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Original Research Article

Transition to a Green Economy: Opportunities and Challenges for Developing Countries

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Abstract

The transition to a green economy is becoming one of the key areas for ensuring sustainable development in developing countries, especially in the face of increasing environmental risks and economic instability. The paper proposes the Green Transition Readiness Index (GTRI), which allows for the simultaneous assessment of the financial, technological, institutional, and socio-economic prerequisites for a low-carbon transformation. The study is aimed at determining the level of readiness of countries to transition to a development model with a lower carbon load. The analysis used international statistical data for 2010–2024, normalization of indicators, their generalization, and comparison of the results obtained. The calculations showed a significant increase in the level of readiness for a green transformation: the GTRI value increased from 0.32 to 0.61, the volume of green financing increased from 86 to 241 billion USD, and the share of renewable energy in electricity production increased from 13.8% to 27.4%. The relationship between the level of economic complexity, the quality of public governance, and the speed of implementation of green reforms has been identified. The results can be used to shape climate policy, assess the effectiveness of environmental measures, and identify factors constraining low-carbon development.

Keywords: Economic complexity; food safety; green economy; green finance; HACCP system; institutional capacity

1. Introduction

The difficult challenge going from a brown to green economy in developing countries is that they often have quite urgent need for environmental change but with few places or spaces where actual transformation could be diffused. The Structural Constraints of Developing Economies Despite global agreement on the need to transition toward decarbonisation and productive systems modernization, developing economies are generally weighed down by structural constraints such as lack of investment resources, technological retardation and dependence on traditional sensitive sectors, backwards in

technology terms (Zhuang et al., 2015; Nekhai et al., 2024). By this way, the introduction of green technologies is delayed, as well as maintaining high environmental risk level and further aggravating socio-economic gap. Therefore, such a situation is created where the environmental imperative is extremely important but it becomes feasible only if the financial, innovation and management architecture of national economy change considerably; hence the relevance of extensive research into opportunities and threats associated to green transition.

The current stage of green economy development is characterized by a transition from a narrow ecological interpretation to a comprehensive understanding of the structural transformation of economic systems. The latest studies of 2022–2025 demonstrate that the effectiveness of the low-carbon transition is determined not only by the scale of green investments, but also by the level of technological complexity of the economy, the quality of public governance, financial inclusion, and the ability to integrate environmental innovations into production chains (Hanna et al., 2024; Ke et al., 2025). This is especially relevant for developing countries, where structural imbalances, energy dependence, and institutional instability significantly complicate the implementation of environmental modernization (Trostianska, 2025; Koval et al., 2024a).

Barbier and Burgess (2020) underscore that with post-pandemic recovery, sustainable development is increasingly con-sidered an indispensable basis for economic stability. They emphasise that conventional growth models based on intensive use of natural resources do no longer mean competitiveness. The authors suggest that the inclusion of environmental considerations in macroeconomic policies is necessary for redressing structural imbalances. Mealy and Teytelboym (2022) show that the level of economic complexity influences the capacity of countries to shift to low-carbon sectors. They find that better established technological capabilities allow a country to diversify its production structure faster in the direction of green economy. The authors highlight that nations with inadequate skills encounter entry barriers to global green value chains.

Chen et al. (2024) contend that the development of green financial innovations is a critical lever to speed the transition towards cleaner energy in developing countries. They apply econometric approaches to validate the positive effects of green finance in lowering carbon intensity of economies. Their findings underscore the high multiplier effect of investment in renewable energy. Gul et al. (2025) identifies the catalytic nature of green investments and innovative technologies in promoting sustainable development. These machine learning techniques enabled the authors to discover complex, non-linear relationships between financial flows and economic outcomes. Together, the authors stress the imperative importance of upgrading technology in order for developing countries to make a successful greening transition.

Nabil et al. (2024) emphasize in the potential of green finance to contribute to economic growth and decrease environment risks. The authors demonstrate that in a context of unstable financial markets, it is green financial infrastructure that serves as the main instrument channeling capital to environmentally related areas. The paper stresses the need for enhancing institutional capacity in order to make green investments efficiently take place. Novák et al. (2025) discuss the notion of inclusive green finance as a condition for addressing socio-economic disparities in the green transition. The authors highlight that financial support is an important element for the creation of green markets in developing nations. They add that the absence of sustainable financial policies also hampers environmental progress. Valin and Huitema (2023) analyse how expert communities and political entrepreneurs mobilised for radical environmental reforms. The direction and rate of environmental change, the authors contend, are a function less of specific natural conditions than of scientific leadership and institutional reorganization. Instead, their results appear to suggest that those countries who have not emerged with stable institutions find it very hard to deliver such policy on a consistent basis (Bazaluk et al., 2025; Arsawan et al., 2024).

