5. Discussion

5.1. Addressing barriers to bottom-up planning

The Vytina case study highlights the transformative potential of bottom-up planning in fostering sustainable development. However, it also exposes significant barriers that impede the success of such approaches. These challenges, which include resource constraints, behavioral resistance, and institutional gaps, underscore the necessity of municipal and central government support to enhance the efficacy of participatory methodologies.

5.1.1. Resource constraints

The lack of funding and technical expertise in Vytina delayed the planning process and limited the scope of proposed strategies. Without financial support, communities often rely on volunteer efforts, which, while commendable, are insufficient for comprehensive planning and implementation. Establishing dedicated funding streams, such as grants or incentives tied to sustainability projects, could alleviate these challenges and provide the necessary infrastructure for success.

5.1.2. Behavioral resistance

Resistance to change, rooted in misconceptions about sustainability or fear of the unknown, posed additional challenges in MU Vytina. Behavioral change is a gradual process, requiring sustained education and awareness campaigns. The inclusion of participatory visioning exercises in the methodology served as a critical

tool in overcoming these barriers, fostering a shared understanding of the community's long-term aspirations.

5.1.3. Institutional gaps

The absence of formal support from municipal and central governments exposed systemic weaknesses. Clear legislative frameworks and streamlined administrative processes are essential for integrating bottom-up initiatives into broader governance structures. Such alignment ensures that local efforts are not isolated but integrated into a cohesive strategy that balances local autonomy with national and international priorities.

5.2. The role of municipal and central government support

While the MU Vytina case demonstrates the resilience and ingenuity of local communities, it also reveals the limits of what can be achieved in the absence of institutional support. Both municipal and central governments play a pivotal role in bridging resource gaps and facilitating the scalability of participatory approaches.

5.2.1. Municipal support

Municipalities can facilitate sustainable development by offering logistical support, technical expertise, and seed funding for participatory initiatives. However, in MU Vytina, the lack of active municipal involvement highlighted the need for:

1) Capacity building programs: Municipal staff must be trained in participatory methodologies to effectively facilitate community-driven planning.
2) Advisory committees: Establishing local committees comprising residents, municipal representatives, and subject matter experts to guide the planning process.
3) Incentive structures: Encouraging resident participation through recognition programs, financial rewards, or reduced fees for community projects.

5.2.2. Central government support

Central governments are instrumental in creating enabling environments through:

1) Legislative frameworks: Aligning local initiatives with broader policies such as the SDGs and national development goals [24].
2) Financial mechanisms: Introducing grants, subsidies, or co-funding arrangements to reduce the financial burden on municipalities and communities.
3) Monitoring and accountability: Establishing clear metrics to evaluate the success of bottom-up initiatives and ensuring transparency in their implementation.

The compatibility between MU Vytina's goals and the broader legislative framework highlights the potential of participatory approaches to contribute meaningfully to national and international objectives. However, the lack of active integration suggests a missed opportunity to harness the full potential of these methodologies.

5.3. Broader implications for sustainable development

The lessons from MU Vytina extend beyond its local context, offering valuable

insights for the global sustainable development agenda. Participatory planning is not only a tool for fostering community ownership but also a mechanism for ensuring that sustainability initiatives are contextually relevant and socially inclusive.

5.3.1. Alignment with the SDGs

The participatory framework adopted in Vytina resonates with the principles of the 2030 Agenda for Sustainable Development. By deriving goals from the community's shared vision, the process aligns with SDG targets while ensuring local ownership. This approach demonstrates how rural communities can contribute to global objectives while addressing unique socio-economic and environmental challenges.

5.3.2. Scalability of the model

The Vytina model underscores the adaptability of participatory planning frameworks across diverse contexts. However, scaling such models requires:

- Institutionalization of participatory practices: Embedding participatory approaches in governance structures to ensure their longevity.
- Knowledge sharing platforms: Facilitating the exchange of best practices among municipalities to foster innovation and collaboration.
- Contextual adaptation: Recognizing the unique needs and constraints of each community and tailoring the methodology accordingly.

5.4. Theoretical implications

Such alignment ensures that local efforts are not isolated but integrated into a cohesive strategy that balances local autonomy with national and international priorities.

5.4.1. Participatory governance

The MU Vytina case reaffirms the critical role of participatory governance in fostering sustainability. Building on Arnstein's [7] ladder of participation, this study demonstrates how inclusive decision-making processes enhance community ownership and resilience.

5.4.2. Adaptive management

The iterative nature of the planning process aligns with principles of adaptive management, which emphasize flexibility and responsiveness to changing circumstances [25]. This approach is particularly relevant in rural contexts, where socio-environmental conditions often evolve unpredictably.

5.4.3. Systems thinking

By treating the community as a complex system, the methodology ensures that strategies address the interplay between social, economic, and environmental factors. his systems-based approach minimizes conflicts and maximizes synergies, reinforcing the principles outlined by Meadows [17] and Senge [18].

5.5. Practical recommendations

To enhance the effectiveness of bottom-up planning, policymakers and practitioners should consider the following recommendations:

1) Strengthen institutional frameworks: Align local initiatives with national policies through clear legislative guidelines and administrative support [13].
2) Invest in capacity building: Provide training programs for both municipal staff and residents to enhance their ability to contribute meaningfully to sustainability initiatives [23,11].
3) Ensure financial sustainability: Establish funding mechanisms that support the long-term implementation of community-driven plans [6,12].
4) Promote awareness and education: Foster a shared understanding of sustainability principles through targeted awareness campaigns.
5) Encourage multi-stakeholder collaboration: Facilitate partnerships between communities, municipalities, and central governments to leverage collective expertise and resources.

5.6. Future research directions

While this study offers valuable insights, it also highlights areas for future research:

1) Long-term impact assessment: Evaluate the sustainability outcomes of participatory initiatives over extended periods.
2) Comparative studies: Investigate the applicability of the Vytina model in diverse rural and urban contexts.
3) Institutional dynamics: Explore the role of intergovernmental coordination in supporting bottom-up planning efforts.
4) Behavioral change mechanisms: Examine strategies for overcoming resistance and fostering pro-sustainability mindsets among stakeholders.

6. Conclusion

6.1. Summary of findings

The Vytina case underscores the transformative potential of bottom-up planning to address local sustainability challenges effectively. The community-driven approach demonstrated how tailored sustainability goals, derived from a shared vision, could foster resident engagement, ownership, and long-term prosperity. However, the study also highlights significant barriers, including resource limitations, resistance to change, and the absence of robust municipal and government support mechanisms.

6.2. Implications for policy and practice

The absence of direct municipal and government support in Vytina emphasizes the need for strategic interventions to reduce planning periods and overcome barriers. Support systems, including financial incentives, technical training, and regulatory frameworks, are essential for aligning local initiatives with broader national and international sustainability objectives, such as the SDGs.

6.3. Future research directions

Future studies should assess the scalability of Vytina’s approach in diverse

contexts and examine how integrated municipal and government support mechanisms influence the success of bottom-up sustainability initiatives. Long-term research could evaluate the lasting impacts of community-driven planning models on rural development and explore innovative ways to localize global sustainability goals effectively.

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