Sustainable Development

WILEY

Sustainable Development

RESEARCH ARTICLE OPEN ACCESS

Synthesizing Green Growth From Dynamic Capabilities Perspectives: New Implications for Sustainable Development Policies Among G-8 Countries

Şeyma Bozkaya[1] | Stephen Taiwo Onifade[2,3]

[1]Department of Economics and Finance, Faculty of Business and Management Sciences, Istanbul Medipol University, Istanbul, Türkiye | [2]School of Accounting and Finance, Economics Department, University of Vaasa, Vaasa, Finland | [3]ARUCAD Research Centre, Arkin University of Creative Arts and Design, Northern Cyprus, Turkey

Correspondence: Stephen Taiwo Onifade (stephen.onifade@uwasa.fi)

Received: 9 October 2025 | **Revised:** 6 January 2026 | **Accepted:** 3 February 2026

Keywords: dynamic capabilities | energy productivity | environmental policy stringency | green growth | sustainable development

ABSTRACT

Holistic approaches to meeting human needs while also protecting environmental resources and securing the ecological capacity needs of future generations are critical for sustainable development. Therefore, it is a strategic priority for firms to develop production and management practices that focus on sustainability at both economic and ecological levels. This study took a novel approach to extend the dynamic capabilities theory to a macroeconomic context of sustainable development. The green growth processes of G-8 countries are examined in the context of dynamic capabilities theory using annual data for the years 1990–2021. We examined how green technology investments and energy productivity levels affect green growth as a major indicator of sustainable development, while controlling for the differences in environmental policy stringency level and the amount of green energy supply. The CS-ARDL method, which is sensitive to cross-sectional dependence, was used in the study. Positive impacts of both green technology investments and energy efficiency on green growth were observed, with insignificant impacts from the duo of environmental policy stringency and the amount of green energy supply. This outcome buttresses the increasing need to not only boost the amount of investment in green technology, but also pay attention to stimulating energy productivity levels for attaining sustainable development goals (SDG-8) among the G-8 countries.

JEL Classification: Q01, Q50, Q55, Q43, C80

1 | Introduction

The implementation of the sustainable development concept is not only for isolated sectors but should encompass all components of the economic system to guarantee long-term welfare. In this context, the Dynamic Capabilities Theory represents a micro-level approach based on sustainable development principles and aimed at implementation at the enterprise level. Dynamic capabilities focus on the capacity of firms to adapt to changing environmental conditions, restructure their resources, and achieve sustainable competitive advantage. Such environmentally friendly strategies and production processes developed at the micro level not only contribute to firm performance but also support the achievement of sustainable development goals at the macroeconomic level.

Dynamic Capabilities Theory (DC) is a theory that emerged to complement the inadequacy of resource-based thinking to interpret the development and redevelopment of existing resources and capabilities in environments experiencing rapid change (Bleady et al. 2018). The theory was first put forward by Teece, Pisano, and Shuen in 1997. This theory is briefly defined as the capacity of a firm or organization to develop the capabilities they need to maintain their existing competitive advantage in line with rapidly changing environmental conditions and to integrate into new situations. Thus, dynamic capabilities theory encompasses the ability of firms to innovate, make strategic decisions in rapidly evolving new situations, and restructure their resources. Considering the analytical objectives of the theory, it can be categorized as the capacity to perceive and navigate opportunities and threats, to take advantage of opportunities, and to maintain competitiveness by developing, protecting, and, when necessary, restructuring the tangible and intangible assets of the business (Teece 2007). In this context, DC theory is a micro-based theory. However, with its sustainable competitive advantage approach, it is also the basis for sustainable development theories in the face of changing environmental conditions in the macro sense (OECD 2011; UNEP 2011).

The concept of sustainable development first entered the literature in 1987 with the “Our Common Future” report published by the United Nations World Commission on Environment and Development. The concept refers to a development model that combines economic growth, environmental protection, and social equity to meet the needs of the current generation without jeopardizing the ability of future generations to meet their own needs (WCED 1987). The relationship between sustainable development and dynamic capabilities theory examines the correlation between the ability of firms and countries to adapt to rapidly changing environmental and economic conditions and their capacity to achieve sustainable development goals. In this context, these two theories are closely related in that one focuses on sustainability from a micro perspective and the other from a macro perspective.