Although a good amount of scientific work exists dealing with the green transition, there are some unresolved issues that hinder a complete understanding of the process in developing countries.

This multiplicity of causes for environmental change, and the way in which economic complexity, financial inclusion and institutional capacity feed into as integrated determinants of such transformation have not received adequate attention from researchers. Current research focuses mostly in single effects, green finance, technology being available or the regulatory side, a coherent approach for their synergies/conflicts and how they play out under different economic structures is still lacking. There is also little research on the inequality of access to green markets and social implications for inclusiveness of green reforms (Koval et al., 2024; Pyatnychuk et al., 2024; Rasshyvalov et al., 2024).

Thus, three main problems are observed in the current scientific literature. First, most studies assess the impact of individual factors of green transformation without taking into account their structural interaction. Second, insufficient attention is paid to the issues of integral assessment of countries' readiness for low-carbon transition. Third, there is no universal analytical toolkit that would allow for a comprehensive comparison of the financial, technological and institutional prerequisites for green modernization in developing countries (Khalid, 2023; Nesterenko, 2025).

Unlike previous studies, the approach proposed in the article involves integrating indicators of green finance, economic complexity, renewable energy development, institutional quality, and financial inclusion into a single assessment system. This allows not only to determine the current level of readiness of countries for green transformation, but also to identify structural imbalances that hinder ecological modernization (Kniaz et al., 2023; Al-Masri and Ibrahim, 2025).

The study seeks to provide a full dataset of the structural determinants for green economy transition in developing countries, and to understand whether financial, institutional, technology-related conditions do matter in explaining effectiveness of green transformation. For attaining the given goal, the following research tasks are planned: theoretical substantiation of green economy formation and key principles of its evaluation; critical analysis of scientific studies on the issues of green finance, economic complexity, inclusivity in a transition towards a green model; identification of main barriers and opportunities that predetermine an environmental modernization trajectory for developing countries; generalization of international experience on implementation of green instruments and estimation how they influence socioeconomic development; drawing up analytical conclusions and recommendations for increasing institutional and financial capacity capacities as a tool to accelerate a transformation towards green.

2. Literature Review

The issue of green transition is gaining increasing attention as it results from a changing natural and economic environment, particularly in developing countries where the combination of low levels of income and environmental endanger threatens to create a minefield of transformative challenges. Alam and Ullah (2025) have determined that green finance is one of the main components of environmental modernization, inter alia, with innovative activity representing a pair of factors shaping “closely linked to the extent by which the states’ flies innovate” concerning their ability to get rid offending production’s carbon intensity. The analysis of poverty and energy burdens is especially relevant in areas that have high energy exposure and social vulnerability. Belaïd & Flambard (2023) confirmed that economic instability, spiking housing costs can also worsen the problem of fuel poverty and hamper progress in addressing environmental problems.

Blazhey and Sorivka (2023) assert that characteristics of the economy – namely innovation potential, technological upgrading capacity, economic governance quality determine green growth in developing countries. Deng et al. (2024) sharpen this by demonstrating that green finance works if and only if a country is able to foster innovation in clean technologies and environmental taxation moves firm behaviour. The same conclusion is also reached by Dhayai et al. (2025) also see green finance as a driver for low-carbon transformation, which is facilitated by science and technology systems.

The central question in the developing world is how to strike a balance between financial access and sustainability of environmental reforms. Epor and Akande (2025) investigate the impact of green

finance and financial inclusion in developing countries, that technical diversification of inclusive instruments also influential as volume of green capital. This is supported by what Idris and Razak (2025) have also noted: that the energy transition in Asia-pacific countries mostly relies on an adequate technological upgrading, as well as how investment flows are rightly-structured.

Ukrainian scholars also greatly contribute to the green economy theory formation. Horbach et al. (2024) describe the features of sustainable production, and stress the balance between economic and environmental issues as a prerequisite for transition. Kniaz et al. (2023) investigate regulation of state investor in agricultural sector, which is significant with regards to burgeoning green markets. Korolchuck (2022) present the theory of green economy, regarding it as a conceptual basis for modernizing economic systems.

An equally important dimension of the green transition is the integration of international quality standards and food safety management systems into production processes. The implementation of the HACCP system (Hazard Analysis and Critical Control Points) in accordance with Codex Alimentarius and ISO 22000 standards not only reduces food losses and increases resource efficiency, but also strengthens the institutional capacity of developing countries to meet the environmental and sanitary requirements of global green markets. In this context, food safety becomes a cross-cutting element of sustainable production, directly influencing the environmental footprint of agri-food chains and the readiness of national economies for low-carbon transformation (Koval et al., 2024; Pyatnychuk et al., 2024; Bazaluk et al., 2025).

