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IMAGE: OBSERVATORY WITH STAR TRAILS ON MOUNTAINS FOR CLEAR SKY

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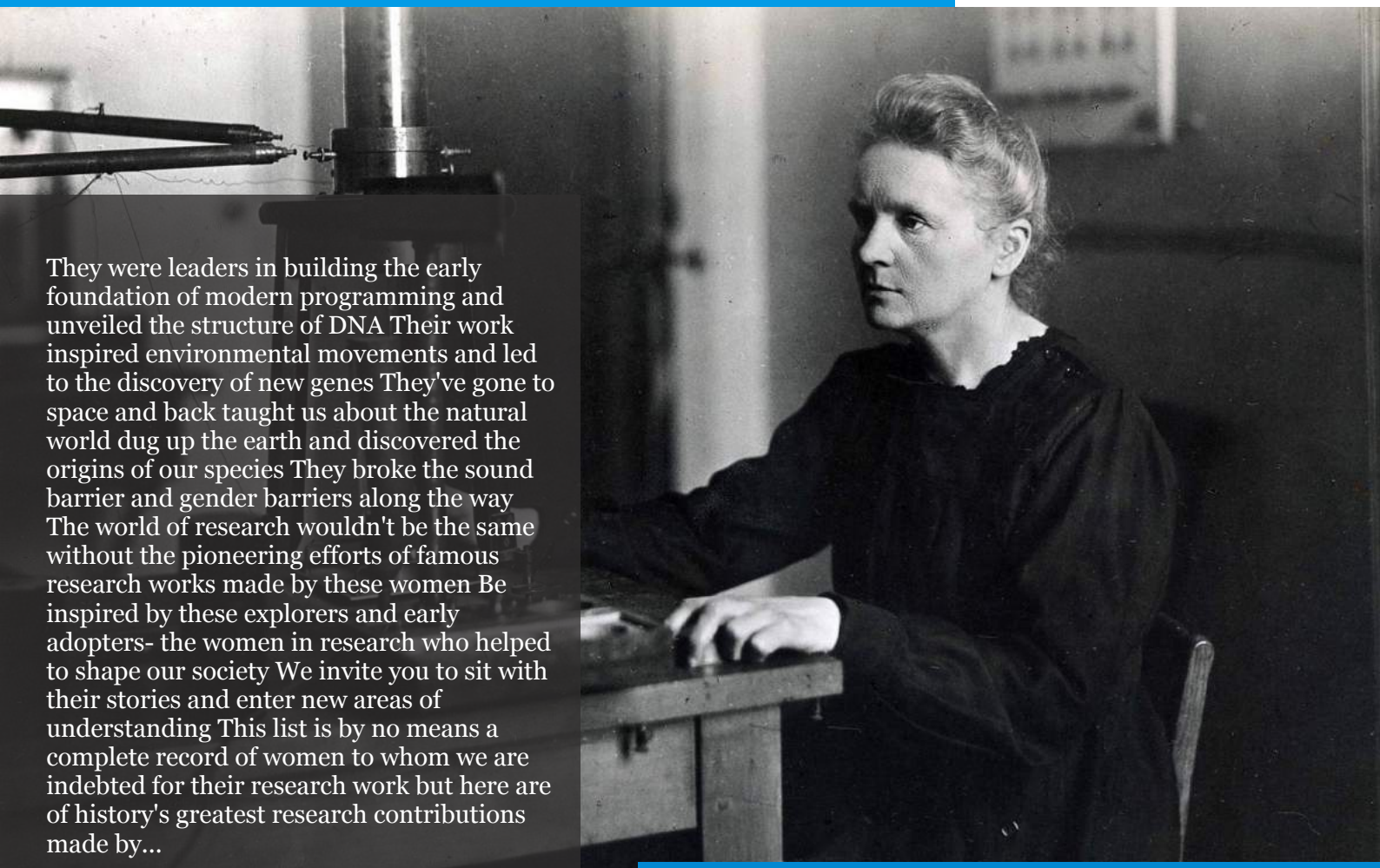
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Effects of Genre-Based Instructional Material on Students' Reading Proficiency

Cindy Pearl M. Quita

Central Mindanao University

ABSTRACT

Genre-Based Instructional Material (GB-IM) is an intervention material that uses the Genre-Based Approach (GBA) to improve the reading proficiency of Grade 7 students for School Year 2022-2023. It follows the four stages of the GBA Model which are: Building Knowledge of the Field (BKOF), Modeling of the Text (MOT), Joint Construction of the Text (JCOT), and Independent Construction of the Text (ICOT), and the design of Research and Development (R&D) by Gall and Borg. This study investigated the effects of Genre-Based Instructional Material (GB-IM) on the students' reading proficiency. Specifically, it sought to determine the level of the teachers' and students' evaluation on the GB-IM, identify the reading proficiency level of the GB-IM and non-GB-IM groups in the pretest and post-test, ascertain if there is a significant difference in the evaluation of the teachers and students on the GB-IM, and assess if there is a significant difference between the pretest and posttest scores in the GB-IM and non-GB-IM groups. Results revealed that teachers and students had higher mean scores on the GB-IM evaluation. Moreover, the students' proficiency level has a significant difference between the GB-IM and Non-GB-IM groups in their mean scores in the post-test results. Though both groups improved their scores, the GB-IM group scored higher compared to the Non-GB-IM group .

Keywords: IM evaluation, genre-based instructional material, reading proficiency.

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Effects of Genre-Based Instructional Material on Students' Reading Proficiency

Cindy Pearl M. Quita

ABSTRACT

Genre-Based Instructional Material (GB-IM) is an intervention material that uses the Genre-Based Approach (GBA) to improve the reading proficiency of Grade 7 students for School Year 2022-2023. It follows the four stages of the GBA Model which are: Building Knowledge of the Field (BKOF), Modeling of the Text (MOT), Joint Construction of the Text (JCOT), and Independent Construction of the Text (ICOT), and the design of Research and Development (R&D) by Gall and Borg. This study investigated the effects of Genre-Based Instructional Material (GB-IM) on the students' reading proficiency. Specifically, it sought to determine the level of the teachers' and students' evaluation on the GB-IM, identify the reading proficiency level of the GB-IM and non-GB-IM groups in the pretest and post-test, ascertain if there is a significant difference in the evaluation of the teachers and students on the GB-IM, and assess if there is a significant difference between the pretest and posttest scores in the GB-IM and non-GB-IM groups. Results revealed that teachers and students had higher mean scores on the GB-IM evaluation. Moreover, the students' proficiency level has a significant difference between the GB-IM and Non-GB-IM groups in their mean scores in the post-test results. Though both groups improved their scores, the GB-IM group scored higher compared to the Non-GB-IM group.

Keywords: IM evaluation, genre-based instructional material, reading proficiency.

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I. INTRODUCTION

In recent years, the Genre-Based Approach (GBA) has gained significance in improving students' reading comprehension [1]. Reading is an imperative skill that needs to develop among students in learning across subject areas. It is more than just a skill because it opens a wider learning horizon. The measure of students' reading proficiency includes reading fluency and reading comprehension.

The Philippines was found to have the highest education poverty rate among students in the ASEAN region, standing at 90.9% [2]. Additionally, the result of English proficiency of Filipino students is very low and ranks lowest in the 2018 Programme for International Students Assessment (PISA) among 79 countries [3]. The country's average score was only 340 points in reading, and it did not reach a minimum level of proficiency in reading, indicating a significant number of low performers compared to other PISA-participating countries and economies. This alarming educational crisis has disturbed the Department of Education (DepEd) in all grade levels for this implied learning poverty which can greatly affect the attainment of quality education.

In Dologon National High School- Kiharong Annex, among Grade 7 learners, there are 68% of students belong to the frustration level and 19% are struggling readers who imperatively need appropriate help. This is very evident in the result of the 2022-2023 Philippine - Informal Reading Inventory (Phil-IRI) pre-reading assessment conducted by the reading teachers at the school [4]. The students may seem to have a poor reading proficiency level due to a lack of knowledge, skills, and strategies. Consequently, the persistent challenge with students' reading proficiency adversely impacts their academic

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performance. To address this issue, educators must implement appropriate reading strategies and provide substantial reading instructional materials to enhance students' literacy skills.

Instructional resources play a significant role in enhancing the performance of students in the English Language [5]. They are powerful scaffolds to teach the language effectively. Teachers in the field are encouraged by DepEd to conduct intervention programs to bridge the learning gaps and promote learning recovery programs. Hence, the researcher decided to develop teacher-made instructional materials that could be advantageous in this current educational situation.

Several investigations on various methods aimed at improving reading comprehension have been conducted over time, and findings consistently demonstrate a substantial impact of these approaches on both students' reading comprehension and motivation. However, reading problems continue to exist and even worsen. Thus, a modification of those strategies such as the use of a Genre-Based Approach (GBA) to be integrated into instructional material to improve the student's reading proficiency is worth investigating. According to Hyland, the GBA significantly enhances language learning by focusing on language, content, and contexts, offering students valuable skills for successful adaptation to diverse academic settings in various disciplines [6]. The significance of instructional materials (IMs) in the teaching and learning process is crucial, as they contribute to the completeness and functionality of the educational experience [7].

The implementation of GBA in language instruction, whether in English as a Second Language (ESL) or English as a Foreign Language (EFL) settings, yielded notable results in enhancing students' reading comprehension.

The context of the mentioned problem concerning students' reading predicaments, especially in reading proficiency and with the current educational learning poverty prompted the researcher to develop this Genre-Based Instructional Material (GB-IM). The innovative IM aimed to determine the level of the teachers' and students' evaluation on the GB-IM, identify the reading proficiency level of the GB-IM and non-GB-IM groups in the pretest and post-test, ascertain if there is a significant difference in the evaluation of the teachers and students on the GB-IM, and assess if there is a significant difference between the pretest and posttest scores in the GB-IM and non-GB-IM groups.

II. METHODOLOGY

This paper employed a quasi-experimental research design where one group (experimental) with 38 students utilized the GB-IM, while the other group (control) with 36 students was exposed to the Non-GB-IM in the teaching of Expository Texts. The study followed the formal communication procedure in conducting the research.

Coin tossing was a technique done to decide which section would be assigned to the GB-IM or non-GB-IM group. The development of the GB-IM was based on the adopted steps of R&D model design by Gall and Borg. The eight steps of the R&D cycle were employed in the study: (1) need analysis (in Gall and Borg's model it is called research and information collecting); (2) development of material (it is planning and developing the preliminary form of the product); (3) Expert's validation; (4) First Revision (main product revision); (5) Try-out (main field testing/piloting); (6) Revision (operational product revision); the final product; and (8) dissemination and implementation [8].

This research is methodically designed as Research and Development (R&D). They define R&D as a development model in which findings of the research are used to develop new products and procedures that meet specified criteria of effectiveness, quality, or similar standards through systematic field tests,

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evaluations, and revisions. The material developer should consider the teaching-learning procedures, processes, and products as well. It is a process that is used to validate educational products.

The GB-IM was developed following the four stages of the GBA model that include: 1) Building of Knowledge of the Field (BKOF); 2) Modeling of the Text (MOT); 3) Joint Construction of the Text (JCOT); and 4) Independent Construction of the Text (ICOT). Also, it did use the KWL technique that activated the prior knowledge of the students and helped them establish a purpose for the lessons. Moreover, the content of the IM particularly the integration of GBA was evaluated by subject experts using the Modified Rubric for Evaluating Reading/Language Arts Instructional Materials for Kindergarten to Grade 5 [9]. The inter-rater reliability was also employed in the study particularly Cramer's V to evaluate the extent to which the GB-IM evaluators agree in their assessment of the instructional material. The researcher adopted the DepEd's Phil-IRI computation to analyze and interpret the students' reading proficiency which included the students' fluency and comprehension.

In addition, 16-item comprehension (pre- and post-) tests from the Phil-IRI Manual were utilized to assess the reading comprehension level of the students. On the other hand, the IM evaluation of the GB-IM was determined through the adapted survey questionnaire checklist [10] and made use of a Likert scale. Furthermore, descriptive statistics such as mean, percentage, and frequency were used to describe the students' reading proficiency level and the teachers' and students' IM evaluation. The inferential statistics specifically the use of an independent t-test was utilized to ascertain if there is a significant difference in the evaluation of the teachers and students on the GB-IM and the use of ANCOVA to assess if there is a significant difference between the pretest and posttest scores in the GB-IM and non-GB-IM groups.

III. RESULTS & DISCUSSION

Table 1 shows the teachers' and students' evaluation of the GB-IM. The measure of the teachers' and students' evaluation was obtained from the frequency and percentage of their ratings. The basis for interpreting the rating of the teachers and participants is from the Modified Rubric for Evaluating Reading/Language Arts Instructional Materials for Kindergarten to Grade 5 [9].

It reflects the consolidated responses of the 3 teachers and 38 students on the evaluation of the GB-IM. It indicates that the majority of the means in the ten (10) indicators in both teachers and students obtained the "Strongly Agree" or equivalent to "The criteria were completely met" in their evaluation of the GB-IM. Although the teachers' evaluation obtains a higher mean of 4.90 (Strongly Agree) than the students' evaluation with a mean of 4.57 (Strongly Agree), both evaluations imply that they both agreed that the GB-IM completely met the criteria.

The teachers' evaluation has the highest mean scores of 5.00 for eight (8) indicators except for indicator 1 (Material uses scaffolding and stimulating questions to engage in high-quality discussions) with a mean score of 4.33 and indicator 2 (Material provides opportunities to adhere the 4 stages of GBA model: 1) Building Knowledge of the Field (BKOF), 2) Modeling of the Text (MOT), 3) Joint Construction of the Text (JCOT), and 4) Independent Construction of the Text (ICOT) of expository text or informational text) with a mean score of 4.67.

On the other hand, the students' evaluation has its lowest mean score of 4.32 in indicator 9 (Content is aligned with reading comprehension for informational texts and text complexity for grade 7 frustration readers) which is equivalent to "Agree" or "The criterion was substantially met" while the remaining nine (9) indicators have a rating evaluation of more than "4.50" which could be rounded off to "5.00" which has a descriptive rating of "Criterion was completely met".

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The results of the study imply that teachers and students have higher evaluation ratings on the instructional material (GB-IM) because they found it motivating, simple, clear, and interesting. The study on the use of graded materials for children with reading difficulties mentioned the use of colorful and attractive pictures helped keep students' interest in further reading the materials [11]. As a result, children increased their reading interest and confidence which eventually improved their reading skills. This is in line with the study of [12] which explored the effect of an innovative and creative IM in teaching among grade IX students in a mountain school in Cebu City, Philippines. The study argued that SIM-based teaching is a more effective approach than the modular approach in improving the students' performance.

In addition, the findings of [13] confirmed that instructional materials contributed to the variation in learners' English reading literacy in primary schools. The arguments imply that failure to provide quality instructional materials to students affects the substantial outcome of learning. Furthermore, the study of [14] on the development of reading skills of students having difficulty in reading through enrichment programs concluded that to develop the reading skills of the students, the construction of an appropriate reading environment and enrichment of reading programs can be effective.

Generally, the overall finding reveals that both the teachers and students have a higher evaluation rating on the GB-IM.

It reveals that they both "Strongly Agree" that the criteria were met in the development of the GB-IM which consequently helped in improving the reading comprehension of the students.

Table 1: Mean scores of teachers' and students' evaluation of the (Genre-Based Instructional Material)

Indicators		Teachers		Students	
		MEAN	VD	MEAN	VD
1	Material uses scaffolding and stimulating questions to engage in high-quality discussions.	4.33	A	4.68	SA
2	Material provides opportunities to adhere the 4 stages of GBA model: 1) Building Knowledge of the Field (BKOF), 2) Modeling of the Text (MOT), 3) Joint Construction of the Text (JCOT), and 4) Independent Construction of the Text (ICOT) of expository text or informational text.	4.67	SA	4.70	SA
3	Material markedly increases the opportunity for regular independent reading of texts that appeal to students' interests to develop both knowledge and love of reading.	5.00	SA	4.51	SA
4	Specific texts are included in materials for teaching various text structures (for example, sequence, comparison, contrast, and cause/effect) to support comprehension and careful reading of narrative and informational text	5.00	SA	4.78	SA
5	Texts provide the opportunity for students to build knowledge through reading and extended discussion	5.00	SA	4.65	SA
6	Material supports instruction that teaches students to identify and describe or explain ideas for informational text (for example, connections between ideas and concepts) in a progressively more complex manner	5.00	SA	4.51	SA

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7	Material supports instruction that teaches students to use the features of text to gain meaning from informational text (for example, use of illustrations and graphs, and structural elements) with increasing complexity	5.00	SA	4.49	SA
8	Material supports instruction that teaches students to understand and analyze various points of view for informational text (for example, what the author wants to explain and multiple accounts of the same event) with increasing complexity	5.00	SA	4.54	SA
9	Content is aligned with reading comprehension for informational texts and text complexity for grade 7 frustration readers	5.00	SA	4.32	A
10	Content is aligned with language development and skills for grade 7 frustration readers	5.00	SA	4.51	SA
OVERALL MEAN		4.90	SA	4.57	SA

Legend:

Scale	Verbal Description (VD)	Qualitative Interpretation (QI)
5	Strongly Agree (SA)	The criterion was completely met.
4	Agree (A)	The criterion was substantially met.
3	Moderately Agree (MD)	The criterion was adequately met.
2	Disagree (D)	The criterion was partially met.
1	Strongly Disagree (SD)	The criterion was not met.

Table 2 shows the pretest and post-test percentage scores of the GB-IM and non-GB-IM groups. The measure of the students' reading proficiency is obtained from the frequency and percentage of their scores in the pretest and posttest. The basis for interpreting the scores of the students is the PHIL-IRI Manual [15].

The result of the study divulges that the GB-IM group outscored the students in the Non-GB-IM group since there was an improvement in the reading proficiency level after the given intervention. Moreover, it was indicated that most of the students in the GB-IM group moved to the instructional level. The GBA intervention material helped them comprehend the text better as they were exposed to the four stages of the GBA model [16-18]. Consequently, the GB-IM provided them with the background knowledge of the text, displayed them the model of the text, and allowed them to work and learn with others before they had to work individually. It coheres with the claim that the teaching genre can help students how to interact with others [19]. GBA is an effective tool to improve students' cognitive processes and critical thinking about the order and linguistic features of the moves of text types [20].

One of the reasons why the students were less aware of these lexico-grammatical concepts (both textual meaning and experiential learning) was because they lacked adequate experience to know how to use the target generic texts during the lessons [21]. For that reason, it is significant to teach explicitly the text structures to the students.

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For instance, the effects of the Strategic Intervention Material (SIM) on the achievement of a selected group of public-school students in Agusan Del Norte revealed a significant increase in improving the least-learned competency of the learners [22].

Table 2: Pretest and posttest percentage scores of students' reading proficiency

Descriptive Level	GB-IM Group				Non-GB-IM Group			
	Pretest		Posttest		Pretest		Posttest	
	N	%	N	%	N	%	N	%
Independent	0	0	2	5.30	0	0	0	0
Instructional	3	7.90	20	52.60	3	8.33	5	13.89
Frustration	35	92.10	16	42.10	33	91.67	31	86.11

The results of the present study show that students exposed to Genre-Based Instructional Material (GB-IM) were observed to improve their reading proficiency as manifested in their scores. Thus, it is important to use a strategy that would suit the learning abilities of the learners at the same time provide them with instructional material that would motivate them to learn better.