Dynamic capabilities play a critical role in supporting sustainable development. In particular, the use of dynamic capabilities in innovation processes targeting sustainability can be effective in improving both environmental and economic performance of firms (Wang and Ahmed 2007). Dynamic capabilities theory can support sustainable development in a macro sense by starting from the known micro basis. Through their ability to adapt to new, changing situations and maintain competitiveness, firms can realize the innovations necessary to achieve environmental sustainability and redirect their resources in a way that is appropriate for long-term strategic goals (Teece 2007). Green technology investments and sustainable development keys, such as energy efficiency, can be supported through dynamic capabilities. These capabilities make it easier for firms to comply with environmental regulations and adopt sustainable business models. Therefore, sustainable development can be realized in line with the desired goals.

Meanwhile, the concept of green growth first came to the agenda at the Rio + 20 Conference on Sustainable Development in 2012 (UN 2012). The theoretical idea of green growth argues that economic expansion can be achieved without necessarily jeopardizing the ecology of our planet (Ayres and Simonis 1993; Weizsäcker et al. 1998). The idea of a green economy is a more innovative and environmentally friendly approach that emerged in line with sustainable development goals (Şahin 2019). Therefore, green growth can be interpreted as a reflection of macroeconomics in view of practices that align with dynamic capabilities. Dynamic capabilities are critical for maintaining a firm's competitive advantage in markets, especially in rapidly changing conditions. This advantage can be made sustainable through green growth strategies (Eisenhardt and Martin 2000). Moreover, dynamic capabilities increase the capacity of firms to develop long-term sustainability strategies in times of environmental uncertainty. This feature contributes to the sustainability of green growth in the long run (Helfat and Peteraf 2003). In this context, dynamic capabilities theory provides a critical framework for green growth strategies to succeed. It enables firms to develop the innovative capabilities necessary to enhance economic growth while achieving environmental sustainability and adapting these capabilities to rapidly changing market conditions. It therefore provides a foundation for green growth in line with sustainable development.

Sustainable development aims to achieve better living conditions while taking into account the limitations of nature. In this regard, in 2015, the United Nations General Assembly approved 17 Sustainable Development Goals (SDGs) that are quite comprehensive, with the aim of promoting the organizational implementation and integration of sustainability to provide a sustainable future that balances economic, social, and environmental development in order to meet the future needs of stakeholders. These goals aim for a future that is economically and socially better and more sustainable, within the limits of the environment, and in an environmentally friendly manner. SDG 13 (Climate Action) targets countries' policy and technology-based adaptation processes and the strengthening of carbon reduction capacity in the fight against climate change (UN 2015). When evaluated at the micro level, dynamic capabilities theory treats climate change as a systemic external shock. It thus provides an effective tool for explaining how economic actors respond to this shock. SDG 17 (Partnerships for the Goals) indicates that sustainable development can be achieved through multi-stakeholder governance, international cooperation, and knowledge sharing (UN 2015). The theory of dynamic capabilities converges with this goal in terms of relational and network-based capabilities. When evaluated from a macro perspective, countries' attitudes, support, and participation in international climate agreements, technology transfer mechanisms, and multilateral R&D collaborations enable the collective development of dynamic capabilities (Helfat et al. 2007). In light of these explanations, the necessity of a strong micro foundation for robust macro stability and sustainable development becomes apparent.

As shown in Figure 1, firm-level dynamic capabilities are linked to the green growth strategy, which is a fundamental component of sustainable development policies and is typically achieved through the transformative processes of green technology and green energy. These processes highlight specific channels through which the DC relationship operates (Ambrosini and Bowman 2009; Eisenhardt and Martin 2000; Hart and Dowell 2011; Lopez et al. 2007; Teece 2007; Teece et al. 1997). Figure 1 shows the dynamic and evolutionary links between dynamic capabilities, green growth (in line with sustainable development goals), and environmental and policy feedback mechanisms as a whole. In this context, dynamic capabilities are seen to be based on R&D, human capital, and technology adaptation, and are functionalized through processes of perception, capture, and transformation. Furthermore, DC processes