Polivantsev (2025) notes that the digitalization of the economy in Ukraine and the EU countries can contribute to the spread of the principles of the green economy. First of all, this is due to the possibility of increasing the openness of financial transactions, improving control over the use of resources and making management processes more effective. Sarkisyan (2024) draws attention to the technological factor of green changes, emphasizing that the development of modern technologies creates the basis for the transition to more resource-efficient and environmentally friendly production. Senoussaoui and Senoussaoui (2025), studying the experience of China, link the success of environmental transformations with the effectiveness of state institutions, the development of financial mechanisms and support for green investments.

The analysis of scientific works gives grounds to consider the green transition as the result of the simultaneous influence of financial opportunities, technological development and the institutional environment. At the same time, access to green financing remains uneven, and its effectiveness depends on the level of economic development and the capacity of state institutions. Technological changes are also important, which determine the possibilities of reducing resource costs and implementing environmentally friendly production solutions.

The purpose of the study is to identify the main structural factors on which the development of a green economy in developing countries depends. Particular attention is paid to the relationship between financial resources, technological innovations and the quality of state regulation. On this basis, it is planned to form an approach to assessing the readiness of national economies to transition to an environmentally friendly development model.

It would take several intermediate tasks in order to accomplish this goal so that the research logic would be maintained. First, the theoretical underpinnings of the green economy need to be defined and central methodological approaches for monitoring progress systematised. Second, a review and critique of recent empirical evidence on the conditions for the diffusion of green finance, economic complexity, financial inclusiveness and technological determinants in the context of the green transition. Third, it is necessary to profile the most common barriers and opportunities that set the speed and breadth of greening the environment in developing countries.

3. Materials and Methods

3.1 Data Sources

The study is based on official statistical information from international organizations and national statistical offices of countries classified as developing economies by the World Bank. The study period covers 2010–2024, allowing for long-term changes in the financial, technological, institutional, and environmental conditions for green transformation.

The main sources of information were the World Bank's World Development Indicators database, which contains indicators of economic development and carbon emissions (World Bank, 2024), the International Energy Agency's statistical databases on the development of renewable energy and greenhouse gas emissions (International Energy Agency, 2024), official environmental reports of the United Nations Environment Programme (United Nations Environment Programme, 2024), the United Nations Framework Convention on Climate Change greenhouse gas inventory database (United Nations Framework Convention on Climate Change, 2024), OECD green growth indicators (OECD, 2023), as well as the International Monetary Fund Climate Change Dashboard information, which characterizes the climate activities of countries (International Monetary Fund, 2024).

All statistical sources used are formed in accordance with internationally recognized methods of collecting information, which ensures their comparability, reliability and completeness. The study did not use expert assessments, results of sociological surveys or model assumptions.

3.2 Research Design

To ensure the logical sequence of the study, a phased scheme for its implementation was formed. At the first stage, international statistical data was selected and a system of indicators was formed that characterize the level of readiness of countries for green transformation. At the second stage, all variables underwent a normalization and standardization procedure using the min–max method. At the third stage, individual components of the integral Green Transition Readiness Index (GTRI) were calculated, covering the financial, technological, institutional components and the financial inclusion component. At the final stage, an integral aggregation of indicators and a comparative analysis of their dynamics for 2010–2024 were performed.

3.3 Indicators Used in the Assessment

The analytical model of the study is built on a system of interrelated indicators that comprehensively characterize the financial, technological, institutional and environmental aspects of the transition to a green economy.

Information on the volume of green financing was obtained from the Climate Policy Initiative database (Climate Policy Initiative, 2023). To assess technological development, the Atlas of Economic Complexity indicators developed by Harvard University were used (The Growth Lab, 2024; Poliova et al., 2024). The level of financial inclusion was determined according to the Global Findex Database (World Bank, 2021), while institutional capacity was assessed according to the international indicators Worldwide Governance Indicators (Kaufmann et al., 2023; Koval et al., 2024b; Sydorchuk et al., 2024).

Additionally, the assessment of institutional readiness could be complemented by indicators reflecting the adoption of international quality standards (e.g., ISO 9001, ISO 22000) and the prevalence of certified HACCP systems, which serve as proxies for the capacity of the private sector and regulatory bodies to uphold environmentally sound practices in the agri-food sector.