Table 3: Difference between the teachers' and students' evaluation of the GB-IM

Group	N	M	(SD)	t-value	
Teachers *Students*	3 38	4.90 4.57	.1000 .2537	-2.215	.033*

**Significant at p<.05*

Table 3 shows that the teachers' evaluation has a mean score of 4.90 which is relatively higher compared to the students' evaluation which has 4.57. Although there is a slight difference in the mean scores, this generally means that both have an evaluation rating equivalent to "Strongly Agree" with the descriptive rating of "The criterion was completely met".

The table also presents a t-value of -2.215 and a probability value of 0.33 which indicates that there is a significant difference between the teachers' and students' evaluation of the GB-IM. This means that the teachers' evaluation of the GB-IM is significantly higher than the students' evaluation. Hence, the hypothesis "there is no significant difference between the teachers' and students' evaluation on GB-SIM is rejected.

The significant result of the study is in support of the previous research [23] shows that teachers have leeway to determine whether the supplemental materials are aligned with the standards and with the goals of the classroom, grade level, and school. Teachers knew the importance of developing their professional judgment to select supplemental materials to enhance the quality of instructions.

Students' evaluation on the GB-IM is slightly lower compared to the teachers but still equivalent to "Strongly Agree" or "The criterion was completely met" because they find the material engaging and relevant. This in line with the study of [10] showed that students have a very high evaluation on the use of Strategic Intervention Material (SIM) because they found it enjoyable and interesting and developed a positive attitude towards learning. Students became motivated when they believed they could be effective in reaching the desired goals under their control [24]. It would consequently inspire and encourage them to learn more concepts about the topic. The finding of the study implies that

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Genre-Based IM employed scaffolding, stimulating questions, developing knowledge, encouraging the love for reading, and reading appropriateness for the students' level as evidenced by their responses in the 10 indicators. The students were able to comprehend the text better because the expository text features were explicated in terms of description, sequence, comparison, cause and effect, problem, and solution. Also, the explicit teaching of each structure which includes its descriptions, cue/signal words, examples, and graphic organizers consciously raised students' awareness and significantly contributed to their better reading comprehension.

The result reveals that students in the experimental group enjoyed reading and doing all the activities in the GB-IM because it offered interesting activities in the Building Knowledge of the Field, Modeling of the Text, Joint Construction of the Text, and the Independent Construction of the Text. This is in congruence with the finding of [25] which indicated that the integration of reading skills in the development of SIMs may facilitate learning since students are actively engaged and participate in activities that connect to real-life experiences. It is remarkable to note that the present study is focused on the expository text which means that the students deal with factual information which they found interesting and enjoyable. In addition, as prescribed, reading interventions should use texts with topics that are familiar to the learners, so they will have notable support and background to access the reading texts and comprehend them [26].

Moreover, instructional materials that captivate the students' attention and make them available would surely produce an effect that contributes to successful a learning outcome [10]. With that, the teaching of reading skills relies on the availability, quality, and utilization of relevant instructional resources and the skill of the teacher [7]. They argued that it is because instructional materials facilitate the understanding of the difficult concepts of the lessons as well as the teaching and learning of the reading skills to make the learners understand and follow the materials more easily. The GB-IM which was utilized in the study provided an opportunity for the students to set up their own pace without being pressured about the time since they were allowed to finish some of the activities at home.

The remarkable students' evaluation on the use of GB-IM is also parallel to the findings of [27] presented their study at the DLSU Research Congress in 2019 at De La Salle University, Manila, Philippines on the "Effectiveness of Competency-Based Strategic Intervention Materials in English 7". The authors observed in the study that learners enjoyed and learned as they went along with the IM. They have improved their least mastered skills and even developed their passion for reading.

The overall finding shows that the GB-IM has a very high evaluation rating for both teachers and students but there is a slight significant difference in their evaluation with the GB-IM.

Table 4: Difference between the Pretest and Posttest Scores of the GB-IM and non-GB-IM Groups

GROUP	N	Mean			Std. Deviation
GB-IM	38	1.63			0.589
Non-GB-IM	36	1.13			0.350
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Group	4.570	1	4.57	28.770	0.000
Covariate (Pretest)	5.870	1	5.87	36.952	0.000
Error	11.278	71	0.159		
Total	165.000	74			

P< significant at 0.05 level.

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The finding indicates that the GB-IM group has a higher mean of 1.63 compared to the non-GB-IM group which has 1.13. It further reveals the probability value of 0.000 which indicates that there is a significant difference in the students' reading proficiency level between groups. This means that the reading proficiency level of the GB-IM group is significantly higher compared to the other group.

The significant result of this study supports the claim of [28] that the classification of the genre as text type is claimed to be particularly helpful to students as it provides a means of understanding different features of the target genres. Besides, according to Henry and Roseberry, the procedure appears to have increased the awareness of the participants in terms of the generic structures and this awareness may have made it easier for the participants to organize and incorporate different elements to achieve their communicative goals, resulting in more elaborate products [29].

Furthermore, it is consistent with the study of Toledo as cited in [30] which showed that a genre-based framework for teaching reading skills is beneficial for reading comprehension. Also, a study by [31] stated that one can only be creative once he understands the conventions of the genre very well. It was affirmed in the study of [32] which mentioned that the genre-based approach allows individual variations and is not fixed and not a rule-governed pattern. This implies that knowledge of the structures of the target genre could contribute meaningfully to a better comprehension of the text. The present study shows that the experimental group outperformed the control group as they were motivated and actively involved in the learning process. This improvement in the reading proficiency level of the students in the experimental group can be attributed to the four stages of the GBA model which include: 1) Building of Knowledge of the Field (BKOF); 2) Modeling of the Text (MOT); 3) Joint Construction of the Text (JCOT); and 4) Independent Construction of the Text (ICOT). Besides, the KWL comprehension technique used contributed to the enhancement of the students' reading comprehension. The technique helped in the activation of the prior knowledge of students and helped them develop their purposes for reading expository texts.

In addition, the significant increase in the mean score of the students who are exposed to the Genre-Based Approach is similar to the findings of the study of [33] which investigated the effect of scientific and genre-based approaches on English reading comprehension among 144 students of eighth grade SMP Negeri 1. The findings of the study showed significant results in the implementation of the approaches to the students' reading comprehension which led to a better comprehension ability of the students after 12 meetings of treatments using those approaches.

Moreover, the positive effect of Genre-Based Instructional Material (GB-IM) on the students' reading comprehension is in congruence with the findings of [34] in the implementation of GBA in reading intervention among 40 Columbian HS learners. The results showed that GBA was highly effective in developing the reading competence of students while displaying work collaboration, active participation, and discovery of their strengths and showed engagement in the reading process. The finding of the study also is congruent with the claim [16] that the implementation of GBA in the teaching of reading following its four stages in senior high school showed a good contribution to the students' language proficiency.

On the other hand, the result of this study is in contrast with [35] wherein 80 Iranian EFL learners were examined on the effect of genre structure on their reading comprehension ability. The data from the study indicated that there was an effect on the reading ability to the instruction of narrative text structure but not in the structure of the expository text. It argued that writing expository texts tends to be arduous because they contain content-specific vocabulary that may be unknown to the reader and there is often insufficient background information to make sense of new information. Thus, it is very important to provide a reading strategy that would suit the students' needs and interests, such as GBA in addressing their reading problems.

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Furthermore, the use of instructional material plays a significant role in the teaching-learning process. This means that students need effective instructional materials that motivate them to learn better. When students become motivated, they can be effective in reaching the desired goals under their control with expended effort [10].

IV. CONCLUSIONS & RECOMMENDATIONS

Based on the findings of the study, the following conclusions were formulated:

First, the overall GB-IM evaluation of the teachers and students were both "Strongly Agree" or equivalent to "The criterion was completely met". This only means that both have higher mean scores in the evaluation of the GB-IM.

Second, the majority of the students from the GB-IM and non-GB-IM groups belonged to the frustration level in the pretest, however, in the post-test, progress is noted. It was observed that more students in the GB-IM group moved to the instructional level and independent level compared to the non-GB-IM group. Thus, the GB-SIM group has a higher reading proficiency increase compared to the non-GB-IM group.

Third, there was a significant difference between the teachers' and students' evaluations on the GB-IM. Thus, this implies that teachers' evaluation on the GB-IM is significantly higher compared to the students' evaluation.

Lastly, there was a significant difference between the pretest and posttest scores of the GB-IM and non-GB-IM groups after the interventions. Hence, the result showed that the use of GB-IM (experimental group) has a higher significant effect on students' reading proficiency compared to the use of non-GB-IM (control group).

Hence, curriculum developers may integrate the Genre-Based Approach (GBA) in the development of instructional materials which would boost students' interest in learning the target language. Teachers are encouraged to consider the use of GB-IM as instructional material for it provides an opportunity to improve students' reading proficiency. Reading and English teachers may utilize GB-IM in the teaching of reading for it improves students' reading proficiency which includes fluency and comprehension. School administrators and curriculum implementers may encourage teachers to develop instructional materials with the integration of appropriate approach/es and by adopting the steps in IM development such as the Research and Development model.

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Optimizing Energy Systems in Chinese Industries: The Role of ESG Metrics in Enhancing Sustainability and Efficiency

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ABSTRACT

This research delves into the critical role of Environmental, Social, and Governance (ESG) metrics in optimizing energy systems within Chinese industries from 2006 to 2020. By harnessing comprehensive datasets from the China Energy Yearbook and Bloomberg, we conduct a detailed analysis of ESG practices across diverse sectors and regions, correlating them with key energy metrics. Our approach utilizes a range of advanced statistical and analytical methods to unravel the multifaceted ESG-energy relationship. Through sophisticated regression analysis, we quantify the impact of ESG metrics on energy efficiency and sustainable practices. We leverage cutting-edge machine learning algorithms, including deep learning and ensemble methods, to predict future energy development trends. Additionally, network analysis and agent-based modeling offer insights into the complex interplay between ESG factors and energy dynamics. Employing advanced econometric tools like VAR and Panel Data Analysis, our study provides both temporal and cross-sectional perspectives on energy optimization in the context of ESG initiatives. The results indicate notable variations in ESG adoption and energy efficiency across different industries and regions, highlighting the imperative for customized sustainability strategies.

Keywords: energy optimization,sustainable energy practices,esg metrics integration,chinese industrial energy,environmental efficiency,econometric energy analysis.

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ABSTRACT

This research delves into the critical role of Environmental, Social, and Governance (ESG) metrics in optimizing energy systems within Chinese industries from 2006 to 2020. By harnessing comprehensive datasets from the China Energy Yearbook and Bloomberg, we conduct a detailed analysis of ESG practices across diverse sectors and regions, correlating them with key energy metrics. Our approach utilizes a range of advanced statistical and analytical methods to unravel the multifaceted ESG-energy relationship. Through sophisticated regression analysis, we quantify the impact of ESG metrics on energy efficiency and sustainable practices. We leverage cutting-edge machine learning algorithms, including deep learning and ensemble methods, to predict future energy development trends. Additionally, network analysis and agent-based modeling offer insights into the complex interplay between ESG factors and energy dynamics. Employing advanced econometric tools like VAR and Panel Data Analysis, our study provides both temporal and cross-sectional perspectives on energy optimization in the context of ESG initiatives. The results indicate notable variations in ESG adoption and energy efficiency across different industries and regions, highlighting the imperative for customized sustainability strategies. This study significantly contributes to the sustainable energy discourse, underscoring the integration of ESG metrics as a pivotal element in shaping efficient and environmentally-conscious energy policies and practices within the rapidly evolving Chinese industrial framework.

Keywords: energy optimization,sustainable energy practices,esg metrics integration,chinese industrial energy,environmental efficiency,econometric energy analysis.

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I. INTRODUCTION

In the evolving landscape of global energy dynamics, the integration of Environmental, Social, and Governance (ESG) metrics with energy development has garnered unprecedented attention, particularly within the context of rapidly industrializing countries like China. This surge of interest is warranted as the transition to sustainable energy systems becomes critical against climate change concerns and shifting policy directives. The intricate relationship between ESG factors and energy dynamics in industrial sectors, especially in China—a global frontrunner in industrialization and energy consumption—is ripe for exploration. This study, situated within the domain of energy engineering and research, seeks to illuminate this intersection, with a specific focus on the Chinese industrial landscape. The interplay between ESG metrics and energy development is complex and multifaceted. Existing research extensively highlights the significance of renewable energy sources, like wind and solar power,

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in fostering sustainable energy transitions (Galimova, Satymov, Keiner, & Breyer, 2024; Daxini & Wu, 2024). These studies underscore the role of technological advancements and environmental considerations in shaping energy systems. However, there is a significant gap in understanding how these advancements interact with social and governance aspects within the energy sector, particularly in China's diverse and rapidly evolving industrial ecosystem. Furthermore, the literature indicates that methods of energy extraction and utilization, such as geothermal energy in the Gonghe Basin (Hou et al., 2024) or the in-situ pyrolysis of oil shale (Zhang et al., 2024), have substantial implications for energy efficiency and environmental impact. These insights highlight the need for optimizing extraction methods and understanding their ecological footprints, thus contributing to sustainable industrial practices. The concept of energy conservation at the workplace, explored by Ahuja and Puppala (2024), introduces an organizational dimension to energy sustainability, resonating with the governance component of ESG metrics. Similarly, the work by Lin and Teng (2024) on the moderating effect of digitization on carbon emission intensity in industrial chains underlines technological innovation's potential to mitigate environmental impacts.

Moreover, the focus on biomass energy projects (Gao et al., 2024) and energy-saving potential in heating systems (Lu et al., 2024) expands the spectrum of sustainable energy practices. These studies contribute to a more comprehensive understanding of renewable energy sources and their practical applications, reinforcing the need for multi-dimensional analysis in energy research. This backdrop informs our primary research question:

How do ESG metrics influence energy efficiency, conservation, and sustainability practices across different industries in China? This question guides our exploration of the complex interdependencies between ESG factors and energy dynamics. Our research aims to synthesize these diverse perspectives into a cohesive narrative focused on China's industrial context, making a novel contribution by integrating disparate elements and employing advanced statistical and analytical models. This approach fills the identified gaps in the literature and promises significant insights for policymakers, industry stakeholders, and the academic community, advancing sustainable energy practices in the context of ESG metrics. Following this introduction, the paper is structured as follows: Section 2 reviews relevant literature, setting the stage for the hypothesis development in Section 3. Section 4 articulates the research methodology, Section 5 discusses the findings,

II. LITERATURE REVIEW

2.1 Renewable Energy Sources and Technological Advancements

The pivot towards renewable energy sources and their technological advancements forms a cornerstone of sustainable energy transitions. Galimova et al. (2024) illustrate the global implications of such transitions by exploring Greenland’s potential as a renewable energy exporter, which is crucial for understanding sustainable energy dynamics. Complementing this, Daxini and Wu (2024) provide a thorough review of solar spectral influences on photovoltaic performance, highlighting the importance of technological nuances in renewable energy production. These studies underscore the environmental component of ESG metrics and their critical role in shaping modern energy systems.

2.2 Energy Extraction and Utilization Methods

Energy extraction and utilization methods significantly influence both energy efficiency and environmental impact. The work of Hou et al. (2024) in geothermal energy extraction in the Gonghe Basin exemplifies this, offering insights into the ecological footprints of such methods. Zhang et al. (2024) further contribute to this discourse through their investigation of oil shale pyrolysis, highlighting the need for optimization to enhance both efficiency and environmental sustainability.

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2.3 Organizational and Governance Aspects of Energy Conservation

The role of corporate and organizational practices in energy conservation is explored by Ahuja and Puppala (2024), who introduced the Workplace Energy Conservation Index (WECI). This study aligns with the governance aspect of ESG metrics, emphasizing organizational strategies in energy sustainability. Similarly, Lin and Teng (2024) delve into the moderating effects of digitization on carbon emission intensity, linking technological innovation with governance and policy in energy practices.

2.4 Practical Applications of Renewable Energy Sources

Focusing on practical applications, Gao et al. (2024) discuss the site selection for biomass energy projects, offering a sustainable perspective on energy demand and environmental protection. Lu et al. (2024) examines energy-saving potentials in heating systems, providing alternative solutions for energy efficiency in specific climatic conditions. These studies enrich our understanding of the practical implementation and impact of renewable energy sources.

2.5 Gaps in Current Literature and Need for Multi-Dimensional Analysis

Despite these comprehensive studies, there is a noticeable gap in the literature concerning an integrated analysis of ESG metrics within China's industrial sectors. Most research tends to isolate individual ESG aspects or specific energy technologies, lacking a holistic exploration of their interplay in an industrial context. This gap is particularly evident in the need for advanced modeling techniques to analyze complex interdependencies within rapidly evolving industrial ecosystems like China's.

III. THEORETICAL FRAMEWORK

The intersection of Environmental, Social, and Governance (ESG) metrics with energy development is a nuanced area of study underpinned by several key theories. Sustainable development theory, a cornerstone in this field, posits the need for balancing environmental protection, social equity, and economic growth, crucial for understanding the multidimensional impact of ESG metrics (Magnér S. 2020). Furthermore, the concept of corporate social responsibility (CSR) is pivotal in examining governance practices within the energy sector, offering insights into how corporations can contribute to sustainable energy goals (Carroll, 1991). Theories surrounding energy policy, especially in the context of China's rapid industrialization, provide a lens to understand the regulatory and policy frameworks influencing energy practices (Cheng H, Hu Y.2010). These theoretical foundations are instrumental in framing the study's approach to exploring ESG metrics within China's energy landscape.

3.1.1 Contextual Background of China's Energy Sector

China's energy sector, characterized by its massive scale and rapid transformation, presents a unique landscape for the application of ESG metrics. The nation's journey from heavy reliance on fossil fuels to increasing adoption of renewable energy sources marks a significant shift in its energy paradigm. This transition, while pivotal for global sustainability efforts, is fraught with challenges such as balancing economic growth with environmental conservation and managing the social implications of energy policy changes (Zhou et al., 2010). Understanding these dynamics is essential for contextualizing our study within the broader narrative of global and national energy trends.

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3.1.2 Review of Advanced Modeling Techniques

In navigating the complexities of ESG metrics' impact on energy dynamics, our study employed a suite of advanced and novel modeling techniques, alongside robust mathematical models, to offer unparalleled insights:

Regression Analysis: Linear and multiple regression analyses were utilized to examine the relationships between ESG metrics and energy outcomes. This technique helped in quantifying the extent to which variations in ESG metrics can explain changes in energy efficiency and sustainability practices.

Predictive Analytics with Machine Learning: Beyond conventional machine learning approaches, we integrated state-of-the-art algorithms like deep learning and ensemble methods. These techniques, known for their ability to handle large datasets and uncover intricate patterns, were pivotal in predicting future trends and behaviors in energy development and ESG metrics integration.

Network Analysis for ESG Interdependencies: Utilizing network analysis, we mapped and analyze the intricate web of relationships between various ESG factors and energy outcomes. This approach helped reveal the systemic interdependencies and influence patterns that traditional analyses might overlook.

Agent-Based Modeling (ABM): ABM were used to simulate the interactions of agents (industries, government bodies, etc.) within the Chinese energy sector. This allows us to understand the emergent behaviors from the bottom-up and see how individual decisions and interactions lead to complex system-level outcomes.