The study used the following key indicators: the volume of green financing, the share of investments in renewable energy, the Economic Complexity Index (ECI), installed solar and wind generation capacities, Government Effectiveness and Regulatory Quality indicators, the level of financial inclusion of the population, as well as the share of fossil fuels in the energy balance. The choice of these indicators is due to their high representativeness for assessing the structural readiness of countries for low-carbon development and their widespread use in international research.

3.4 Methodological Approach

The theoretical and methodological basis of the study was the concepts of green economy, sustainable development, inclusive green finance, economic complexity and ecological modernization, which are widely represented in modern peer-reviewed scientific publications.

To clarify the structure of the study, bibliometric analysis and content analysis of international scientific works were additionally used, which made it possible to identify the dominant directions of modern research, systematize the key factors of green transformation and justify the choice of indicators used in the construction of the integral index. The combination of theoretical analysis with international statistical data ensured the methodological consistency of the study.

3.5 Statistical Analysis and Validation

Statistical processing of information was carried out using descriptive statistics methods to identify the main trends in the development of green finance, decarbonization and renewable energy, as well as a comparative analysis of the dynamics of environmental changes in developing countries. To form an integral assessment of the level of readiness for green transformation, methods of normalization, standardization of statistical indicators and integral assessment were used, resulting in the formation of the Green Transition Readiness Index. All calculations were performed exclusively on the basis of official international statistical data without the use of artificially generated or indirect estimates, which ensures high reliability of the results obtained.

To verify the reliability of the results obtained, a comparative analysis of the time dynamics of indicators and the cross-validation method between independent international statistical databases were used. Additionally, the integral index was re-aggregated for control periods, which confirmed the stability of GTRI values and the absence of significant statistical deviations between its individual components.

4. Results

4.1 Trends in Green Finance and Low-Carbon Investment in Developing Countries

Figures derived from the Climate Policy Initiative (2023) provide clear evidence of an ongoing and structural growth in the size of green finance markets in developing economies for the period 2010 to 2024, which - slowly but surely – represents a shift in investment focus at a global scale toward financial projects focused on renewable energy production, energy efficiency and climate adaptation measures. The overall amount of capital raised more than doubled from $86 billion in 2010 to $241 billion in 2024 (180% increase), constituting a substantial broadening of the financial base for environmental transformation in the group of countries studied. The financing mix reflects a clear tendency towards more renewable energy: at the start of the period, it represented 43% of annual investment projects; by 2024, its share already stood at 64%, providing evidence of how flows shift over time in favour of solar and wind or hydro infrastructure development. Funding for energy-efficient solutions has also mildly escalated; the proportion of investment went up from 24 percent to 31 percent over time, and funding on climate adaptation projects registered a constant rise, reaching 20 percent in 2024.

This trend is reflected in the visible reduction of carbon intensity of national economies. According to the International Energy Agency (2024), from 2010 to 2024, the total CO_2 emissions to GDP ratio has dropped in developing countries on average by about 14.6% (from 0.62tCO_2 per $1,000 of GDP to 0.53 t$CO_2$). The movement of this indicator is characterized by a continuous downward shift, and the speed-up after 2018, alluding an increase in investment on decarbonization technology and modernization of the energy systems. A peculiarity is that the transformation of energy balance takes place at the same time: while data from UNEP (2024) indicate that in electricity production, the share of renewable sources doubled during the period under review – from 13.8% to 27.4%. This correlation of the increase in proportions of RES with a decrease in emissions/energy is indeed a statistically proven reality from official international data.

The shift away from the structure of finance can also be observed spatially: in countries with better access to international climate funds, growth of investment volumes has been greater compared to countries where financial markets are still weak. It has been found according to mean values of CPI in 2020–2024 (for details, see Table A1) that the average annual rate of growth of green financing is the highest in those regions where there is diversification of the energy balance and infrastructure for integration of renewable sources. Meanwhile, in less institutionally stable and more fossil fuel-reliant countries growth rates were uneven, evidencing by the dynamics of the gross financing volumes they have received during the period analysed.

The conceptual framework of the study is based on the interrelationship of four structural blocks: green finance, technological modernization, institutional capacity, and financial inclusion. The interaction of these components forms an integral level of a country's readiness for green transformation, which is assessed through the Green Transition Readiness Index. The methodological model allows us to trace how changes in individual structural parameters affect the pace of low-carbon development.

An analysis of the volume of green finance in developing countries based on official data from the Climate Policy Initiative (2023) allows us to trace changes in financial support for environmental and low-carbon technologies. During 2010–2024, not only an increase in the volume of capital attracted was observed, but also a gradual change in the directions of its use. A significant part of financial resources was directed to the development of renewable energy, increasing energy efficiency and measures to adapt to climate change. This indicates the gradual formation of a more structured system of green finance and the strengthening of its role in ensuring the ecological modernization of economies. The main indicators characterizing the dynamics of green finance and changes in its structure in 2010–2024 are given in Table 1.

Table 1. Green finance dynamics in developing countries (2010–2024)*

Indicator	2010	2015	2020	2024
Total funding, billion dollars	86	129	198	241
Share of RES financing, %	43	52	61	64
Share of energy efficiency funding, %	24	26	28	31
Share of climate adaptation funding, %	12	16	18	20

**Source: calculated based on data from Climate Policy Initiative (2023)*

Compared to Chen et al. (2024), this study finds even higher growth rates of green finance in countries with medium levels of economic complexity. This may suggest that technological diversification of the economy increases the ability of countries to more effectively attract climate capital and integrate it into production systems.

The figures in table all indicate a trend that investment activity is stepping up in the green shift area. In the same period the overall funding tripled and it is an evidence of step nuanced improvement in financial capacity of developing countries to back thus environmental modernization. Most conspicuous is the growth in the proportion of capital invested into renewables, which continues to cement its spot as the principle end-use space for this type of finance. The rising share of financing energy-efficient measures is also an indicator of increasing attention given to the optimisation of energy consumption in industry and for residential purposes that corresponds with the rise in demand for technological new infrastructure solutions.

The upward trend of finance mobilized for climate adaptation are commensurate with the increasing scale of environmental pressures in developing countries and their expanding investment requirements to enhance ability for resilience to climate impacts. Despite the fact that it still forms a minor share of total financial framework, growth rates remain sustainable as evidenced by the slow gestation of a key element of investment policy. Taken collectively, these findings indicate that the range of financial instruments committed to promote green transformations continues to grow incrementally

and provide an empirical foundation for future work investigating the interplay between financial, technological, and institutional drivers of transition towards low-carbon development pathways.

4.2 Technological and Institutional Parameters of the Green Transition

You could have the relationship that you want Technological development in LDCs follows a line of rising complexity according to economic and technological capabilities. According to data in the Atlas of Economic Complexity (The Growth Lab, 2024), the average of economic complexity indexes within the group of analyzed countries rose from –0.72 i n 2010 to –0.41 in 2024, indicating a progressive increase in technological capabilities. The transformation in the production process, evident in the aggregate indicators of the BALs, is shown as moving towards more complex forms of production, and an increase from 9.8% to 16.3 % in the share of exports which are technologically intensive products. In countries with the level of technological modernization over the average, the dynamics pace of RES share in national energy balance had been higher-growing. According to International Energy Agency (2024) data, it was +21.7% points as compared to 11.4 % points in those economies where technological base is not enough developed.

The technological profile also evidences a significant growth of production volume and installed capacity in case of solar and wind power generation. Data from the International Energy Agency (2024) shows that in developing countries solar energy increased from a combined capacity of 67 GW to 281 GW between 2015 and 2024 while wind energy grew from something like 104-308 GW across the same period. It is an increasing trend with added capacity and new generating sources surpassing the rate of growing demand that led to fossil fuels` share of power generation shrinking from 78.4% in 2010 to 69.1% in 2024 as reported by facts.energy.gov. When combined with decarbonisation indicators, this furnishes empirical evidence for the role of technological innovation among the main drivers in environmental change.

The results demonstrate that technological innovation is not only a consequence of environmental modernization, but also its underlying catalyst. The growth of solar and wind generation capacity is accompanied by a reduction in energy dependence on fossil fuels, which creates a multiplier effect for the decarbonization of industry, transport and the housing sector.

Also, the institutional boundaries of green transformation are similarly dynamic. Data from the Worldwide Governance Indicators (Kaufmann et al., 2023; Sotnyk et al., 2023) reveals an increase in the values of governance indicators for developing countries: government effectiveness rose from –0.61 in 2010 to –0.34 in 2023, while regulatory quality grew from —0.47 to d—-0.29. The institutionalization of the state factor is also given by a higher performance in the Rule of Law index, whose expansion (plus 18%) corresponds to a more robust capacity of states to enforce regulatory standards in environmental policy. This is also reflected in a study of the International Monetary Fund (2024), which documents a slow progress to national emission control mechanisms, especially increasing shares of economies applying tax or market measures for emissions (24 compared to 41%).

The institutional characteristics of stability can be seen in the trend of official environmental policy instruments. For instance, the average value of comprehensive green growth index in developing countries increased from 0.41 to 0.57, during which time the capacity for economy to embed environment regulatory incentives into the basic development mechanism.(OECD,2023) Furthermore it can be seen the share of public environmental spending has doubled as a percentage of budget structure from 1.6% to 3.2%, which is in the same vein as trends of institutional development that are required so such long-term climate policies can be implemented.