Advanced Econometric Models: We employed cutting-edge econometric models, such as Vector Autoregression (VAR) and Panel Data Analysis, to quantitatively assess the dynamic relationships over time and across different industries and provinces.

Mathematical Modeling of Energy Systems: Building custom mathematical models enable us to precisely quantify the impact of various ESG metrics on energy efficiency and sustainability. These models were designed to integrate complex variables and parameters specific to China's energy sector, providing a tailored analytical approach.

Scenario Analysis through System Dynamics Modeling: To explore various future scenarios in China's energy sector, system dynamics modeling was used. This helps us in understanding the long-term implications of different ESG strategies under various policy and environmental conditions. Each of these methods is chosen for its ability to dissect the multi-layered relationship between ESG metrics and energy development, ensuring that our analysis is not only comprehensive but also at the forefront of methodological innovation.

3.1.3 Preliminary Discussion on Data Sources

The study utilizes two comprehensive datasets: one focusing on ESG metrics across various industries and provinces in China, and the other detailing energy-related metrics in these contexts. These datasets provide a rich source of information for analyzing the interdependencies between ESG factors and energy dynamics. The data spans several years from 2006 to 2020 allowing for an in-depth temporal analysis, and covers multiple industries, offering a broad perspective on the industrial application of ESG metrics in relation to energy practices. This preliminary overview sets the stage for a detailed exploration in the methodology section.

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3.2 Hypotheses

Hypothesis 1: ESG Metrics and Renewable Energy Adoption

H1: Higher ESG metrics in industries are positively correlated with increased adoption of renewable energy sources.

This hypothesis is informed by the findings of Galimova et al. (2024) and Daxini & Wu (2024), who highlight the significance of renewable energy in sustainable transitions. The hypothesis posits that industries with higher ESG scores, indicative of stronger environmental commitments, are more likely to adopt renewable energy technologies. This aligns with sustainable development theories, suggesting that environmental stewardship drives renewable energy initiatives.

Hypothesis 2: ESG Metrics and Energy Efficiency in Industrial Processes

H2: Industries with higher ESG ratings demonstrate greater energy efficiency in their operations.

Drawing from the studies by Hou et al. (2024) and Zhang et al. (2024), which emphasize the need for optimizing energy extraction methods, this hypothesis proposes that industries with robust ESG practices will exhibit more energy-efficient operations. It aligns with the concept of corporate social responsibility, where efficient energy use is seen as part of broader responsible industrial practices.

Hypothesis 3: Organizational ESG Practices and Workplace Energy Conservation

H3: Strong governance components of ESG metrics are associated with more effective workplace energy conservation strategies.

Based on Ahuja and Puppala's (2024) exploration of workplace energy conservation, this hypothesis suggests that organizations with better governance (as part of ESG metrics) will have more effective energy conservation measures in place. It reflects the role of organizational structures and policies in facilitating energy sustainability.

Hypothesis 4: Impact of Digitalization on ESG and Energy Dynamics

H4: The integration of digital technologies in industries positively influences the relationship between ESG metrics and energy sustainability.

Informed by Lin and Teng's (2024) work on digitization and carbon emissions, this hypothesis explores the moderating role of digital technologies in enhancing energy sustainability within the framework of ESG metrics. It posits that digitalization can be a catalyst in strengthening ESG practices, particularly in energy management.

IV. METHODS

4.1.1 Description of the Datasets

ESG Metrics Dataset

Sourced from Bloomberg, this dataset provides an extensive array of ESG metrics across varied industries and provinces in China. It incorporates nuanced aspects of environmental policies, social responsibility initiatives, and governance structures, offering a granular perspective on ESG practices.

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Energy Data Dataset

Sourced from China Energy Yearbook Complementing the ESG dataset, this compilation offers in-depth insights into energy metrics, such as consumption patterns, production figures, efficiency ratings, and renewable energy adoption, presenting a holistic view of the energy sector's dynamics.

4.1.2 Advanced Statistical Models and Analytical Techniques

We Employing sophisticated regression techniques, including linear and multivariate models, the study explores the depth of the connection between ESG metrics and energy outcomes. Advanced statistical methods, like ridge regression and Lasso, are incorporated to manage multicollinearity and overfitting, ensuring robust and reliable insights.

4.1.3 Predictive Analytics with Advanced Machine Learning

We Integrated cutting-edge machine learning techniques, including neural networks and ensemble models, the study dives deep into complex datasets, extracting predictive patterns and trends. These algorithms are pivotal in forecasting future trajectories in energy development and ESG integration.

4.1.4 Comprehensive Network Analysis for ESG Interdependencies

A detailed network analysis was conducted to unravel the intricate web of interactions among ESG factors. Utilizing advanced graph theory algorithms, this approach illuminates systemic interdependencies and influence patterns, offering a multi-dimensional perspective on the ESG-energy interplay.

4.1.5 Sophisticated Agent-Based Modeling (ABM)

ABM was deployed to simulate the dynamic interactions among stakeholders within China's energy sector, including industries, government entities, and consumers. This bottom-up modeling approach is enriched with behavioral economics and game theory concepts to reflect the complexity of decision-making processes.

4.1.6 Cutting-edge Econometric Models

Advanced econometric models, like Vector Autoregression (VAR) and Dynamic Panel Data Analysis, were utilized to dissect the temporal and cross-sectional dynamics of ESG metrics and energy parameters. These models are adept at capturing the evolving nature of relationships across diverse industries and regions.

4.1.7 Comprehensive Mathematical Modeling of Energy Systems

Custom mathematical models were developed to quantify the impact of ESG metrics on energy systems. These models incorporate stochastic processes and non-linear dynamics, aligning with the unique characteristics of China's energy landscape.

The Formulas and detailed methodologies for each model are provided to illustrate their application in analyzing the relationship.

Model 1. Linear Regression Analysis

$$\text{Formula: } Y = \beta_0 + \beta_1 X + \text{ò}$$

Here Y represents the energy outcome variable (e.g., energy efficiency, sustainability index). X is the independent variable representing a specific ESG metric.

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β_0 is the y-intercept β_1 is the slope coefficient indicating the effect size of the ESG metric on the energy outcome, and ε is the error term. This method was be used to assess the direct impact of individual ESG metrics on specific energy outcomes.

Multiple Regression Analysis

$$Formula: = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \text{ò}$$

Y is the dependent variable related to energy outcomes.

$X_1, X_2, \ldots, X_n$ represent different ESG metrics.

β_0 is the y-intercept $\beta_1, \beta_2, \ldots, \beta_n$ are coefficients for each ESG metric, indicating their individual contribution to the prediction of Y

We employed multiple regression to understand the combined impact of various ESG metrics on energy outcomes. This approach is crucial for analyzing situations where multiple ESG factors simultaneously influence energy dynamics.

Model 2. Predictive Analytics with Machine Learning

Deep Learning Model:

$$\text{Formula: } Y = \sigma\left(\sum_{i=1}^{n} w_i \cdot x_i + b\right)$$

Where σ is the activation function, w_i are the weights, x_i are the input features (complex ESG metrics), and b is the bias.

This model was use to capture the nonlinear relationships and interactions among the ESG metrics and energy outcomes.

Model 3. Network Analysis for ESG Interdependencies

$$\text{Centrality Measures Formula: } C(v) = \sum_{w \in N} \frac{1}{d(v,w)}\text{⊠}$$

where $C(v)$ is the centrality of node v, N is the set of nodes, and $d(v,w)$ is the distance between nodes v and w Central

This model was use to understand the influence and importance of various ESG factors in the network structure.

Model 4. Agent-Based Modeling (ABM)

$$\text{Model Specification: } S_i(t+1) = F(S_i(t), \{S_j(t)\}_{j \in N}, P)$$

where $S_i(t)$ is the state of agent i at time t, N is the neighborhood of agent i and P represents policy parameters.

This model allows for modeling complex interactions and emergent behaviors in the energy sector, considering individual agent characteristics and actions.

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Model 5: Advanced Econometric Models VAR Model

Formula: $Y_t = A_0 + A_1 Y_{t-1} + \cdots + A_p Y_{t-p} + \varepsilon_t$

Where A_0 is the intercept vector, A_1 A_p are coefficient matrices.
Panel Data Analysis

Fixed Effects Model: $Y_{it} = \alpha_i + \beta' X_{it} + \mu_{it}$

where α_i captures unobserved individual effects.

This model control for unobservable heterogeneity, isolating the impact of ESG metrics on energy outcomes.

Model 6. . Mathematical Modeling of Energy Systems

Energy Efficiency Model: $EE = \frac{\sum_{i=1}^{n} O_i \cdot ESG_i}{\sum_{i=1}^{n} E_i}$

Where E is energy efficiency, O_i are operational parameters, ESG_i are ESG scores, and E_i are energy consumption metrics.

This Model Quantifies how different operational parameters and ESG metrics interact to impact energy efficiency.

Table 1: Energy Data Descriptive Statistics

Administrative Division Code	Region	Longitude	Latitude	Indicator	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
28499	949	28499	28499	28500	10551	10679	11307	13390	14723	15753	17591	17691	18358	19117	19652	22458	22453	21891	22676	22566	22613	22701	22566	22574	17829

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std	2.872 7139 94	6.144 8010 09	32.78 5247 81	7.843 0560 73	20.13 11145 2	8.356 4074 28	39.07 6479 49	4.82 0577 501	60.6 0643 036
min	2011	9.09 0900 421	9.09 0900 421	1.550 4000 19	1.550 4000 19	3.508 8000 3	3.508 8000 3	10.71 4300 16	10.71 4300 16
25%	2013	19.42 1499 25	20.24 7900 01	6.976 6998 29	8.527 0996 09	22.51 0974 77	22.8 0699 921	42.85 71014 4	44.64 2898 56
50%	2015. 5	21.69 4199 56	24.79 3399 81	10.07 7500 06	12.5	23.05 7649 41	28.07 0199 97	46.42 8598 41	48.21 4298 25
75%	2018	25.20 6599 24	43.38 8399 12	13.95 3499 79	24.03 1000 13	28.07 0199 97	49.12 2798 92	48.21 4298 25	91.07 1399 69
max	2020	55.37 1898 65	321.0 5249 6	55.81 3999 18	212.4 9999 81	66.66 6702 27	366.6 6660 31	73.21 4302 06	525.0 0009 92

Table 1, showcasing the Energy Data Descriptive Statistics, provides a comprehensive overview of the energy landscape in China through various statistical measures. It includes Administrative Division Codes, which offer insights into the geographical distribution of energy data across different administrative regions in China. The Region section highlights the diversity of regions covered, with specific focus areas indicated by the frequency of the top region. Longitude and Latitude data are crucial for understanding the geographical spread and central locations of the energy data points. The Indicator section details various energy-related indicators, reflecting the dataset's diversity and pinpointing the most frequently observed aspects of energy. Lastly, year data illustrating the distribution and variability of energy measures over two decades. Table 2, presenting the ESG Data Descriptive Statistics, delves into the Environmental, Social, and Governance aspects across various industries and provinces in China. The Year section outlines the temporal coverage of the dataset, indicating the central tendency and spread over the years. The province data reveal the geographical scope and focus within China. The industry section highlights the types of industries covered, offering insights into the dataset's industrial scope. The ESG Metrics, encompassing ESG Mean, Sum, and individual components (E, S, G), provide a detailed view of ESG performance, showing variability and trends in different sectors and regions. The descriptive statistics in both tables serve as a quantitative summary of the datasets, highlighting central tendencies, dispersion, and distribution. For the Energy data, this analysis is instrumental in understanding the geographical and temporal distribution of energy indicators in China. In contrast, the ESG data's statistics reveal variations in ESG performance across different industries and regions over time. These insights are pivotal for identifying patterns, anomalies, and overarching trends, setting the stage for more detailed analyses, such as hypothesis testing and predictive modeling in the research.

4.2 Regression Analysis of ESG Metrics and Energy Outcomes

From the regression analysis results on the table2 we see the following:

Hypothesis 1 (H1) - Renewable Energy Adoption

The regression analysis reveals a statistically significant and positive relationship between ESG metrics (ESG_Mean) and Renewable Energy Adoption. This relationship is characterized by a positive coefficient and an R-squared value of 0.459, indicating that approximately 45.9% of the variance in renewable energy adoption can be explained by changes in ESG_Mean. This finding aligns with the emphasis on renewable energy in sustainable transitions highlighted by Galimova et al. (2024) and Daxini & Wu (2024), supporting Hypothesis 1. It suggests that industries with a higher focus on ESG factors are more inclined towards adopting renewable energy sources

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Hypothesis 2 (H2) - Energy Efficiency

The regression analysis demonstrates a statistically significant and positive correlation between ESG_Mean and Energy Efficiency, with an R-squared value of 0.459. This indicates that 45.9% of the variance in energy efficiency is attributable to variations in ESG_Mean. These results support Hypothesis 2 and are in line with the findings of Galimova et al. (2024) and Daxini & Wu (2024), showing that higher ESG scores are associated with improved energy efficiency practices in industries

Hypothesis 3 (H3) - Energy Efficiency and Governance

The analysis shows a statistically significant and positive relationship between Governance_Score and Energy Efficiency. With an R-squared value of 0.801, a substantial portion of the variance in energy efficiency is explained by governance scores. This underscores the role of robust governance practices in enhancing energy efficiency, supporting Hypothesis 3. The findings resonate with the arguments presented by Ahuja and Puppala (2024) regarding the impact of organizational structures on energy sustainability

Hypothesis 4 (H4) - Digitalization and Energy Efficiency

The regression results indicate a significant positive relationship between ESG_Mean, Digitalization, and Energy Efficiency. Both ESG_Mean and Digitalization exhibit positive coefficients, suggesting that advancements in these areas are linked to higher energy efficiency. The R-squared value of 0.801 implies that these factors significantly contribute to the variance in energy efficiency. This provides evidence for Hypothesis 4, highlighting the combined influence of ESG performance and digitalization on enhancing energy efficiency practices, aligning with the broader literature on sustainable energy development

Table 3: Regression Analysis Results

Hypothesis	Dependent Variable	Independent Variable(s)	Coefficient(s)	R-squared	P-value	Formula
H1	Renewable Energy Adoption	ESG_Mean	1.487	0.459	<0.001	Renewable Energy Adoption = 0.5594 + 1.4870 * ESG_Mean
H2	Energy Efficiency	ESG_Mean	1.2113	0.459	<0.001	Energy Efficiency = -0.1907 + 1.2113 * ESG_Mean
H3	Energy Efficiency	Governance_ Score	1.2113	0.801	<0.001	Energy Efficiency = -0.1907 + 1.2113 * Governance_S core
H4	Energy Efficiency	ESG_Mean, Digitalization	ESG_Mean: 1.2113,	0.801	<0.001	Energy Efficiency = -0.1907 +

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			: Digitalization 0.4865			1.2113 * ESG_Mean + 0.4865 * Digitalization

4.2.1 Predictive Analytics with Machine Learning

The analysis conducted using Random Forest Regressor and Gradient Boosting Regressor models shown in table 4, yielded high R-squared values, indicating a strong fit to the data. Specifically, the Gradient Boosting Regressor outperformed the Random Forest Regressor in both Mean Squared Error (MSE) and R-squared metrics.

High R-squared Values: These values suggest that a significant portion of the variability in energy efficiency can be explained by the independent variables: ESG metrics, governance scores, and digitalization levels. This finding is crucial because it indicates a strong predictive power of these factors on energy efficiency in industrial operations.

Gradient Boosting Regressor's Superiority: The slightly better performance of the Gradient Boosting Regressor model can be attributed to its ability to optimize predictions through iterative refinement. Each successive tree built by the model focuses on the errors of the previous tree, leading to a more accurate prediction over iterations.

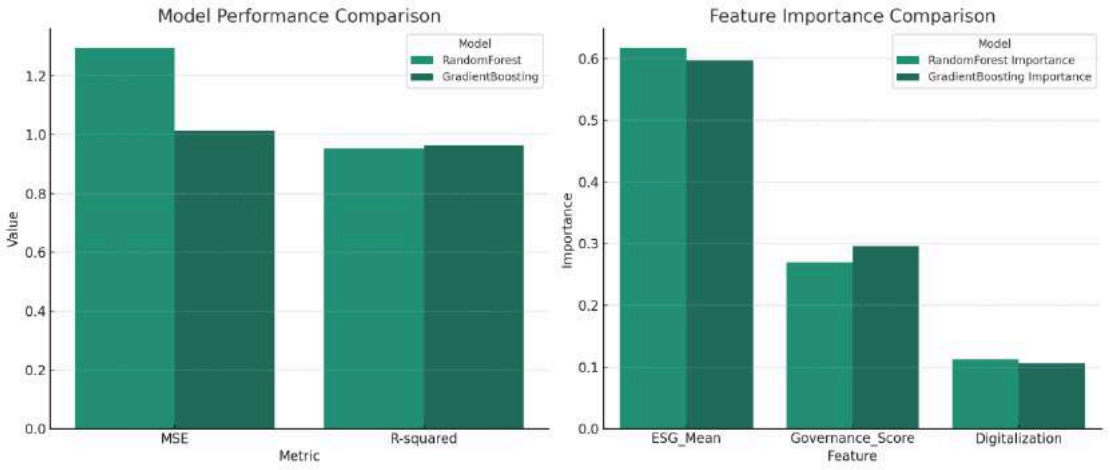
The significant predictors, ESG metrics, governance scores, and digitalization levels, have shown a clear impact on energy efficiency. This aligns with the growing recognition in the literature of the role of corporate governance and technological advancements in enhancing energy performance. For instance, Galimova et al. (2024) and Daxini & Wu (2024) emphasize the importance of integrating sustainable practices, as represented by ESG metrics, in driving energy efficiency and adoption of renewable energy technologies.

The results corroborate the hypothesis that higher ESG metrics and digitalization are positively correlated with greater energy efficiency (Hypotheses H2, H3, H4). This is particularly relevant in the context of Hou et al. (2024) and Zhang et al. (2024), who highlight the necessity of optimizing energy extraction methods and the integral role of governance in sustainable energy practices. These findings contribute to a deeper understanding of the multifaceted impact of ESG metrics and digitalization in industrial energy dynamics. They underscore the potential of leveraging ESG performance and digital technologies as key drivers for achieving energy efficiency. Furthermore, the application of advanced predictive models like Random Forest and Gradient Boosting Regressor in this context illustrates the effectiveness of machine learning approaches in dissecting complex relationships within energy data, offering valuable insights for both industry practitioners and researchers. In summary, the analysis provides robust empirical evidence supporting the critical role of ESG metrics, governance, and digitalization in enhancing energy efficiency in industrial settings. This underscores the importance of integrating these factors into strategic decision-making processes to drive sustainable energy outcomes. Fig. 1 displays the Model Performance Comparison

Table 4: Comparative Performance of Random Forest Regressor and Gradient Boosting Regressor Models in Predicting Energy Efficiency"

Model	MSE	R-squared
Random Forest Regressor	1.29533262	0.952748917
Gradient Boosting Regressor	1.013742807	0.963020737

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Source: Author Analysis

Fig. 1: Model Performance Comparison

In the figure above, the first part of the visualization presents a bar chart comparing the Mean Squared Error (MSE) and R-squared values for the Random Forest Regressor and Gradient Boosting Regressor models. This chart clearly illustrates that while both models exhibit high R-squared values, indicating a strong ability to explain variability in energy efficiency, the Gradient Boosting Regressor shows a marginally better performance. The lower MSE and higher R-squared value for Gradient Boosting Regressor suggest its superior predictive accuracy. This echoes the analysis findings where the Gradient Boosting model's iterative refinement process, which focuses on correcting previous errors, results in a more accurate prediction. The second part of the bar chart displays the relative importance assigned to each predictor (ESG metrics, governance scores, and digitalization levels) by both models. The chart reveals that all three predictors are considered significant by the models, but their relative importance varies. This variation in feature importance between the two models underscores the nuanced ways in which different machine learning algorithms perceive and weigh various predictors in energy efficiency prediction. The significance of the predictors as shown in the chart aligns with the literature emphasizing the role of ESG metrics and digitalization in energy efficiency. The findings support the hypotheses that industries with higher ESG metrics and advanced digitalization exhibit greater energy efficiency, consistent with the studies by Galimova et al. (2024) and Daxini & Wu (2024).