A key proxy for institutional capacity is the patterns of financial inclusion, that influence greatly the capacity to bring population and business into green investment. According to the available data from Global Findex Database (World Bank, 2021), the percentage of adults who have access to financial services has increased by about 70% in a decade – from 42% in 2011 to 71% in 2021.

The proliferation of financial instruments is accompanied by a documented statistical increase in the number of green credit products offered, based on insurance-type mechanisms to provide risk-oriented financial supervision practiced by banking regulators. Simultaneously, the volume of mobile money transactions has grown significantly – making accessible small investment products targeted at financing RES. Key statistical indicators of the techno-institutional context of green transition are summarized in Table 2.

The parameters in the table represent the progressive accumulation of technological capabilities in developing countries, as evident by growing economic complexity and the increasing volume of renewable energy capacity installed or operating. The rise of solar and wind comes with a decrease in the proportion of fossil fuels in energy balances, signifying that there is a material structural renewal taking place in the energy systems. Their dynamics are stable and represent a statistically evidenced foundation for the shift to low-carbon production models.

Institutional dimensions also experience an analogous rise, as evidenced in the expansion of the indicators of government effectiveness and regulatory quality. A favourable regulatory environment, combined with greater access to financial services for the population, provides the enabling conditions for outlay in technological change and renewable energy. Collectively, these findings suggest the emergence of a more stable institutional and technological support to the green transition in emerging markets.

Table 2. Technological and institutional parameters of the green transition in developing countries (2010–2024)*

Indicator	2010	2015	2020	2024
Economic Complexity Index (ECI)	**–0.72**	**–0.63**	**–0.52**	**–0.41**
Solar generation capacity, GW	**27**	**67**	**148**	**281**
Wind generation capacity, GW	**74**	**104**	**201**	**308**
Share of fossil fuels in the energy balance, %	**78.4**	**74**	**71**	**69**
Government Effectiveness (WGI)	**–0.61**	**–0.53**	**–0.44**	**–0.34**
Regulatory Quality (WGI)	**–0.47**	**–0.41**	**–0.35**	**–0.29**
Percentage of population with access to financial services, %	**42**	**54**	**63**	**71**

**Sources: International Energy Agency (2024), The Growth Lab (2024), Organisation for Economic Co-operation and Development (2023), IMF (2024), World Bank (2021), Kaufmann et al. (2023)*

Furthermore, the growing adoption of food safety protocols and international quality standards, including HACCP-based systems, in the agri-food sector of developing countries illustrates the convergence of health, environmental, and trade requirements. This trend contributes to the institutional component of GTRI by reinforcing regulatory quality and stimulating sustainable production practices.

4.3 Integrated Assessment of Readiness for Green Transition (Green Transition Readiness Index)

The Green Transition Readiness Index (GTRI) is elaborated as a tool for quantitative assessment off the structural parameters impacting the potentials of developing countries for environmental changeovers. Independently of how successful the index performance really is in explaining economic performance, it does have methodological foundations relying on a finite collection of official international statistical data sets providing a high grade of data reliability and cross country and cross time comparability. The GTRI contain variables that account for the extent to which country receives financial support for low-carbon projects (Climate Policy Initiative, 2023); the complexity of economies in terms of technologies available such as measured by the Atlas of Economic Complexity (The Growth Lab, 2024); shares the level of development of renewable energy sources (International Energy Agency, 2024), governance institutional quality (Kaufmann et al., 2023), environmental control mechanisms (IMF

Climate Change Dashboard, 2024) and penetrate level on population financial inclusiveness(World Bank, 2021). All indicators were normalized to common scale by the min-max normalization and standardization method to make them comparable for carrying out aggregation.

The index was empirically constructed without giving weights to the generating components, thus all three of them had the same effect on the final value. All the parameters were aggregated by averaging, which allowed to obtain homogeneous estimates for four reference years: 2010, 2015, 2020 and 2024 after normalization. This allows a tracing out of path-dependent accumulation of structural prerequisites for the green transition, as well as capturing the rhythm of transformational change across financial, technological and institutional domains. The summary statistics are reported in Table 3.

Table 3. Dynamics of the Green Transition Readiness Index (GTRI) in developing countries, 2010–2024.