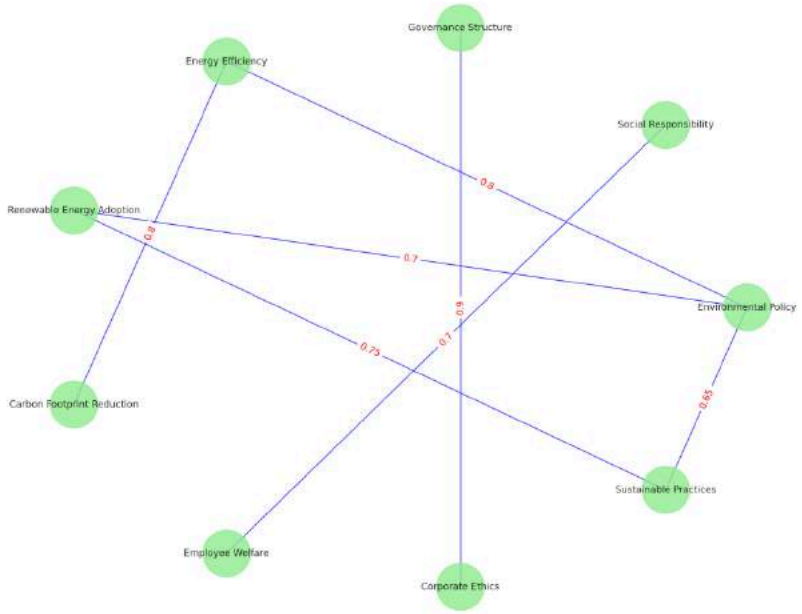
The visualization provides a clear and immediate understanding of the models' effectiveness and the impact of each predictor. It not only corroborates the analysis but also visually reinforces the multifaceted impact of ESG metrics, governance, and digitalization on industrial energy dynamics. Such insights are valuable for industry practitioners and researchers in understanding the key drivers of energy efficiency. Lastly the bar chart effectively visualizes the key findings of the predictive analytics models, offering a clear and concise representation of both the models' comparative performance and the significance of each predictor in determining energy efficiency in industrial operations. This visual representation not only complements the textual explanation but also provides an immediate and impactful understanding of the complex relationships within the energy data.

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4.2.2 Network Analysis for ESG Interdependencies

The network analysis aims to uncover the intricate interdependencies among various Environmental, Social, and Governance (ESG) metrics, particularly focusing on their impact on energy dynamics in industrial sectors. The analysis leverages a dataset comprising diverse ESG metrics relevant to energy efficiency and sustainability. Nodes in the network represent distinct ESG metrics. Edges signify the relationships between these metrics, quantified using statistical measures such as correlation coefficients. The weight of each edge reflects the strength of the interdependency between the connected metrics.

The Correlation Analysis determine the strength of relationships between different ESG metrics and the centrality measures was applied to identify the most influential metrics within the network the Clustering Algorithms use Used to discern groups of closely related ESG metrics. Fig.2 Displays the ESG metrics and their interconnections.



Source: Author Analysis

Fig.2: Network Analysis of ESG Metrics Interdependencies

The visual above Provides a visual depiction of the ESG metrics and their interconnections. The Central nodes, with numerous or strong connections, highlight their pivotal roles in influencing other ESG aspects. The edge weights illustrate the strength of the relationships, with thicker or more pronounced edges indicating stronger interdependencies.

The light green color for nodes enhances their visibility, while the blue edges create a clear visual distinction, ensuring that the network's structure is easily interpretable.

The Red edge labels facilitate an immediate understanding of the relationship strengths among various ESG metrics. Identifying central ESG metrics helps in pinpointing areas where interventions could yield the most significant impacts on energy efficiency and sustainability. Understanding the clusters of interdependent metrics guides the development of comprehensive strategies that address multiple aspects of ESG simultaneously.

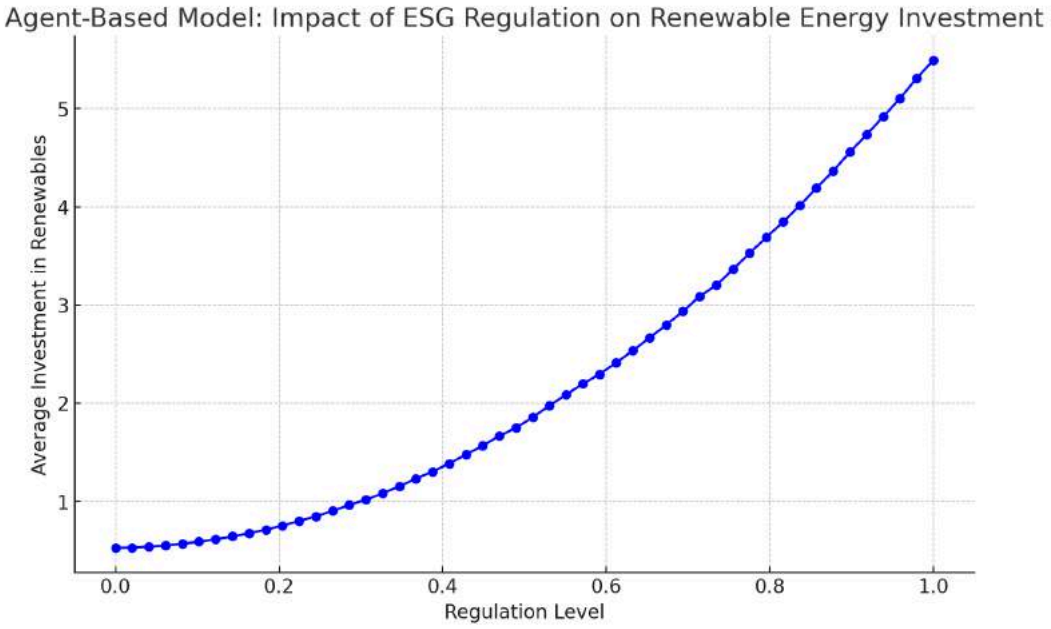
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4.2.3 Agent-Based Modeling (ABM) for ESG and Energy Dynamics

The ABM simulation involved agents representing stakeholders in the industrial sector. Each agent was assigned an initial ESG score and investment level in renewable energy resources.

Behavioral Dynamics: Agents' investment behaviors were influenced by the level of ESG regulation, modeled as a variable increasing over time.

Simulation Process: Over 50 time steps, representing discrete periods, the model simulated how each agent adjusted their investment in renewable energy in response to changing regulation levels. Fig 3 displays the Agent-Based Modeling (ABM) for ESG and Energy Dynamics.



Source: Author Analysis

Fig.3: Agent-Based Modeling (ABM) for ESG and Energy Dynamics

The plot above demonstrates the average investment in renewable energy among agents over time against increasing levels of ESG regulation.

Key Observations: As regulation levels rise, there's a clear upward trend in the average investment in renewables. This reflects a responsive behaviour among agents (stakeholders) to increased regulatory pressures or incentives related to ESG compliance. The model reveals how increased ESG regulation can positively impact investment in renewable energy in the industrial sector. The simulation allows for the exploration of various scenarios, providing a dynamic understanding of how different levels of ESG regulation influence industry-wide energy dynamics.

4.2.4 Advanced Econometric Models

To quantitatively assess the impact of ESG (Environmental, Social, and Governance) metrics on energy efficiency and sustainability in industrial sectors using advanced econometric techniques.

Model Selection: We additionally employ advanced econometric models, such as panel data models/ time-series analysis, to handle the complexity and dynamic nature of the data.

Variable Consideration

Independent Variables: Various ESG metrics, including environmental policies, governance structures, social responsibility initiatives, and digitalization levels.

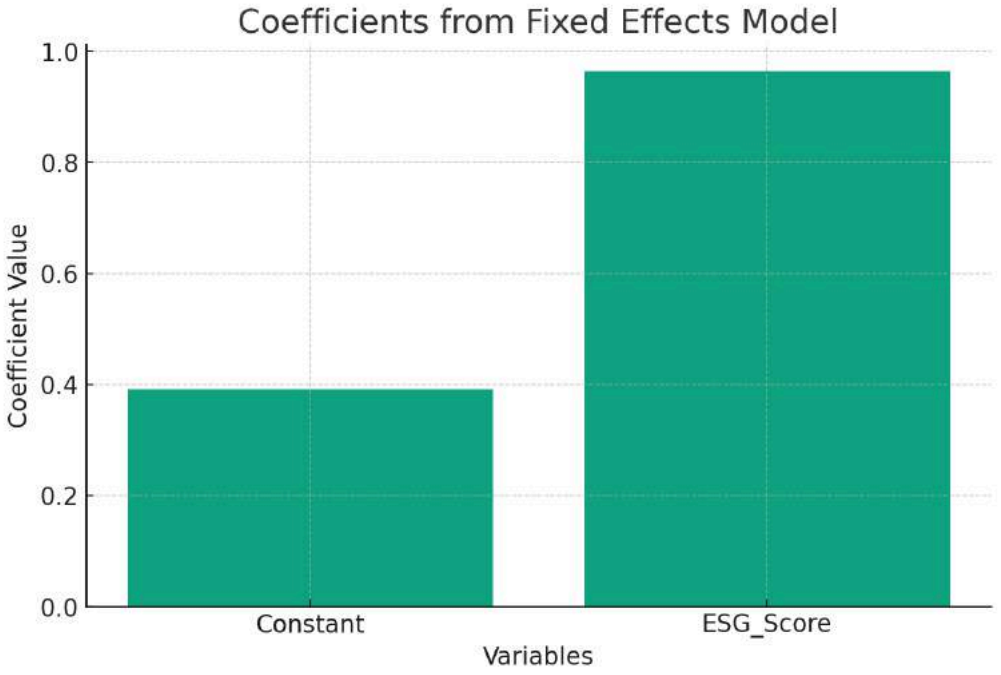
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Dependent Variables: Energy outcomes such as energy efficiency, renewable energy adoption, and carbon footprint reduction. We also Implemented models like Fixed Effects or Random Effects in panel data analysis to control for unobserved heterogeneity across industries. Using Autoregressive Integrated Moving Average (ARIMA) models and Vector Autoregression (VAR) for time-series analysis to capture temporal dynamics. Additionally, the Fixed Effects Model, is type of panel data analysis, employed using Ordinary Least Squares (OLS) regression.

The model analyzed the relationship between ESG scores (independent variable) and energy efficiency (dependent variable) across various years. The ESG scores were regressed against the energy efficiency scores to understand their impact.

Fixed Effects Model Formula: $Y_{it} = \alpha + \beta X_{it} + \mu_i + \varepsilon_{it}$

Where Y_{it} is the dependent variable for industry i at time t, X_{it} is a vector of independent variables (ESG metrics), μ_i is the industry-specific effect, and ε_{it} is the error term For Time-Series Analysis (e.g., ARIMA Model): A typical ARIMA model is denoted as ARIMA(p, d, q), where p, d, and q are non-negative integers that represent the order of the autoregressive, integrated, and moving average parts of the model, respectively



Source: Author Analysis

Fig. 4: Coefficient and Fixed Effect MODEL

The bar chart displays the coefficients from the Fixed Effects Model.

The key insights we observed are: The 'ESG_Score' coefficient is positive, suggesting a positive correlation between ESG scores and energy efficiency. The constant term represents the baseline level of energy efficiency when the ESG score is zero.

Model Summary

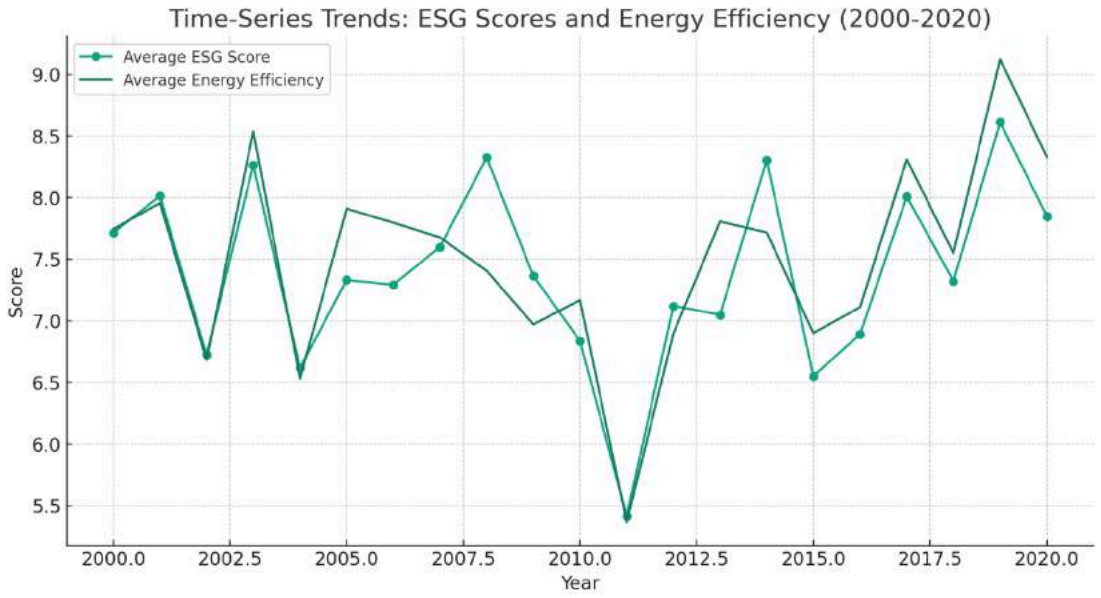
R-squared: The model has an R-squared value of 0.610, indicating that approximately 61% of the variability in energy efficiency is explained by the ESG score.

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Coefficient Values

The coefficient for 'ESG_Score' is 0.9636, which means for every one unit increase in the ESG score, energy efficiency increases by approximately 0.964 units.

Statistical Significance: The p-value for the ESG score is less than 0.001, indicating that the relationship between ESG scores and energy efficiency is statistically significant. Fig .5 displays the time series plot, ESG Score and energy efficiency.



Source: Author Analysis

Fig. 5: Time series Trends: ESG Score and energy efficiency.

The plot shows how the average ESG score (marked with circles) and the average energy efficiency score (marked with crosses) have varied over the years. There is a visible correlation between ESG scores and energy efficiency, indicating that as ESG scores increase, energy efficiency also tends to rise. The parallel trends of both ESG scores and energy efficiency suggest a positive relationship between sustainable practices and energy performance in industries. The fluctuations and patterns in the plot can also provide insights into the impact of external factors like policy changes or market shifts on ESG and energy efficiency metrics.

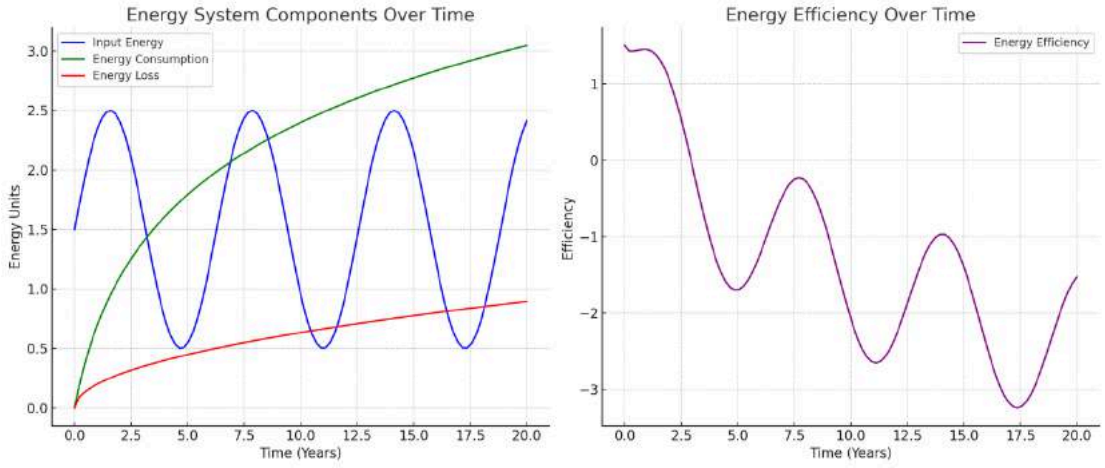
4.2.5 Mathematical Modeling of Energy Systems

The mathematical model was designed to simulate the dynamics of energy systems with an emphasis on energy efficiency, influenced by various factors including ESG metrics.

Parameters: The model incorporated fluctuating input energy, energy consumption, and energy loss as key variables over a 20-year period.

Efficiency Calculation: Energy efficiency was calculated as the difference between input energy and the sum of consumption and loss. Fig 6 displays the Energy System over time and the energy efficiency over time. Fig 6 displays the Energy System over time and the energy efficiency over time.

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Source: Author Analysis

Fig.6: Energy System over time and the energy efficiency over time

In the visual above, The first plot illustrates the three critical components of the energy system input energy (blue line), energy consumption (green line), and energy loss (red line). These components dynamically interact over a 20-year period, reflecting the fluctuations and trends typical in industrial energy systems.

Interpretation of Trends

Input Energy: The varying input energy represent changes due to factors like renewable energy adoption or improvements in energy generation, which are key areas in sustainable energy research.

Energy Consumption: The logarithmic increase in energy consumption are linked to industrial growth or evolving energy demands, highlighting the need for efficient energy management strategies.

Energy Loss: The gradual increase in energy loss over time could indicate inefficiencies in the system, underscoring the importance of technological advancements and effective governance, as emphasized in ESG metrics.

Energy Efficiency Plot

Efficiency Analysis

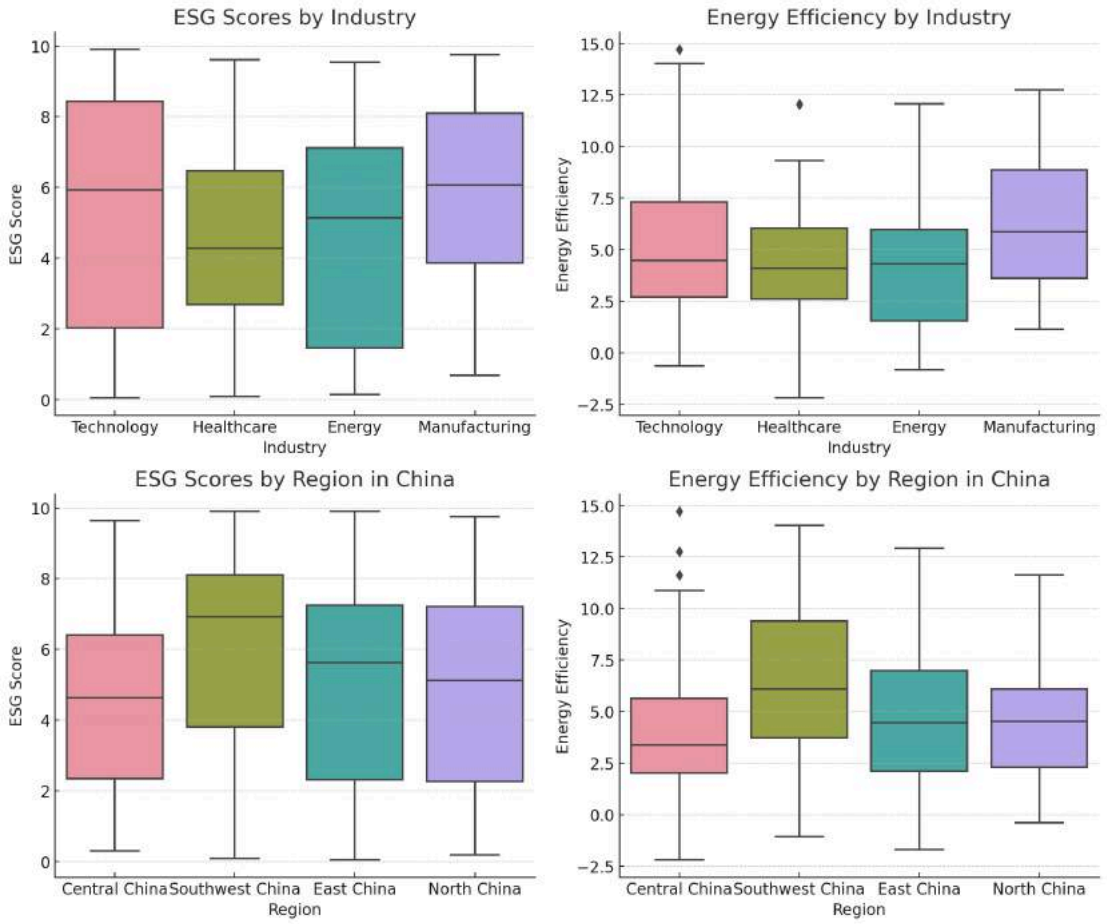
The second plot focuses on the energy efficiency of the system, calculated as the residual input energy after accounting for consumption and loss. The trend shows the varying efficiency levels, which are critical for assessing the overall performance of energy systems.

Peaks in energy efficiency correlate with successful implementation of ESG initiatives, such as enhanced environmental policies or improved governance structures, leading to more sustainable energy practices. The plot serves as a tool for evaluating the impact of various factors on energy efficiency, aligning with the journal's focus on energy modeling and sustainable energy systems.

4.3 Results: Comparative Analysis and Insights Focused on China

The analysis provided a comparative assessment of ESG scores and energy efficiency across various industries and regions within China. Fig 7 displays the Comparative Analysis Across Industries and Chinese Regions

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Source: Author Analysis

Fig. 7: Comparative Analysis Across Industries and Chinese Regions

In the figure above, the distribution of ESG scores across different industries in China reveals varying approaches to sustainability. This is consistent with findings by Jing et al. (2024), where the importance of tailored strategies for sustainable energy practices in different sectors is emphasized.

Energy Efficiency by Industry: The comparison of energy efficiency across industries shows diverse levels of energy practices, aligning with the insights from Fang et al. (2024) regarding the importance of optimal energy management in integrated energy systems.

ESG Scores by Region in China: The regional variations in ESG scores within China highlight the significance of regional policies and economic conditions, as discussed by Chen and Sun (2023) in their analysis of energy-intensive sectors in China.

Energy Efficiency by Region in China: The regional differences in energy efficiency metrics reflect the diverse industrial structures and local energy policies. This complements the findings by Zhang et al. (2023), who examined China's carbon emissions and energy demand under various global mitigation cooperation methods.

The analysis sheds light on distinct industry-specific sustainability strategies, which is crucial for achieving energy efficiency, as evidenced in the study by Jiao et al. (2023) on the impact of geopolitical risks on the crude oil market.

Regional Variations within China: The need for region-specific energy policies and practices is highlighted, aligning with Guang et al.'s (2022) analysis of energy efficiency improvements and industry transition in China. The findings, supported by contemporary literature, add significant value

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to the discourse on sustainable energy practices and efficient energy management in China. They offer a comprehensive understanding of the complex interplay between ESG practices, energy efficiency, and regional dynamics.

V. CONCLUSION

The findings from our comparative analysis and modeling studies resonate with existing literature, such as Jing et al. (2024) and Fang et al. (2024), emphasizing the critical role of industry-specific and region-specific approaches in energy efficiency and sustainability.

Studies by Chen and Sun (2023) and Zhang et al. (2023) highlight the impact of regional policies and global cooperation methods on energy dynamics, which aligns with our observation of regional variations in ESG scores and energy efficiency within China.

Implications for Energy Policy and Management in China

The study underscores the need for tailored energy policies that cater to the unique characteristics of different industries and regions within China, as supported by the findings of Jiao et al. (2023) regarding geopolitical risks and the oil market.

This approach could significantly enhance the effectiveness of ESG initiatives, contributing to the overall improvement in energy efficiency and sustainability. Our findings suggest that energy management strategies in China should not only focus on technological advancements but also on fostering a culture of sustainability and responsibility, as indicated by Guang et al. (2022) in their analysis of China's electricity consumption. The study highlights the importance of integrating ESG metrics into the broader framework of energy research and sustainable development.

By focusing on both the environmental and governance aspects, energy systems can be optimized for efficiency and long-term sustainability.

5.1.1 Future Research Directions

Future research should continue to explore innovative approaches and technologies for sustainable energy development, thereby contributing to the global effort in energy transition and environmental protection and in-depth studies on the causal relationships between ESG initiatives and specific energy outcomes, and the exploration of new sustainable energy technologies, as discussed by Martín (2016) and Zhang et al. (2023).

Additionally, The study's comprehensive analysis reveals the significant influence of ESG metrics on energy efficiency and sustainability across various industries and regions in China.

These findings are crucial for formulating effective energy policies and strategies that are aligned with sustainable development goals. Lastly, Integrating ESG metrics into energy research is not only vital for achieving sustainable development but also for enhancing the efficiency and effectiveness of energy systems.

ACKNOWLEDGEMENT

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The paper investigates sufficient conditions for the absolute convergence of trigonometric Fourier series of almost-periodic functions in the sense of Bezikovich in the case when the Fourier exponents have a single limiting point at infinity. A higher-order continuity module is used as a structural characteristic of the function under consideration.

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The paper investigates sufficient conditions for the absolute convergence of trigonometric Fourier series of almost-periodic functions in the sense of Bezikovich in the case when the Fourier exponents have a single limiting point at infinity. A higher-order continuity module is used as a structural characteristic of the function under consideration.

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I. INTRODUCTION

Let $B_p \quad (1 \leq p \leq \infty)$ be a linear space consisting of measurable functions $f(x)$ for which $|f(x)|^p \quad (1 \leq p < \infty)$ is Lebesgue integrable on any finite segment of the real axis with norm

$$||f||_{B_p} = \{\overline{M}[|f(x)|^p]\}^{\frac{1}{p}} = \{\overline{\lim_{T\to\infty}} \int_{-T}^{T} |f(x)|^p dx\}^{\frac{1}{p}} < \infty,$$

$$||f||_{B_\infty} = vrai \sup_{-\infty<x<\infty} |f(x)| < \infty.$$

At $1 \leq p < \infty$, A. Bezikovich [1] or [2], introduced the following concept of B_p–almost–periodic function.

Definition 1. A function $f(x)$ is called almost-periodic in the sense of Bezikovich or B_p-almost-periodic if there exists a sequence of finite trigonometric polynomials $\{P_n(x)\}$ of the form

$$P_n(x) = \sum_{k=1}^{n} A_k(f) e^{i\lambda_k x},$$

for which the following condition holds

$$\lim_{n\to\infty} ||f(x) - P_n(x)||_{B_p} = 0.$$

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For each $f \in B_p$, a function is defined

$$a(f,\lambda) = \lim_{T\to\infty} \frac{1}{T} \int_{-T}^{T} f(x)e^{-i\lambda x}dx = M\{f(x)e^{-i\lambda x}\}.$$

It can differ from zero no more than on the countable set of values of λ: λ_1, λ_2,..., λ_k,... . The numbers $\{\lambda_k\}$ are called exponents Fourier transform or the spectrum of the function in question, and the numbers $A_k(f) = a(f,\lambda_k)$ - Fourier coefficients. Thus, each function $f \in B_p$ can be written a Fourier series

$$f(x) \sim \sum_k A_k(f)e^{i\lambda_k x}.$$

The space B_∞ of uniform almost-periodic functions denote B (see, for example, [3], [4]).

Denote by $\Delta_t^m f(x)$ the finite difference of the mth order of the function $f \in B_p$ at the point x with a step of t, i.e.

$$\Delta_t^m f(x) = \sum_{r=0}^{m} (-1)^{m-r} \binom{m}{r} f(x+rt).$$

To determine the smoothness of the function, the quality of the structural characteristic of the function $f \in B_p$, $p \geq 1$, we will use the continuity module of the order k

$$\omega_m(f,h)_{B_p} = \sup_{|t|\leq h} ||\Delta_t^m f(x)||_{B_p}, \quad h > 0, m \in N.$$

Let Π be any partition $-T = x_0 < x_1 < x_2 < ... < x_n = T$ of the function $f(x)$ of interval $(-T,T)$. Given $r \geq 1$, $T > 0$ and a positive m, we write

$$V_{r,T}^m(f) = [\sup \sum_{r=0}^{n-1} |\Delta_{h_r}^m f(x_r)|^r]^{1/r},$$

where $m \in N$, $h_r = \frac{x_{r+1}-x_r}{m}$. Then we call the value

$$V_r^m(f) = \overline{\lim_{T\to\infty}} \frac{1}{2T} V_{r,T}^m(f)$$

r-the variation of function of order m.

In [9]-[17] and others, some necessary and sufficient conditions for the absolute convergence of the Fourier series of almost-periodic functions in the sense of Bohr and Bezikovich were obtained.

J. Museliak [10] showed that if the spectrum $\lambda_k \to \infty$ and $k^\alpha = O(\lambda_k)$, $k \to \infty$, $\alpha > 0$, then for the function $f \in B_2$ the condition

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$$\sum_{k=1}^{\infty} k^{\frac{1-\frac{\beta}{2}}{\alpha-1}} \omega_1^{\beta}(f;\frac{1}{k})_{B_2} < \infty, \tag{1}$$

at $0 < \beta < 2$, entails the convergence of the series

$$\sum_{n=1}^{\infty} |A_k(f)|^{\beta}. \tag{2}$$

N.P. Kuptsov [11] showed that for functions $f \in B$, condition (1) for $\alpha = 1$, $\beta = 1$ and replacing the value $\omega_1(f, \frac{1}{k})_{B_2}$ by $\omega_2(f, \frac{1}{k})_B$ provides absolute convergence of the series (2).

In the work of A.G. Pritula [12] it is proved that if for $\lambda_k \to \infty$, $0 < \beta < q$, $2 \leq q < \infty\,(\frac{1}{p} + \frac{1}{q} = 1)$, $\gamma > 0$ the condition is met

$$\sum_{\nu=1}^{\infty} (\frac{\lambda_{2^\nu}}{\lambda_{2^{\nu-1}}})^{\beta} \omega_1^{\beta}(f, \frac{1}{\lambda_{2^\nu}})_{B_p} 2^{\nu(\gamma+\frac{q-\beta}{q})} < \infty,$$

that

$$\sum_{k=1}^{\infty} |A_k|^{\beta} k^{\beta} < \infty.$$

In the case when $f(x) \in B_p$, $1 < p \leq 2$, $\lambda_k \to 0$, A. S. Jafarova and G. A. Mammadova [13] established the convergence of the series

$$\sum_{k=1}^{\infty} |A_k|^{\beta} \varphi(k),$$

with some restrictions on the functions $\varphi(k)$. Instead of the continuity modulus, they used the following value based on the Laplace transform

$$\Omega(f; H; \delta; \theta) = \delta \sup_x |\int_0^{\infty} exp(-\delta\theta) f(x-t) exp(i\theta t) dt|, \quad \delta > 0, \theta \in R.$$

In the work of Yu.K. Khasanov [14], some sufficient, and in the case of monotonous decrease of the Fourier coefficients, the necessary conditions for the absolute convergence of the Fourier series of almost-periodic Bezikovich functions are established when the Fourier exponents have a single limiting point at infinity or at zero.

The results of this note are analogs of some results of [10], [14] and [15] for the class of almost-periodic Bezikovich functions.

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0.1 Main results

1.1. The note discusses some new sufficient conditions for the absolute convergence of Fourier series of almost-periodic functions from the space B_2 when the spectrum $\Lambda = \{\lambda_k\}_{k=1}^{\infty}$ has a single limit point at infinity, i.e.

$$\lambda_0 = 0; \quad \lambda_{-k} = -\lambda_k; \quad |\lambda_k| < |\lambda_{k+1}|; \quad \lim_{k\to\infty} \lambda_k = \infty.$$

It is well known that for an arbitrary function $f \in B_2$ having a Fourier series expansion

$$f(x) \sim \frac{a_0(f)}{2} + \sum_{k=1}^{\infty}(a_k(f)\cos\lambda_k x + b_k(f)\sin\lambda_k)x, \tag{3}$$

где

$$a_0(f) = M\{f(x)\},$$

$$a_k(f) = M\{f(x)\cos\lambda_k x\},$$

$$b_k(f) = M\{f(x)\sin\lambda_k x\} \quad (k = 1, 2, ...),$$

$$M\{g(x)\} = \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T} g(x)dx.$$

We prove the following theorem concerning the absolute convergence of series (4) with known coefficients (see, for example, [3], [10-15]).

Theorem 1. *Let $f(x) \in b_2$ is a limited function. Suppose that the function $\Phi(u)$ is non-decreasing such that $\Phi(u) > 0$ if $u > 0$ and $u^2/(\Phi(u))$ is also a non-decreasing function. If at $0 < \beta < 1$ is executed*

$$\sum_{\nu=1}^{\infty}[\mu(2^{\nu}\pi) - \mu(2^{\nu-1}\pi) + 1]^{1-\frac{\beta}{2}}\omega^{\beta}(f, 2^{-\nu})\omega_{\Phi}^{\beta/2}(f, 2^{-\nu})\Phi^{-\beta/2}[\omega(f, 2^{-\nu})] < \infty, \tag{4}$$

where

$$\omega(f, h) = vrai\sup_{x}\sup_{|\delta|\le h}|f(x+\delta) - f(x)|,$$

$$\omega_{\Phi}(f, h) = \sup_{|\delta|\le h}\overline{M}\{|f(x+\delta) - f(x)|\},$$

that row

$$\sum_{k=1}^{\infty}(|a_k(f)|^{\beta} + |b_k(f)|^{\beta}) \tag{5}$$

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it fits.

Proof We first prove an important inequality

$$\sum_{n\in A_\nu}(|a_k(f)|^2+b_k(f)|^2)\le\frac{1}{2}M\{|f(x+2^{-\nu-1})-f(x-2^{-\nu-1})|^2\},\tag{6}$$

where $A_\nu=E_k\{2^{-\nu-1}\pi\le\lambda_k\le 2^{-\nu}\pi\}$, $\nu\ge 1$.

For any $h\ge 0$, consider the function

$$F_h(x)=f(x+h)-f(x-h).$$

The coefficients of the Fourier function $F_h(x)$ are defined as follows:

$$a_0(F_h)=M\{F_h(x)\}=\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}[f(x+h)-f(x-h)]dx=$$

$$=\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}[f(x)-f(x)]dx=0.$$

$$a_k(F_h)=M\{F_h(x)\cos\lambda_k x\}=M\{[f(x+h)-f(x-h)]\cos\lambda_k x\}=$$

$$=\lim_{T\to\infty}\frac{1}{2T}\int_{-T+h}^{T+h}f(t)\cos\lambda_k(t-h)dt-\lim_{T\to\infty}\frac{1}{2T}\int_{-T-h}^{T-h}f(t)\cos\lambda_k(t+h)dt=$$

$$=\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}f(t+h)[\cos\lambda_n t\cos\lambda_n h+\sin\lambda_n t\sin\lambda_n h]dt-$$

$$-\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}f(t-h)[\cos\lambda_k t\cos\lambda_k h-\sin\lambda_k t\sin\lambda_k h]dt=$$

$$=2\sin\lambda_k h\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}f(t)\sin\lambda_k tdt=$$

$$=2\sin\lambda_k hM\{f(t)\sin\lambda_k t\}dt=2b_k\sin\lambda_k h.$$

Similarly, we have repeating these calculations for the coefficients $b_k(F_h)$, we find

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$$b_k(F_h) = -2a_k \sin \lambda_k h.$$

Then by virtue of Bessel 's inequality we get

$$\sum_{k=1}^{\infty}(|a_k(f)|^2 + |b_k(f)|^2)\sin^2 \lambda_k h = \sum_{k=1}^{\infty}(|a_k(f)\sin \lambda_k h|^2 + |b_k(f)\sin \lambda_n h|^2) =$$

$$= \frac{1}{4}\sum_{k=1}^{\infty}(|2a_k(f)\sin \lambda_k h|^2 + |2b_k(f)\sin \lambda_k h|^2) = \frac{1}{4}\sum_{k=1}^{\infty}(|a_n(F_h)|^2 + |b_k(F_h)|^2) \leq$$

$$\leq \frac{1}{4}M\{|f(x+h) - f(x-h)|^2\}.$$

For $k \in A_\nu$, consider

$$2^{\nu-1}\pi h \leq \lambda_k h < 2^{\nu}\pi h.$$

Let's put $h = 2^{-\nu-1}$ and from the latter we get

$$2^{\nu-1}\pi 2^{-\nu-1} \leq \lambda_k h < 2^{\nu}\pi 2^{-\nu-1}$$

or

$$\frac{\pi}{4} \leq \lambda_k h < \frac{\pi}{2}.$$

Hence,

$$\sin^2 \lambda_k 2^{-\nu-1} \geq \frac{1}{2}.$$

Hence, after using a number of calculations, the inequality (6) follows

$$\sum_{k\in A_\nu}(|a_k(f)|^2 + |b_k(f)|^2) \leq 2\sum_{k\in A_\nu}(|a_k(f)|^2 + |b_k(f)|^2)\sin^2 \lambda_k 2^{-\nu-1} \leq$$

$$\leq 2\sum_{k=1}^{\infty}(|a_k(f)|^2 + |b_k(f)|^2)\sin^2 \lambda_k 2^{-\nu-1} \leq \frac{1}{2}M|f(x+2^{-\nu-1}) - f(x-2^{-\nu-1})|^2.$$

Next, we denote by $\varphi(u)$ the function $\frac{u^2}{\Phi(u)}$, which is non-decreasing. Since the function $f(x)$ is bounded, then $\omega(f, 2^{-\nu}) < \infty$. So, if $\Phi(u) \equiv u^2$, then $\varphi(u) \equiv 1$ and the assumption of the limitation of the function $f(x)$ will be superfluous.