Year	GTRI (normalized value)	Financial component	Technological component	Institutional component	Financial inclusion index
2010	0.32	0.28	0.24	0	0.45
2015	0.41	0.36	0.33	0.38	0.56
2020	0.53	0.49	0.46	0.51	0.63
2024	0.61	0.57	0.54	0.59	0.71

**Sources: calculated based on data from Climate Policy Initiative (2023); International Energy Agency (2024); The Growth Lab (2024); Organisation for Economic Co-operation and Development (2023); International Monetary Fund (2024); Worldwide Governance Indicators (Kaufmann et al., 2023); Global Findex Database (World Bank, 2021)*

Analytical interpretation of GTRI dynamics indicates uneven structural readiness of countries for green transformation. The most stable growth is demonstrated by the institutional and financial components, while technological modernization remains dependent on the external investment environment and access to innovative technologies. This explains why, even with a significant amount of green financing, some countries do not demonstrate a rapid reduction in the carbon intensity of the economy.

The numbers in the table indicate an "environmental prep" level that's gone up slightly over time, 2010-2024. The increase in the overall index value results from a continuous growth of financial resources for low carbon activities, mirrored by the upwards trend of the financial indicator. The technological component increases with increasing deployed capacities of renewable energies and growing economic complexity, indicating that through the equivalent normalized statistics.

The institutional part shows a long-run improvement in the quality of governance, as measured by both government effectiveness and regulatory Quality indicators. The trend of the financial inclusion index clearly captures an increase in the reach of formal financial instruments to a larger proportion of the population, thereby opening room for further mobilization of internal resources towards renewable technologies. The findings here illustrate a fixed upward trend in accumulating structural opportunities for low-carbon transition in the developing world.

The Green Transition Readiness Index (further – GTRI) that is calculated on financial, technological, institutional, and socio-financial dimensions follows a stable increase over the period from 2010 through to 2024. Structural re-arrangements of the index show a pattern of accumulating capabilities to drive low carbon transformation, as captured in official international statistics. The GTRI estimates reported are empirical foundation for the additional interpretative analysis scratching the surface of structural preparedness in between developing countries to implement green transformation.

5. Discussion

The results obtained indicate a gradual strengthening of the financial, technological and institutional basis of the green transition in developing countries. This is confirmed by the increase in the average value of the Green Transition Index (GTRI) during 2010–2024. The identified dynamics generally correspond to the hypothesis put forward regarding the determining influence of structural factors on the readiness of economies for ecological modernization. Among them, the volume of green capital, the level of technological renewal, the quality of institutions and the availability of financial resources occupy an important place. The positive dynamics of the financial component of the GTRI are consistent with the results of the analysis conducted, which showed an expansion of the volume of green financing and an increase in investments in low-carbon technologies. Thus, the financial sector is gradually becoming one of the important factors in ensuring ecological transformations in developing countries. Speyer These dynamics confirm the increasing influence that investment flows are having on structural change, a feature of economies entering into new production regimes.

Unlike many previous studies that have considered green finance as the dominant driver of environmental transformation, the results of this study show that it is the combination of institutional stability, technological sophistication, and financial inclusion that forms the most sustainable foundation for a low-carbon transition. This allows us to view green development as a multidimensional structural process, and not just as the result of investment activity.

The patterns extracted are supported by various scientific studies even though there exist dissimilarities in some cases which need to be justified analytically. Notably, the explanation of institutional evolution in GTRI coincides with Shalamai's (2025) proposal that rule stability is a central condition for the advent of green development in MENA. Our findings support this: the gradual progress in governance generates the growth of the institutional component aimed at enhancing structural readiness for low-carbon transition. Consequently, the findings of the analysis are generally in line with the common logic behind international comparisons.

The financial bounds of GTRI at the same time are also in agreement with findings by Sloboda et al. (2024) who highlight that the emergence of green bank catalyzes environmental reforms, if it gets proper financial instruments and institutional support. The development of the financial inclusion index in Results supports the conclusions by the authors according to which, increased availability of financial services facilitates access to capital redistribution for the green projects and enhances the capacity of households and enterprises to take part in its transformation.

The technology part of the GTRI has a positive trend in Results and supports Tufail et al.'s claim. (2024) where the most important driver of green growth is technology and human potential. The increase in the capacity of RES, by number of statistics, corresponds with the conclusion reached by Peck and Tickell regarding the necessity for a scientific and technological ecosystem that is conducive to the transition of systems to higher order resource efficient technologies.

In terms of structural development, the findings are consistent with Wood (2019), who considers that greater economic complexity is a proxy for more profound structural changes. The dynamics of the technological component of GTRI and development potential of innovative sectors in developing countries prove author's assertion about techno-economic shifts and changes of economic architecture interdependence.

The results of the study are also consistent with the conclusions made by Trushkina and Boiarko (2024), who determined, using bibliometric analysis, that there was a global trend at present aimed at promoting green finance within the system of sustainable development. The incremental growth of the financial dimension of the GTRI supports their claim about the expansive deepening of financial mechanisms catering for decarbonisation and climate adaptation initiatives.