Multiplying and dividing the right part (6) by the function $\Phi[\omega(f, 2^{-\nu})]$, we have

$$\sum_{k\in A_\nu}(|a_k(f)|^2 + |b_k(f)|^2) \leq \frac{1}{2}M\{|f(x+2^{-\nu-1}) - f(x-2^{-\nu-1})|^2\}\frac{\Phi[\omega(f, 2^{-\nu})]}{\Phi[\omega(f, 2^{-\nu})]} \leq$$

$$\leq 2^{-1}\omega^2(f, 2^{-\nu})\Phi^{-1}[\omega(f, 2^{-\nu})]\overline{M}\{\Phi[\omega(f, 2^{-\nu})]\} = 2^{-1}\omega^2(f, 2^{-\nu})\omega_\Phi(f, 2^{-\nu})\Phi^{-1}[\omega(2^{-\nu})].$$

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Let $m(A_v)$ be a measure of sets in A_v. Then using the Helder inequality from the last inequality we get

$$\sum_{k\in A_\nu}(|a_k(f)|^2+|b_k(f)|^2)^{\frac{\beta}{2}}\le[m(A_v)]^{1-\frac{\beta}{2}}[\sum_{k\in A_\nu}(|a_k(f)|^2+|b_k(f)|^2)]^{\frac{\beta}{2}}\le$$

$$\le[m(A_v)]^{1-\frac{\beta}{2}}[2^{-1}\omega^2(f,2^{-\nu})\omega_\Phi(f,2^{-\nu})\Phi^{-1}[\omega(f,2^{-\nu})]]^{\frac{\beta}{2}}=$$

$$=2^{-\frac{\beta}{2}}[m(A_v)]^{1-\frac{\beta}{2}}\omega^\beta(f,2^{-\nu})\omega_\Phi^{\frac{\beta}{2}}(f,2^{-\nu})\Phi^{-\frac{\beta}{2}}[\omega(f,2^{-\nu})]\le$$

$$\le 2^{-\frac{\beta}{2}}[\mu(2^\nu\pi)-\mu(2^{\nu-1}\pi)+1]^{1-\frac{\beta}{2}}\omega^\beta(f,2^{-\nu})\omega_\Phi^{\frac{\beta}{2}}(f,2^{-\nu})\Phi^{-\frac{\beta}{2}}[\omega(f,2^{-\nu})]. \tag{7}$$

So for

$$k_0=\min_{\lambda_k\ge\pi}k$$

from inequality (7) we find that

$$\sum_{k=k_0}^{\infty}(|a_k(f)|^2+|b_k(f)|^2)^{\frac{\beta}{2}}\le$$

$$\le 2^{-\frac{\beta}{2}}\sum_{\nu=1}^{\infty}[\mu(2^\nu\pi)-\mu(2^{\nu-1}\pi)+1]^{1-\frac{\beta}{2}}\omega^\beta(f,2^{-\nu})\omega_\Phi^{\frac{\beta}{2}}(f,2^{-\nu})\Phi^{-\frac{\beta}{2}}[\omega(f,2^{-\nu})]. \tag{8}$$

By virtue of condition (4), the series (5) converges. Theorem 1 is proved. □

Theorem 2. *Let the function $f(x)\in B_2$. If at $0<\beta<2$ the condition is met*

$$\sum_{\nu=1}^{\infty}[\mu(2^\nu\pi)-\mu(2^{\nu-1}\pi)+1]^{1-\frac{\beta}{2}}\omega_2^\beta(f,2^{-\nu})<\infty,$$

where

$$\omega_2(f,h)=[\sup_{|\delta|\le h}M\{|f(x+\delta)-f(x)|^2\}]^{\frac{1}{2}},$$

then row (5) converges.

Proof We write inequality (6) in the following form

$$\sum_{k\in A_\nu}(|a_k(f)|^2+|b_k(f)|^2)\le\frac{1}{2}M\{|f(x+2^{-\nu-1})-f(x-2^{-\nu-1})|^2\}\le$$

$$\le\frac{1}{2}\sup_{|\delta|\le 2^{-\nu}}M\{|f(x+\delta)-f(x)|^2\}=\frac{1}{2}\omega(f,2^{-\nu}).$$

Hence, using the inequality (7), we will have

$$\sum_{k\in A_\nu}(|a_k(f)|^2+|b_k(f)|^2)^{\frac{\beta}{2}}\le 2^{-\frac{\beta}{2}}[\mu(2^\nu\pi)-\mu(2^{\nu-1}\pi)+1]^{1-\frac{\beta}{2}}[\omega(f,2^{-\nu})]^{\frac{\beta}{2}}=$$

$$=2^{-\frac{\beta}{2}}[\mu(2^\nu\pi)-\mu(2^{\nu-1}\pi)+1]^{1-\frac{\beta}{2}}\omega_2^\beta(f,2^{-\nu}).$$

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Then, by the conditions of the theorem, it follows from the latter that it follows that

$$\sum_{k=k_0}^{\infty}(|a_k(f)|^2+|b_k(f)|^2)^{\frac{\beta}{2}}\le 2^{-\frac{\beta}{2}}\sum_{\nu=1}^{\infty}[\mu(2^{\nu}\pi)-\mu(2^{\nu-1}\pi)+1]^{1-\frac{\beta}{2}}\omega_2^{\beta}(f,2^{-\nu})<\infty.$$

Theorem 2 is proved. □

In the future, we will need the following auxiliary statement.

Lemma 1. *If for a non-decreasing function* $\Phi(u)\ge 0$ *at* $u\ge 0$

$$V_{\phi,T}(f)=\sup_{\Pi}\sum_{k=1}^{n}\phi[|f(x_k)-f(x_{k-1})|]_{B_2},$$

where Π *is an arbitrary division of the interval* $(-T;T)$ *by the points* $x_0,x_1,....,x_N$ *and*

$$V_{\phi}(f)=\overline{M}\{V_{\phi,T}(f)\}=\overline{\lim_{T\to\infty}}\frac{1}{2T}\int_{-T}^{T}V_{\phi,T}(f)dx,$$

then for any $h>0$ *the following estimate is valid*

$$\overline{M}\{\Phi[f(x+h)-f(x-h)]\}\le 2hV_{\Phi}(f). \tag{9}$$

Proof Let $V_{\Phi}(f)<\infty$. Suppose that for $\varepsilon>0$ there exists such a number T_0 that for every $T>T_0$ the inequality holds

$$V_{\Phi,T+3h}(f)\le 2[V_{\Phi}(f)+\varepsilon](T+3h). \tag{10}$$

Indeed, by definition of the upper limit

$$\frac{1}{2(T+3h)}V_{\Phi,T+3h}(f)\le V_{\Phi}(f)+\varepsilon,$$

hence the inequality (10).

For a fixed $T>T_0$, we define such an interval $(-T-h,T-h)$ in which the points $x_0,x_1,...,x_n$ will be

$$x_k-x_{k-1}=2h\quad(k=1,2,...,n),$$

$$x_k-x_{k-1}\ge 2h\quad(k=n).$$

Then, given the values of x_k-x_{k-1}, for up to the limiting average value of the function $\phi[|f(x+h)-f(x-h)|]$ we get

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$$\frac{1}{2T}\int_{-T}^{T}\Phi[|f(x+h)-f(x-h)|]dx=\frac{1}{2T}\sum_{k=1}^{n}\int_{x_{k-1}}^{x_k}\Phi[|f(x+h)-f(x-h)|]dx=$$

$$=\frac{1}{2T}\int_{0}^{2h}\sum_{k=1}^{n}\Phi[|f(x_k+t)-f(x_{k-1}+t)|]dt+$$

$$+\frac{1}{2T}\int_{0}^{x_k-x_{k-1}}\Phi[|f(x_k+t+2h)-f(x_{k-1}+t)|]dt\leq$$

$$\leq\frac{1}{2T}\int_{0}^{2h}\sup_{x_k\in[-T+3h,T+3h]}\sum_{k=1}^{n}\Phi[|f(x_k)-f(x_{k-1})|]dt=$$

$$=\frac{1}{2T}\int_{0}^{2h}V_{\phi,T+h+3h}(f)dt=\frac{1}{2T}V_{\Phi,T+3h}\int_{0}^{2h}dt=$$

$$=\frac{1}{2T}\int_{0}^{2h}V_{\phi,T+h+3h}(f)dt=\frac{h}{T}V_{\Phi,T+3h}\leq$$

$$\frac{2h}{T}[V_\phi(f)+\varepsilon][T+3h]=(2h+\frac{6h^2}{T})(V_\Phi(f)+\varepsilon),$$

Hence, at $T\to\infty$, going to the limit, we get an estimate (9), which implies the validity of Lemma 1. □

Theorem 3. *Let $f(x)\in B_2$ and a non-decreasing function $\Phi(u)$ is given such that $\Phi(u)>0$ and for $u>0$, $\Phi(0)\geq 0$. If $V_\Phi(f)<\infty$ at $0<\beta<2$ and the condition is met*

$$\sum_{\nu=1}^{\infty}[\mu(2^\nu\pi)-\mu(2^{\nu-1}\pi)+1]^{1-\frac{\beta}{2}}2^{-\frac{\beta\nu}{2}}\omega^\beta(f,2^{-\nu})\Phi^{-\frac{\beta}{2}}[\omega(f,2^{-\nu})]<\infty, \tag{11}$$

then the series (5) converges.

Proof The theorem is proved using Theorem 1 and Lemma 1. Indeed, since

$$\omega_\Phi(f,2^{-\nu})=\sup_{|\delta|\leq 2^{-\nu}}\overline{M}\{\Phi[|f(x+\delta)-f(x)|]\}\leq$$

$$\leq 2hV_\phi(f)=\sup_{|\delta|\leq 2^{-\nu}}\sum_{\nu=1}^{\infty}\phi[|f(x+2^{-\nu})-f(x)|]\leq 2^{-\nu},$$

then substituting $2^{-\nu}$ instead of $\omega_\Phi^{\frac{\beta}{2}}(f,2^{-\nu})$ into inequality (4), we get inequality (8), which proves theorem 3. □

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In the future, we will establish the convergence condition of series (5) for the existence of the spectrum $\Lambda = \{\lambda_k\}_{k=1}^{\infty}$. In this case, we need to prove the following

Lemma 2. *If $a_1, a_2, \ldots$ are positive numbers, then for any χ series*

$$\sum_{\nu=1}^{\infty} 2^{\chi\nu} a_{2^\nu}$$

and

$$\sum_{k=1}^{\infty} k^{\chi-1} a_k,$$

either converge or diverge at the same time.

Note that this lemma is implicitly contained in [10] (see page 13).

Indeed, due to the monotony of a_k, for any ν we have

$$2^{\chi\nu} a_{2^\nu} \le 2^{|\chi|+1} \sum_{k=2^{\nu-1}+1}^{2^\nu} k^{\chi-1} a_k \le 2^{2|\chi|+1} 2^{\chi(\nu-1)} a_{2^{\nu-1}},$$

and from here

$$\sum_{k=1}^{\infty} k^{\chi-1} a_k = a_1 + \sum_{\nu=1}^{\infty} \sum_{s=2^{\nu-1}+1}^{2^\nu} s^{\chi-1} a_s.$$

Lemma 3. *If $a_k \downarrow 0$ and $\sum_{k=1}^{\infty} a_k = +\infty$, then the flat $\Delta a_k = a_k - a_{k+1}$, we have*

$$\sum_{k=1}^{\infty} k \Delta a_k = +\infty.$$

Let 's put

$$k^{\chi-1} a_k = \sum_{\nu=1}^{k} \nu \Delta a_\nu.$$

By virtue of $a_k \downarrow 0$ we have $\Delta a_\nu \ge 0$ $(\nu = 1, 2, \ldots)$. So all $k^{\chi-1} a_k \ge 0$ and does not decrease monotonically. We need to prove that $k^{\chi-1} a_k \to \infty$. If this were not true, then

$$k^{\chi-1} a_k \uparrow a \quad (a \ne +\infty).$$

Then $k^{\chi-1} a_k = a - \varepsilon_k$, $\varepsilon_k \downarrow 0$, and hence since

$$k^{\chi-1} a_k - (k-1)^{\chi-1} a_{k-1} = k \Delta a_k = (a - \varepsilon_k) - (a - \varepsilon_{k-1}) = \Delta \varepsilon_{k-1},$$

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that

$$\Delta a_k = \frac{\Delta \varepsilon_{k-1}}{k}.$$

By virtue of $a_k \to 0$ and $\Delta \varepsilon_\nu \geq 0$ we have

$$a_k = \sum_{\nu=k}^{\infty} \Delta a_\nu = \sum_{\nu=k}^{\infty} \frac{\Delta \varepsilon_{\nu-1}}{\nu} \leq$$

$$\leq \frac{1}{k} \sum_{\nu=k}^{\infty} \Delta \varepsilon_{\nu-1} = \frac{\varepsilon_{k-1}}{k},$$

and therefore $ka_k \to 0$

But, applying to the sum representing $k^{\chi-1}a_k$, the Abel transform, we find

$$k^{\chi-1}a_k = \sum_{\nu=1}^{k} \nu \Delta a_\nu = \sum_{\nu=1}^{k+1} a_\nu = a_1 + a_2 + ... + a_{k+1},$$

and since $k^{\chi-1}a_k \to a$, and $ka_k \to 0$, then $a_1 + a_2 + ... + a_{k+1} \to 0$, which contradicts the condition

$$\sum_{k=1}^{\infty} a_k = +\infty.$$

Let $\sum_{k=1}^{\infty} k^{\chi-1}a_k$ be a convergent series with $k^{\chi-1}a_k \downarrow 0$. We believe

$$r_n = \sum_{k=1}^{\infty} k^{\chi-1}a_k.$$

We will say that a series satisfies condition (A) if

$$r_n = O(k^{\chi-1}a_k). \tag{12}$$

If the terms of the series decrease no slower than some geometric progression, that is, if

$$(k+1)^{\chi-1}a_{k+1} < \theta k^{\chi-1}a_k, \quad 0 < \theta < 1,$$

then it satisfies condition (A), but the reverse conclusion is, of course, incorrect, as at least such an example shows

$$(2k-1)^{\chi-1}a_{2k-1} - (2k)^{\chi-1}a_{2k} = \theta^k, \quad k \in N; \quad 0 < \theta < 1.$$

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We show that if a series satisfies condition (A), then whatever $\theta < 1$, it can be divided into a finite l series (l envy of θ) so that the terms of each of them decrease no slower than the geometric progression with the denominator θ.

Indeed, condition (12) means that $r_n < ck^{\chi-1}a_k$, where c is constant. Let θ be given. Let's choose the number l so that

$$l = [\frac{c}{\theta}]. \tag{13}$$

Then by virtue of the monotonous decreasing of the numbers $k^{\chi-1}a_k$ and by virtue of (13) we have

$$(l+1)(k+l)^{\chi-1}a_{k+l} \leq \sum_{\nu=k}^{\nu=k+l} \nu^{\chi-1}a_\nu \leq \sum_{\nu=k}^{\infty} \nu^{\chi-1}a_\nu \leq ck^{\chi-1}a_k, \tag{14}$$

and therefore it follows from (14) that

$$(k+l)^{\chi-1}a_{k+l} \leq \frac{c}{l+1}k^{\chi-1}a_k \leq \theta k^{\chi-1}a_k.$$

Hence, all l series

$$1^{\chi-1}a_1 + (1+l)^{\chi-1}a_{1+l} + (1+2l)^{\chi-1}a_{1+2l} + ...,$$

$$2^{\chi-1}a_2 + (2+l)^{\chi-1}a_{2+l} + (2+2l)^{\chi-1}a_{2+2l} + ...,$$

.....,

$$l^{\chi-1}a_l + (2l)^{\chi-1}a_{2l} + (3l)^{\chi-1}a_{3l} + ...,$$

it can be decomposed into a series

$$\sum_{\nu=1}^{\infty} \nu^{\chi-1}a_\nu,$$

which decreases no slower than the geometric progression with the denominator θ.

1.2. Let the spectrum be λ_k and for $\rho > 0$ the condition $k^\rho = O(\lambda_k)$ is satisfied. Let's choose an increasing function $\lambda(x)$ such that $\lambda(k) = \lambda_k$ then

$$y^\rho = x\frac{y^\rho}{\lambda(y)} = O(x) \quad (x = \lambda(y)),$$

hence

$$y = O\{x^{\frac{1}{\rho}}\}.$$

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Hence

$$\mu(2^{\nu}\pi) - \mu(2^{\nu-1}\pi) \leq \mu(2^{\nu}\pi) + 1 = O\{2^{\frac{\nu}{\rho}}\},$$

and condition (4) can be replaced by the condition

$$\sum_{\nu=1}^{\infty} 2^{\frac{(1-\beta)\nu}{\rho}} \omega^{\beta}(f, 2^{-\nu}) \omega_{\Phi}^{\beta/2}(f, 2^{-\nu}) \Phi^{-\beta/2}[\omega(f, 2^{-\nu})] < \infty,$$

или согласно леммы 2

$$\sum_{\nu=1}^{\infty} k^{\frac{(1-\beta)\nu}{\rho}-1} \omega^{\beta}(f, k^{-1}) \omega_{\Phi}^{\beta/2}(f, k^{-1}) \Phi^{-\beta/2}[\omega(f, k^{-1})] < \infty.$$

The statement of Lemma 2 is obtained from the fact that the function $\frac{u^2}{\Phi(u)}$ is non-decreasing. By virtue of Theorem 2 , the following holds.

Theorem 4. *Let $k^{\rho} = O(\lambda_k)$ when $\rho > 0$. And let for the function $f \in B_2$ at $0 < \beta < 2$ takes place*

$$\sum_{k=1}^{\infty} k^{\frac{1-\frac{\beta}{2}}{\rho}-1} \omega_2^{\beta}(f, k^{-1}) < \infty, \tag{15}$$

where $\omega_2(f,h) = [\sup_{|\delta|\leq h} M\{|f(x+\delta) - f(x)|^2\}]^{\frac{1}{2}}$. Then the series (7) converges.

For $\rho = 1$ and $\omega(h) = O\{h^{\alpha}\}$, the result is obtained in $\beta > \frac{2}{2+\alpha(2-r)}$ (see [8], p. 137), and for $\rho = \beta = 1$ we get Bernstein (see [7], p. 231)

$$\sum_{k=1}^{\infty} \frac{1}{\sqrt{n}} \omega_2(f, k^{-1}) < \infty.$$

Now we denote $V_r(f) = [V_{\Phi}(f)]^{1/r}$ for $\Phi(u) = u^r$. The value of $V_r(f)$ is called r-a variation of the function $f(x)$.

According to Theorem 3 and Lemma 2 , the following statement holds

Theorem 5. *Let $k^{\rho} = O(\lambda_k)$ when $\rho > 0$. If at $0 < r \leq 2$ the function $f \in B_2$ has a finite r-variation, besides at $0 < \beta < 2$ exists*

$$\sum_{k=1}^{\infty} k^{\frac{1-\frac{\beta}{2}}{\rho}-\frac{\beta}{2}-1} \omega_n^{\beta(1-\frac{r}{2})}(f, k^{-1}) < \infty,$$

then the series (5) converges.

In the case when $\rho = 1$ and $\omega(h) = O\{h^{\alpha}\}$ we get $\beta > \frac{2}{2+\alpha(2-r)}$, which for $r = 1$ obtained by Varashkevich and Zygmunde (see [8], p. 138). For $\rho = \beta = 1$, we obtain the following statement about the absolute convergence of the series (3).

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Theorem 6. *Let $f \in B_2$ and $k^\rho = O(\lambda_k)$ when $\rho > 0$. Suppose that $\omega(h) = O\{h^\alpha\}$ and $V_r(f) < \infty$ for $\alpha > 0$, $0 < r \leq 2$. Then the series (3) absolutely converges.*

This theorem for $r = 1$ was obtained by Sigmund. If in Theorem 5 $\rho = \beta = r = 1$ we obtain the known condition of absolute convergence of series (3) ([7], p. 231)

$$\sum_{k=1}^{\infty} \frac{1}{k} \sqrt{\omega(f, k^{-1})} < \infty,$$

which generalizes Sigmund's result.

1.3. **Definition 3.** A sequence of natural numbers

$$n_1 < n_2 < ... < n_k < ...$$

are called lacunar if there exists such a $q > 1$ that

$$\frac{n_{k+1}}{n_k} \geq \quad (k = 1, 2, ...).$$

Now let the lacunar condition

$$\frac{\lambda_{k+1}}{\lambda_k} > q > 1$$

be satisfied for the spectrum $\Lambda = \{\lambda_k\}_{k=1}^{\infty}$. Then the spectrum $\frac{\lambda_k}{q^k}$ will be increasing. Let's choose such a function $\lambda(x)$ so that the function $\frac{\lambda(x)}{q^x}$. was increasing and $\lambda(k) = \lambda_k$. Then also increasing and denoting $y = \mu(x)$ we have

$$y = log_q x - log_q \frac{\lambda(y)}{q^{y-1}} + 1,$$

then in the case of $y_1 = \mu(2^{\nu-1}\pi)$, $y_2 = \mu(2^\nu \pi)$ we have

$$\mu(2^\nu \pi) - \mu(2^{\nu-1}\pi) + 1 = log_q 2 - log_q \frac{\lambda(y_2) q^{y_1}}{q^{y_2} \lambda(y_1)} + 1 \leq$$
$$\leq log_q 2 + 1 = O\{1\} \tag{16}$$

By virtue of Lemma 2, condition (6) can be replaced by the condition

$$\sum_{k=1}^{\infty} \frac{1}{k} \omega^\beta(f, \frac{1}{k}) \omega_\Phi^{\frac{\beta}{2}}(f, \frac{1}{k}) \Phi^{-\frac{\beta}{2}}[\omega(f, \frac{1}{k})] < \infty.$$

Theorem 7. *Let the function $f \in B_2$ be bounded at $\frac{\lambda_{k+1}}{\lambda_k} > q > 1$. And let the condition of Theorem 1 be satisfied for the function $\phi(u)$, for $\alpha > 0$, $\omega_\phi(h = O\{h^\alpha\})$. Then for each $0 < \alpha < 2$ the series (5) converges.*

Theorem 8. *Let $\frac{\lambda_{k+1}}{\lambda_k} > q > 1$. Then if $f \in B_2$ and for $\alpha > 0$ the condition $\omega_2(h = O\{h^\alpha\})$ is satisfied, then for $0 < \alpha < 2$ the series (5) converges.*

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By virtue of Theorem 3 we get:

Theorem 9. *Let* $\frac{\lambda_{k+1}}{\lambda_k} > q > 1$ *and the function* $\phi(u)$ *satisfy the conditions of Theorem 3. Let the function* $f \in B_2$ *be bounded and* $V_\phi(f) < \infty$. *Then at* $0 < \alpha < 2$ *the series (5) converges.*

For proofs, it is sufficient to note that the condition

$$\sum_{\nu=1}^{\infty} 2^{\frac{-\beta\nu}{2}} \omega^\beta(f, 2^{-\nu}) \Phi^{-\frac{\beta}{2}}[\omega(f, 2^{-\nu})] < \infty \tag{17}$$

follows when substituting (16) for (11). However, according to Lemma 2, the condition (17) is equivalent to the condition

$$\sum_{\nu=1}^{\infty} \frac{1}{k^{1+\frac{\beta}{2}}} \omega^\beta(f, \frac{1}{k}) \Phi^{-\frac{\beta}{2}}[\omega(f, 2^{-\nu})] < \infty,$$

which follows from the limitations of the spectrum

$$\omega^\beta(f, \frac{1}{k}) \Phi^{-\frac{\beta}{2}}[\omega(f, 2^{-\nu})]$$

and is performed when $\beta > 0$.

When $f(x)$ is a bounded function, theorems 7, 8, 9 at $\beta \geq 1$ are weaker than Sidon's results stating that the lacunar series of periodic and bounded absolute functions converge (see [8], page 139), for almost-periodic functions [6].

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Divergent Paths of Neo-Endogenous Rural Development: A Comparative Analysis of Rural Villages in South Korea

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ABSTRACT

This paper compares two villages in Songak-myeon, Asan City of Chungnam Province in Korea. It tries to show how the joint village project, which began with the support of the same external organization, produces different results depending on the internal conditions and circumstances of the villages. From the end of the 1990s, Pyeongchon-ri and Sugok-ri started developing villages under the influence of the environmentally friendly farming movement. And subsequent supports were provided by local organizations for the development of the village. The village project in Sugok-ri, which initially focused on economic performance, later turned out to be a failure, leading the residents to pursue individual economic interests instead. On the other hand, In Pyeongchon-ri, cooperation among villagers was strengthened in implementing support projects by external agencies with similar goals. Additionally, community ties and identity have been strengthened as residents cooperated to solve problems during the promotion of the village project.

Keywords: neo-endogenous rural development, exogenous development, endogenous development, village project. environmental farming movement, economic performance, cooperation, networks, community ties, identity, rural development.

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Divergent Paths of Neo-Endogenous Rural Development: A Comparative Analysis of Rural Villages in South Korea

ABSTRACT

This paper compares two villages in Songak-myeon, Asan City of Chungnam Province in Korea. It tries to show how the joint village project, which began with the support of the same external organization, produces different results depending on the internal conditions and circumstances of the villages. From the end of the 1990s, Pyeongchon-ri and Sugok-ri started developing villages under the influence of the environmentally friendly farming movement. And subsequent supports were provided by local organizations for the development of the village. The village project in Sugok-ri, which initially focused on economic performance, later turned out to be a failure, leading the residents to pursue individual economic interests instead. On the other hand, In Pyeongchon-ri, cooperation among villagers was strengthened in implementing support projects by external agencies with similar goals. Additionally, community ties and identity have been strengthened as residents cooperated to solve problems during the promotion of the village project. Nevertheless, projects undertaken in Pyeongchon-ri with the aim of improving economic performance all failed. Through these findings, this paper asserts that the neo-endogenous rural development approach, utilizing external support based on internal cooperative network among villagers, must be a very useful method for rural development in contemporary societies.

Keywords: neo-endogenous rural development, exogenous development, endogenous development, village project. environmental farming movement, economic performance, cooperation, networks, community ties, identity, rural development.

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I. INTRODUCTION

Rural development policy has been reshaped since the mid-2000s (Kim & Lowe, 2012). In particular, the OECD's declaration of "Farm Policy 3.0" (OECD, 2015) in 2015 can be said to be a manifestation that the rural development policy is shifting from an economic-oriented exogenous development policy to an endogenous one that focuses on improving the quality of life and well-being of rural residents. However, considering that the OECD announced changes in rural policy paradigm in 2006(OECD, 2006) and then held subsequent seven conferences worldwide over ten years before the release of rural policy 3.0 in 2015, it does not seem that the shift to an endogenous rural development policy was easy. In other words, a shift in rural policy can only occur when numerous stakeholders are persuaded through various theoretical frameworks that explain the changes in real circumstance, rather than

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solely relying on individual ideas from policymakers.[1] Therefore, there is a need for a concept to encompass the various examples that may arise during these transitions, and what has emerged for this purpose is the concept of 'Neo-Endogenous Rural Development'. (Lowe et al., 1995; Ray, 2001; Kim & Lowe, 2012)

There are various studies (Ward et al., 2005; Kim, 2007; Shucksmith, 2009) that apply the concept of Neo-Endogenous Rural Development (NERD), but its actual application is primarily focused on rural areas in Western societies. In countries like South Korea, where exogenous development has historically dominated development policy, finding cases of NERD is challenging. However, Kim (2016) argues that NERD is a transitional policy that emerges during the shift from exogenous to endogenous development. Considering his argument, it is possible to identify cases of NERD in South Korea as well. Given that endogenous development is ultimately the most desirable policy direction for all countries worldwide, this suggests a pathway for transitioning from an exogenous development-oriented country like South Korea to an endogenous development policy.

From this point of view, this paper firstly examines the contents and characteristics of the NERD concept, and then applies it to the cases of two villages, Pyeongchon-ri and Sugok-ri, in Asan City in Chungnam Province. In fact, the development of both villages commenced with support from the same nationwide organization called Hansalim, which could have been considered a form of exogenous development in the initial stage. However, the communities of the two villages responded differently during the implementation processes, resulting in different consequences. To elucidate this development process, this paper ultimately seeks to demonstrate that NERD in South Korea can be explained in a similar way to those applied in Western studies.

II. THE CONCEPT OF NEO-ENDOGENOUS RURAL DEVELOPMENT AND THE CHARACTERISTICS

2.1 The Definition

The concept of Neo-Endogenous Rural Development emerged from the limitation of both the exogenous and endogenous development concepts, which struggled to explain the various forms of rural development in Europe since 1970s. Lowe et al. (1995) criticized the geographical dichotomy inherent in both exogenous and endogenous development concepts. Instead, they advocated for the application of a network paradigm, identifying the network relationships of local stakeholders as a key component of regional development. Ray (2001: 4) coined the term Neo-Endogenous Rural Development, defining it as ‘an endogenous-based development in which extra-local factors are recognised and regarded as essential but which retains belief in the potential of local areas to shape their future'. In other words, the process of forming diverse and complex network relationships within and outside the region is integral to regional development. The process of forming and operating these networks has emerged as a valuable factor to evaluating the extent of development in rural areas where the network relationship between various entities have been relatively loose. As shown in <Table 1>, the characteristics of new endogenous development, centered on network formation, are compared to those of conventional exogenous and endogenous development.

[1] For more information, refer to Kim's article (2015) on so-called “theory-ladenness.”

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Table 3: Features of Exogenous, Endogenous and Neo-Endogenous Rural Development

	Exogenous RD	Endogenous RD	Neo-Endogenous RD
Key principle	- economies of scale and concentration	- Economies of scope - the specific resources of an area (natural, human and cultural) hold the key to its sustainable development	- Network. - Diverse drivers of development
Dynamic force	- urban growth poles (the main forces of development conceived as emanating from outside rural areas)	- local initiative and enterprise	- Interplay of local and extra-local resources
Function of rural areas	- food and other primary production for the expanding urban economy	- diverse service economies	- diverse productive and service economies
Major rural development problems	- low productivity and peripherality	- the limited capacity of areas and social groups to participate in economic and development activity	- Inequalities and asymmetries within network, - Imbalance local and extra-local control - Weak networks (under circuits, power, knowledge and capital)
Focus of rural development	- agricultural industrialisation and specialisation - encouragement of labour and capital mobility	- capacity-building (skills, institutions, local networks and infrastructure) - overcoming social exclusion	- Decentralisation - capacity-building of local actor to steer larger processes and actions - Valuing rural areas (and resources) within wider economic development (incubation and catalyst of growth)

Source: Kim & Lowe. 2012.

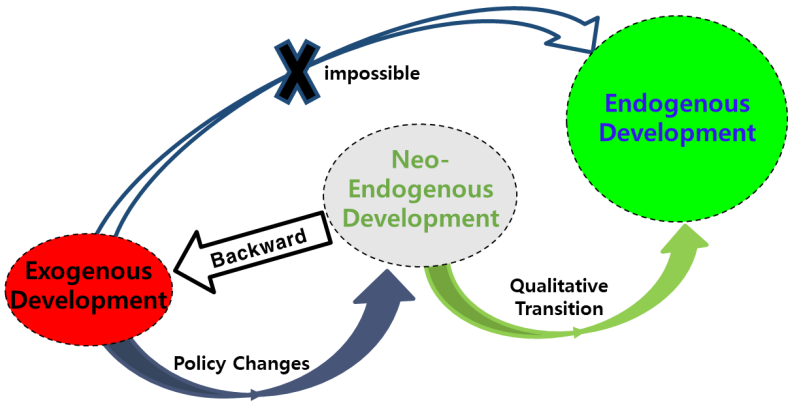
Unlike exogenous and endogenous developments, the NERD argues that rural development is actually driven by various factors and network relationships among stakeholders connected to internal and external factors of the region. In fact, economic performance, previously valued in the process of creating local networks, is explicitly excluded from the purpose of rural development itself. Economic performance is considered only as an implicit factor in the comprehensive goal of network formation and activation of various forces. Therefore, non-economic factors are chosen as explicit goals of development, while economic performance is treated as a sub-goal. These changes in basic objectives have significant impacts on the dynamic force of development, the function of rural areas, perspective on rural problems, and the identification of major development tasks. In essence, most existing economic performances are considered secondary, with the formation and utilization of social relationships emerging as the most important task for regional development, ultimately activating local network relationships. While exogenous development emphasized economic growth primarily based on modernization and neoclassical economic theory, empirical findings (Lowe and Kim, 2003) suggest that many cases of successful rural development were primarily achieved through networking based on the formation of various social relationships.

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In the end, the aim of NERD is to create a sustainable productive and service economy in rural areas based on the networks and the utilisation of (extra) local resources. The obstacles to achieving these objectives are mainly the inequality and asymmetry of networks between internal and external region, imbalances between local and external controls, and the lack of circulation of resources within the region, weakening the network in terms of capabilities, knowledge, and capital of the region. Therefore, to pursue NERD, development must be directed toward the decentralization of power, strengthening the capacity of local actors, and increasing the value of local resources. In essence, NERD is a process that addresses these phenomena as they emerge.

2.2 Implementation of NERD

NERD essentially criticizes exogenous development for proceeding in a manner that undermines local internal capabilities and resources, even if it can enhance economic performance. Furthermore, NERD also critiques the lack of alternatives for internal development, despite the ideal values of pursuing regional industrial links and economic cycles through the development of diverse economic activities in the region. (Kim & Lowe, 2012) In essence, NERD acknowledges the value that endogenous development aims for but highlights that limitations that make it challenging to implement in reality. As argued by Lowe et al. (1995), 'development is not simply caused by in localities, but through the combination of local resources and labor.' Therefore, the implementation of NERD should prioritize establishing the proper utilization of local internal and external resources.



source : Kim, 2016.

Fig. 1: The concept of NERD Implementation.

In NERD, development always occurs under the relationship between local internal resources and the external environment. Thus, creating a system that values local resources while considering external (positive or negative) forces and maintains their performance within the region is both a process and an objective of development. This cannot be achieved unless it adequately responds to external forces. In other words, developments utilizing local residents and resources could revert to an exogenous form at any time unless there is sufficient capability to establish an economic cycle within the region in response to government policy intervention and globalization (Kim and Lowe, 2012). Therefore, it is crucial to analyze the relationship between local resources and extra-local factors during the implementation of development and identify any emerging network imbalances in the process. Ultimately, if the influence of internal actors outweighs that of external factors, it can be considered 'endogenous development'. Conversely, if the impact of external factors exceeds the capacity of internal network, the development may not transition to endogenous development and may revert to the form of in the,process of promoting ‘exogenous development'. These relationships are illustrated in <Fig.1>.

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III. VILLAGE OVERVIEW AND EARLY DEVELOPMENT PROCESS

3.1 Overview of Pyeongchon-ri

Songak-myeon in Asan City of Chungnam Province is a typical mountainous village located in the midst of South Korea, while Pyeongchon-ri features a relatively high percentage of plain area compared to other villages. The village has a history of over 400 years and is currently home to 45 households. Rice farming is the main agricultural production in the village, with approximately 70 % of agricultural households and agricultural land dedicated to environmentally friendly farming practices. Moreover, opportunities for various non-agricultural economic activities are emerging, particularly with the nearby Oeam Historic Village becoming a nationwide tourist destination. Additionally, the opening of road links to Cheonan City and other areas is attracting more people to consider returning to the village. However, the rising land prices resulting from increased accessibility to cities pose challenges not only to agricultural activity but also to the expansion of various village projects.

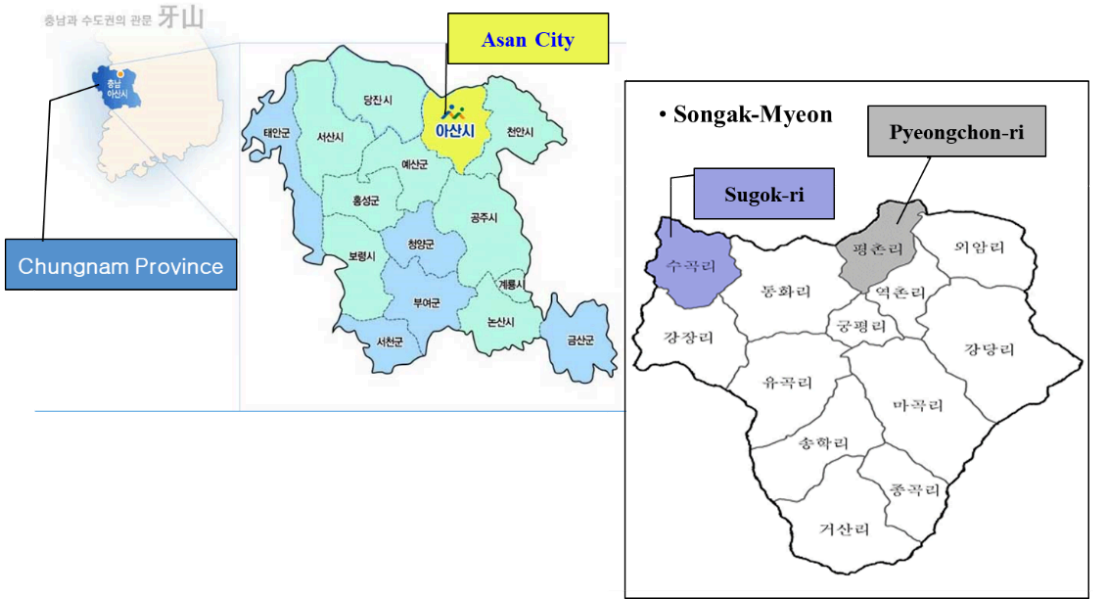


Fig. 2: Geographical location of the villages

3.2 Overview of Sugok-ri

Sugok-ri is a village located at the northeastern tip of Songak-myeon, divided into Sugok 1 and Sugok 2-ri. The focus here is on Sugok 2-ri, which comprised 26 households in 2014. Despite the total number of households remaining constant for over 30 years, with 20 households residing in the village for that duration, Sugok-ri faces a significant challenge of an aging population, as few newcomers settle in the village. Currently, the youngest farmer is 53 years old, with only 5 households in their 50s. Despite being a mountainous village, Sugok-ri has a higher proportion of rice paddies compared to crop fields. However, younger residents are increasingly turning to cultivating farm crops for higher income opportunities. Main crops cultivated include soybeans, pumpkins, sweet potatoes, tomatoes, and cucumbers. Additionally, there is one cattle-shed in the village.