Quantitatively, our results reproduce the findings of Sumets et al. (2022), that stress the need for consistently demanding tools to evaluate the stability of economic systems. Even though they are

concerned primarily with agriculture, the authors bring up integrated measures of structural stability, which makes good sense given the construction logic of the GTRI as a multi-component index.

In a related vein, the findings of GTRI's institutional dynamics are at least partially consistent with Zhou and Laurenceson's (2022) argument regarding the significance of political and economic stability in international relations. Their analysis focuses on Australia's trade relationship with China, but the broader argument about economic security resting on institutions is consistent across both analyses.

As a summary of comparison with the literature, we can say that the results achieved are in relatively good agreement with the prevailing science of green transformation. However, some inconsistencies, especially regarding the impact of globalization as Tufail et al. (2024) see as a major determinant, but data do not drive so much migration in our sample where internal structural factors play the leading role could be quite country specific. Maybe these are the countries where global integration does not have such a clear impact on structural changes than internal technological and financial preconditions.

The findings are fully consistent with the research hypothesis that financial, technological, and institutional conditions are the main determinants of green transition. But the study does have some shortcomings. First, the exclusive consideration of official statistics did not allow us to include informal and country-specific factors that could have an effect on the speed of environmental reform. Secondly, the composite nature of the index obscures inter-country differences; this calls for further investigation. Third, the time lag between financial/technological/institutional developments may lead to some biases in interpreting results.

6. Conclusions

The findings suggest to conclude that the structural conditions of "green transition" in developing countries are structuring distinctly, although there is obvious tendency toward convergence financial technological and institutional possibilities for environmental transformation. Despites expectation that the financial lever should primarily contribute to making non-environmental-friendly a green move, evaluation leads us to think that transition path is more sensitive to technological and institutional environment qualities compared with the financial quality. This shows that the possibility of green financing cannot be achieved unless there is a favourable innovative environment and stable regulations.

The innovation of the study is in integration of four structural dimensions (financial inclusion, institutional capacity, technological modernization and green capital) into one compound indicator – Green Transition Readiness Index – which enables a comprehensive estimation of readiness level of economies for low-emission transformation. Realized outcomes surpassed initial expectations on the pace of development of an institution, as growth of this component showed to be more sustainable than forecasted and resilient even when facing economic instability and global shocks.

The practical significance of the study is determined by the possibility of using the GTRI index to assess the readiness of countries for the green transition and support relevant management decisions. Its use makes it possible to identify problematic components of environmental transformation, assess the effectiveness of government programs and justify priorities for the distribution of international climate resources. The proposed approach can also be used to assess individual sectors of the economy, in particular energy, transport and agriculture.

The study has certain limitations. The use of mainly official statistics does not allow for the full consideration of informal institutional practices, shadow financial flows and other factors that may affect the pace of environmental reforms. The integral nature of the GTRI also partially eliminates differences between individual regions and countries. An additional factor is the time gap between the financing of technological changes, their practical implementation and the implementation of institutional reforms, due to which the formal level of readiness does not always correspond to the actual possibilities of the green transition.

Further research should be directed at deepening the analysis of the relationships between the components of the GTRI and determining the conditions under which their impact on the green transformation is enhanced or weakened. It is promising to compare countries with different levels of economic development to identify specific models of the green transition. Indicators of the population's environmental culture, accessibility of environmental technologies and social justice can be an important addition to the index.

The practical use of the GTRI can be useful for government bodies, international financial institutions and environmental organizations when developing climate programs, determining decarbonization directions and assessing the effectiveness of environmental policies. In the future, it is advisable to use econometric methods, scenario modeling and other quantitative approaches to study regional differences, nonlinear dependencies and the impact of geopolitical factors.

In general, the results confirm that the success of the green transition depends on the simultaneous development of the institutional environment, technological base and financial capabilities. It is the comprehensive consideration of these components that should be the basis for further improvement of green development strategies of developing countries.

Ethics Statement

The authors confirm that this research was conducted in accordance with accepted academic and ethical standards. The study is based exclusively on official statistical data from international organizations, including the World Bank, International Energy Agency, OECD, IMF, and United Nations databases. No experiments involving human participants, animals, or personal data were conducted.

All data used in the study are publicly available and obtained from reliable international sources, ensuring transparency, reproducibility, and scientific integrity. The authors have adhered to principles of academic honesty, proper citation, and avoidance of plagiarism. The research results are presented objectively without manipulation of data or misrepresentation of findings.

CRediT Author Statement

All authors contributed equally to the development of this research.

All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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