3.3 The start of village projects

The development of the villages Pyeongchon-ri and Sugok-ri began with an emphasis on environmentally friendly farming practices. New changes have emerged in the existing farming methods as some farmers from these villages participated in the Hansalim Asan City Producers'

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Association (Kim Tae-yeon, 2010), which was established in the mid-1990s. In particular, several village development projects have been launched in these villages since 2000, coinciding with the establishment of the Prundle Farming Cooperative corporation by farmers engaged in environmentally friendly farming in Asan. This cooperative aimed to promote regionally-based agriculture and the development of producer associations (Kim Tae-Yeon, 2010)

In Pyeongchon-ri, 13 out of the total 45 households in the village engaged in environmentally friendly farming, while the remaining local residents participated in producer-consumer exchange events promoted by Hansalim. These events provided an opportunity to strengthen ties and cooperation between farmers and residents. Although most farmers were not directly involved with Hansalim, ordinary residents actively took part in village events organized with external organizations. Meanwhile, the development of the village was directly triggered by the establishment of the Songak Alley Farming Corporation in 2006. This corporation took on the production of bean sprouts to supply the Hansalim market, originating from the Prundle Farming Corporation. This initiative was part of the local agricultural movement of the Cheonan-Asan Hansalim, aiming to support self-reliant development through projects at the village level. Supplying bean sprouts to Hansalim laid the groundwork for the growth of the Prundle Farming Corporation, which was later allocated to the 'Songakgol Farming Corporation' in Pyongchon-ri. Additionally, as part of a collaborative event with Hansalim consumers, the corporation organized a milk vetch flower festival. These flowers were planted to prepare environmentally friendly manure, and during the spring season, they were used for various farming and rural experience activities for tourists. The festival, operated in collaboration with farmers and residents, naturally led to strengthened unity and cooperation among residents.

The development of Sugok-ri village also commenced with the participation in Hansalim's environmentally friendly farming campaign. In 2000, this initiative was introduced to the village when 12 out of the total 38 agricultural households joined the Asan City Producers' Association. The farmers viewed this movement as a promising opportunity to secure stable income through contract cultivation and supplying to Hansalim, particularly because they faced relatively lower income levels compared to those in other villages.

In the meantime, the Prundle Farming Corporation established a plan to develop Sugok-ri into a central village for environmentally friendly farming in Asan City. During this period, the large-scale relocation of Samsung Group's plants into Asan City was planned, exerting significant development pressure on rural areas and causing land prices to increase rapidly. Consequently, Prundle faced difficulties in maintaining environmentally friendly farming sites in the Asan region. In response to this situation and as part of a long-term plan to develop environmentally friendly farming in Asan City, Prundle internally devised a local agricultural development plan to nurture the rural areas of Sugok-ri as a model village community and create a self-reliant Hansalim community around the village unit. This plan was based on the belief that Sugok-ri, with its relatively small number of farming households compared to other villages and location in areas less affected by Samsung's development plans, would be relatively easier to garner cooperation and participation among villagers.

To advance this plan, Prundle initiated a project to supply Hansalim with salted cabbage, focusing on the village of Sugok-ri in 2006. This marked the first time that joint projects funded by external organizations were launched for residents of Sugok-ri, who had never voluntarily applied for support projects from central or local governments. During the kimchi-making season, Hansalim was required to produce and supply salted cabbage to consumers, assigning Sugok-ri to handle the business. This

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initiative provided an opportunity to raise basic village funds for revitalizing the village community, while also offering residents a chance to earn additional income compared to other villages.

IV. THE PROCESS OF THE VILLAGE DEVELOPMENT

4.1 Pyeongchon-ri Village Project : the start of external support projects

4.1.1 Expanding the village projects

The village project in Pyeongchon-ri, which originated from participation in Hansalim's environmentally friendly farming movement, was selected for 'The Project for Establishing Traditional Theme Village' funded by the Rural Development Administration (RDA) in 2008. This selection was made through cooperative efforts among the villagers during the application process, and it synergized with other joint projects planned for the village. Under this project, Pyeongchon-ri received a total of 200 million won in funds, primarily allocated for the construction of an experience center. The plan aimed to enhance visitor convenience during Chinese milk vetch festivals and provide a center for villagers to use regularly, offering accommodation and food services. However, as discussions about the existence and potential abolition of the RDA, the organization responsible for supporting the project budget, arose as a social issue, proper budget support for the traditional theme village project was not secured, resulting in delays for Pyeongchon-ri's project. Consequently, the delay in budgetary support caused fluctuations in building material prices, necessitating an additional 30 million won beyond the original budget plan.

To cover these additional expenses, the village head and residents convened a series of village council meetings and decided to support the project through residents' investments. After three village council meetings, it was decided to allow households to contribute up to 1 million won each and to provide an annual dividend of approximately 8%. Ultimately, 33 out of the total 45 households in Pyeongchon-ri contributed 30 million won to bridge the gap, effectively involving the entire village in the initiative, except for a few older households. This process of addressing the challenges stemming from the delayed financial support from the RDA further bolstered cooperation among residents, strengthening community bonds.

After the completion of the experience center, various rural experience projects were conducted, including the milk vetch festivals, attracting approximately 7,000 visitors annually. Moreover, the festival generated additional profits by covering various expenses and providing daily allowances for residents participating in the experience activities, as well as selling agricultural products grown in the village to visitors. Residents earned profits each year from these activities, consistent with the promised 8% dividend. For villagers who needed to sell farm products directly at the market, aside from supplying Hansalim, sales of agricultural products through experience activities proved highly beneficial. In particular, the significant percentage of visitors who experienced the festival returned to the area, enhancing the reliability of agricultural products grown in the village.

Throughout the promotion of the village project, residents discovered that deviations from the original plan served as a catalyst to overcome challenges through voluntary cooperation. Ultimately, navigating external influences via internal collaboration bolstered the self-esteem and identity of residents. Furthermore, the collaborative experience among residents significantly contributed to fostering amicable relations and cultivating a cooperative atmosphere throughout the entire village.

The traditional theme village project, initially funded with a total of 200 million won from the RDA, presented an opportunity for the economic and social development of Pyeongchon-ri. The experience center, equipped with dining facilities, offices, lecture rooms, and accommodations, served as a gathering place for villagers during periods without visitors' stays, facilitating mutual exchange among

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residents. Currently, the experience center can accommodate approximately 50 people at a time, and as a management principle, it does not exceed this capacity.

This operational approach deviates from the typical expansion of accommodations seen in most other experience centers, where the goal is to accommodate more visitors. However, Mr. Ahn, the center's manager, believed that accommodating a large number of people would not contribute to the village's long-term development, as it would inevitably hinder the establishment of deep interpersonal connections. Therefore, the policy of the Pyeongchon-ri Experience Center is to encourage visitors to return and engage in in-depth experiential activities and human interactions within a set number of participants.

Initially intended to receive funding for two years, the project has been continually monitored by the RDA, which provides additional support if necessary. Moreover, the RDA continues to cover all personnel expenses for the current operation of the experience center. This ongoing oversight and support from the RDA have greatly assisted Pyeongchon-ri in carrying out other necessary activities.

4.2 Expanding to operate village-run factory (2010 - 11)

With the successful operation of the traditional theme village project, a growing sense of confidence in expanding community initiatives emerged among the residents. Building on this newfound self-assurance, the village enterprise project was launched to create job opportunities, boost income for residents, tap into new markets for farm products, and increase value-added outputs. In 2010, the project applied for village enterprise support under a policy aimed at establishing a factory for making Jangahchi, specializing in sliced vegetables preserved in soy sauce or soybean paste, and received a total of 50 million won in support from the MAFF. Additionally, an additional 20 million won was raised from residents who had previously contributed to other community ventures, bringing the total funding for the factory to 70 million won.

The Jangahchi plant, a modest-sized facility spanning 80 square meters, focused on producing and selling side dishes primarily made from agricultural products sourced locally in the village. The project operated by supplying side dishes to visitors at the experience center and offering affordable options to households in the village. Due to its low initial investment and utilization of local labor, the project maintained continuous operation with minimal overhead costs.

The Jangahchi project encountered no significant challenges in sustaining the factory's operations, as its primary objective was to enable residents to earn supplementary income through their own efforts and boost their self-esteem in the process, rather than solely focusing on maximizing profits. In essence, the village's food-processing endeavors prioritized enhancing residents' self-esteem and fostering cooperation over pursuing high returns, and as long as the processed products were primarily accessible to residents, the operations could be sustained with modest revenue.

4.3 Package business and social enterprise for economic purpose (2012-13)

4.3.1 Management of Package Business

Building on the successful operations of the experience center and the Jangahchi factory, Pyeongchon-ri ventured into the package business starting in 2012. The establishment of the 'Darami Farming Corporation' within the village aimed to generate additional income for residents through the sale of agricultural products. Recognizing that the income generated from the experience center and the Jangahchi factory was limited, the package business was initiated with the expectation that direct sales of agricultural products produced by residents would yield higher returns. In contrast to many

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other projects focused on fostering cooperation, harmony, or enhancing the self-esteem and identity of residents, the package business prioritized economic objectives aimed at achieving higher income levels.

> "First of all, we decided that the high percentage of visitors who visited Pyeongchon-ri as experienced visitors was highly reliable, so we carried out activities to register visitors to experience centers as pack members. In addition, we started membership registration for consumers connected to sales activities of other farming business in the village." (Interviewed with Mr. Ahn)

In 2013, the project was initiated to deliver packages of agricultural products to registered members. Each package contained whole vegetables, tofu, dairy eggs and Jangahchi, along with other agricultural products produced in the village.

4.3.2 Starting up the social enterprise for vegetable cultivation

"In 2013, alongside the package business, Pyeongchon-ri established a vegetable park aimed at enhancing the income of villagers. This initiative was registered as a preliminary social enterprise in Chungnam Province to secure support for labor costs. Initially operating as a subsidiary of Songakgol Farming Corporation, Pyeongchon-ri constructed three 2,000㎡ vinyl greenhouses and employed a total of 10 vulnerable workers. With an annual labor cost of approximately 150 million won under social corporate certification, the project received significant subsidies from the MAFF to build the vinyl greenhouses. Given Pyeongchon-ri's primary focus on rice farming and the limited number of farms generating high incomes, the project was initiated to promote agricultural diversification at the village level.

4.4 Failure of package business and social enterprise (2014-15)

4.4.1 Suspension of social enterprise for vegetable cultivation

Pyeongchon-ri's village project, which had been expanding until 2013, encountered several setbacks upon entering 2014. Initially, problems arose in the vegetable park business, established as a social enterprise. Ten employees were hired with approximately 150 million won in annual labor costs supported by the government. However, in addition to the actual direct pay, there were additional expenses of about 6 million won per month, totaling around 70 million won per year. While this additional cost might not have been a significant issue if employees could be utilized continuously throughout the year like a regular company, the challenge arose due to the seasonal nature of agriculture. During the winter, there was a low stock of vegetables, leading to insufficient profits. Consequently, it was difficult to cover the additional 70 million won in labor costs annually, resulting in a deficit in business performance.

Furthermore, the revelation that employees of the social enterprise received their salaries from the county office rather than the corporation raised concerns regarding sincerity. During the process, a significant debate ensued regarding whether to continue operating the social enterprise, especially after the office manager inadvertently omitted documents in the project application, leading to a failure to secure support. Consequently, the village council of Pyeongchon-ri ceased operating the vegetable park as a social enterprise and transferred the business to Darami Village Farming Corporation. Currently, the vegetable park project continues to employ four workers in the village without government support, but its performance is comparable to when ten employees were employed previously.

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4.4.2 The cessation of the package business

On the other hand, the package business failed to adhere to food-related laws and regulations, leading to its suspension. Various processed foods such as bean sprouts, tofu, and Jangahchi were included to cater to consumer preferences during the operation of the package business. However, delivering processed food by courier without proper authorization was deemed illegal. Additionally, consumer complaints increased when processed foods spoiled during the delivery process. Consequently, the village unit found it challenging to continue implementing the package business, which included various agricultural products and processed foods according to orders. As a result, the package business is currently on hold.

4.4.3 The Development of the Sugok-ri Project

1) The outcomes of salted cabbage business

Since 2006, when the salted cabbage project began in Sugok-ri, several significant changes have occurred. First, while village common facilities were previously limited, external assistance enabled the establishment of processing facilities for salted cabbage, serving the common interests of the villagers. Second, the village lacked special economic activities after the rice harvest, but the salted cabbage project provided villagers with opportunities for seasonal employment and additional income. Third, additional farming activities were introduced to cultivate cabbage for kimchi-making and other seasoned vegetables. Although the distribution of environmentally friendly agricultural products is restricted to members of the farming community, the unforeseen economic opportunities have encouraged more farmers to consider joining the community. Fourth, previously scarce cooperative activities among villagers have begun to emerge with the implementation of the salted cabbage project.

2) Discontinuation of the salted cabbage business

The salted cabbage project in Sugok-ri, previously supplied by Hansalim, has been highly controversial since 2007. Initially, salted cabbage was sourced from Sugok-ri and Asan City. However, with Hansalim's rapid expansion across the country, there was a significant increase in demand, leading to an absolute shortage of salted cabbage from Sugok-ri. Consequently, Hansalim began purchasing large quantities of salted cabbage nationwide, including from Haenam county in the southern coastal area of Korea. This, in turn, resulted in a sharp decline in profitability for the Sugok-ri business. Additionally, poor cabbage crop yields in Sugok-ri further exacerbated the deficit. This decline in economic feasibility also impacted the revenue of Prundle, responsible for supplying salted cabbage, ultimately leading to the suspension of the Sugok-ri project in 2010.

Another contributing factor was the lack of willingness to address the residents' issues in Sugok-ri. The salted cabbage project was chosen not through the efforts of the villagers, but by Prundle. Consequently, the residents of Sugok-ri became reliant on Prundle rather than taking initiative to resolve issues stemming from the project. Compounding this, since most residents were elderly, the need to hire external workers further compromised the business's viability. Additionally, during the promotion of Hansalim Organic Farming from 2008, Sugok-ri members attempted to collectively manage a livestock shed. However, conflicts among village members over work distribution led to the project's failure."

3) Other community activities (after 2011)

The joint project of Sugok-ri, intended to serve as a model for community development by Hansalim, rapidly disintegrated following the failure of both the salted cabbage project and the operation of the livestock shed. Subsequently, economic interaction between Hansalim members and other village residents nearly ceased, leading to a reduction in Hansalim households from 13 to 5 by 2001. One

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significant reason for this sharp decline was the difficulty experienced by elderly farmers in adhering to the production rules of agricultural practices, which demanded substantial labor. Consequently, there was an increase in the number of farming households leaving Hansalim.

Moreover, cooperative activities among farming households, even among Hansalim members, were rare due to the cultivation of different items. Consequently, limited cooperation among villagers made support from external organizations unfeasible. Shortages of labor during the farming season were addressed not through cooperation or assistance from residents, but by hiring external workers. Consequently, the sale of agricultural products primarily occurred through direct sales to local markets, except for the contracted amounts supplied to Hansalim. Consequently, residents of Sugok-ri began individually seeking ways to increase their own income.

V. PERFORMANCE AND LIMITATIONS

5.1 The Pyeongchon-ri Project

5.1.1 Performance of the village project

The greatest achievement of the Pyeongchon-ri project was the heightened awareness of pride and identity among villagers, as well as the recognition of the necessity for mutual cooperation through the village project. Preventing the formation of a community fund in the early years aimed to avoid creating a sense of prestige disparity between the rich and the poor in the village, fostering an atmosphere of mutual respect among all residents. This served as the foundation for residents to foster a spirit of unity in carrying out future joint projects. Additionally, the economic activities not only maximized profits for some residents but also provided opportunities for the elderly, in need of modest incomes at the level of pocket money, to earn from their own labor. This contributed to a relative boost in confidence and self-esteem, crucial in promoting various economic projects and encouraging residents to participate in the village project.

In Pyeongchon-ri, the experience center and the Jang Ah Chi factory project were maintained in the village through the voluntary investment and participation of residents. Thus, cooperative management among residents emerged as a crucial factor in the continuous maintenance and development of these projects. Any issues arising during the project's operation were addressed through a democratic process in village council meetings and made public to residents. This approach effectively prevented conflicts between residents during the project implementation process.

5.1.2 Implications of the village project

Some of the failed projects in Pyeongchon-ri provide valuable lessons. Primarily, the suspension of both the package business and the social enterprise vegetable complex underscores their shared goal of increasing economic income for residents. However, the failure of these projects can be attributed to their attempts to generate revenue without due consideration. In the case of the package business, efforts to meet consumer preferences and expectations led to challenges in maintaining the quality of agricultural products during delivery. Ultimately, the business not only violated food delivery laws but also failed to meet consumer expectations. Similarly, the failure of the social enterprise vegetable cultivation project stemmed from excessive investment and employment, driven by a desire to maximize profits through increased government subsidies and production. This approach neglected the unique characteristics of vegetable parks, resulting in misallocation of resources. The failure of these village projects in Pyeongchon-ri highlights the importance of prioritizing cooperation and community awareness over profit maximization in rural development initiatives. Fostering a communal spirit of cooperation can effectively address the various challenges that arise in business operations.

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5.2 The Sugok-ri Project

Sugok-ri exemplifies a typical rural village in Korea, characterized by geographical disadvantages, an aging population, a shortage of young farmers, and low farming income. Reflecting on the failures of the village projects in Sugok-ri, it becomes evident that the fundamental issue lies in the projects not originating from the residents' requests. Essentially, residents participated in the salted cabbage project primarily to earn additional personal income, rather than to strengthen community ties or foster village growth. Similarly, conflicts arose in the proposed livestock shed project in Sugok-ri due to a lack of cooperation among villagers in accommodating each other's time and conditions. The joint projects in Sugok-ri serve as typical examples of how economically driven initiatives are prone to failure once they become financially unsustainable. Moreover, economically motivated relationships among villagers are easily dismantled. Consequently, fostering mutual trust and cooperation among villagers emerges as crucial for inducing fundamental changes in rural villages and ensuring their continuous maintenance. These relationships are essential components of villagers' self-esteem and identity. It's imperative to recognize that village projects supported by central or local governments may be hindered by the disruption of social relations within villages if they solely prioritize short-term economic gains.

VI. CONCLUSION

The comparison of the development processes of Pyeongchon-ri and Sugok-ri yields several implications. Firstly, even in countries like Korea, which have traditionally relied on exogenous developments, recent success stories in rural development primarily stem from non-economic initiatives. Policies aimed solely at enhancing economic performance often result in the success of specific business entities but fail to foster sustainable development within villages or communities.

Secondly, to cultivate a distinct identity and community consciousness in rural communities, it is imperative to implement policy-supported projects based on cooperative activities. These initiatives naturally encourage the establishment of activities that strengthen mutual cooperation and bonds among village residents. Leveraging the cooperative atmosphere of rural society, support for additional social and economic projects should be implemented to facilitate community development.

Thirdly, the case of village development in Pyeongchon-ri demonstrates the effectiveness of the neo-endogenous rural development approach in promoting successful village development. This suggests the need to reform rural development policies to prioritize internal organization within rural areas and utilize external support based on internal needs."

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