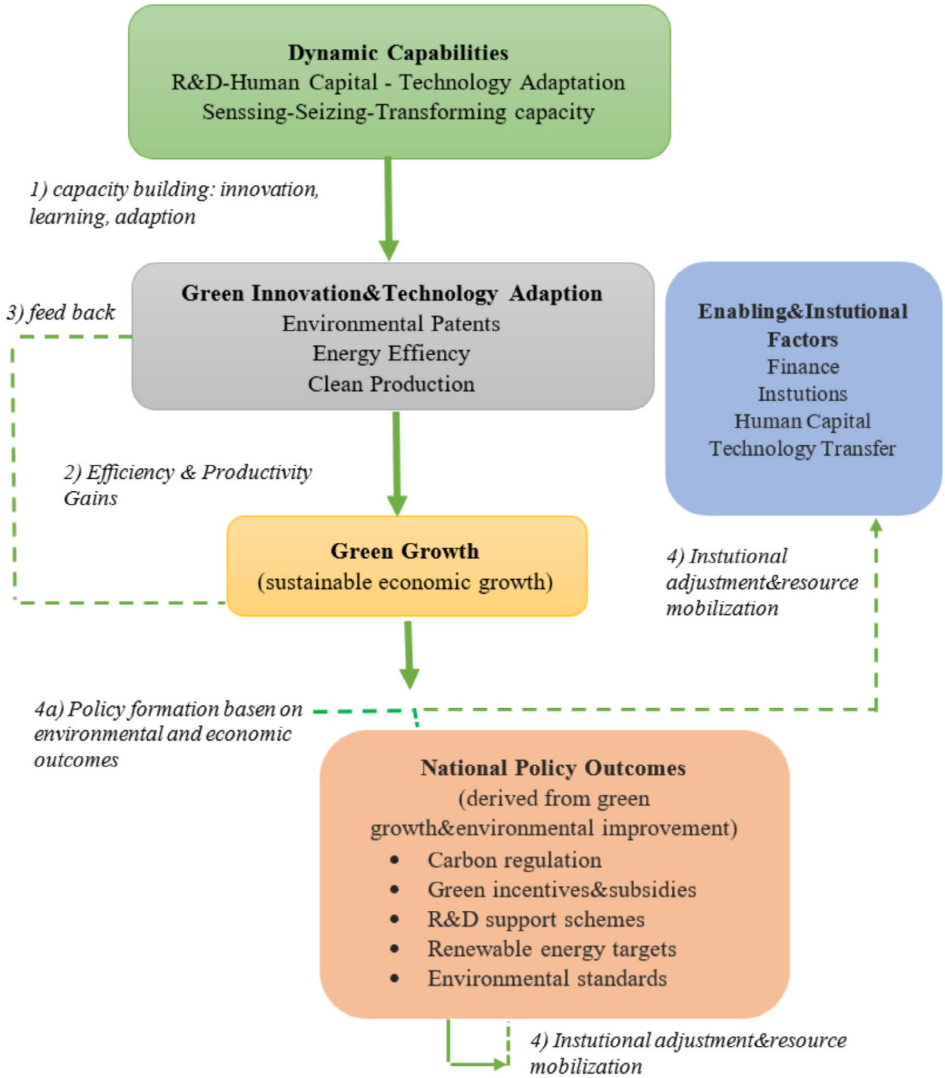

FIGURE 1 | Schematic link among dynamic capability, green growth and the environment. *Source:* Authors' design.

conceptualize the fundamental capacity development mechanism that enables green innovation and technology adoption. These innovations bring about increases in efficiency and productivity. Thus, they initiate a process towards green growth, expressed as sustainable economic growth and reduced environmental pressures. This figure also reveals linear relationships by showing the feedback loops between DC and macro variables. As can be seen from the arrows in the figure, environmental improvements and enhanced ecosystem services provide ecological feedback by supporting more advanced innovation. In line with this process, green growth policies translate into national policy responses such as carbon regulations, green incentives, R&D support programs, and renewable energy targets. National policy goals and implementations, in turn, shape innovation behavior and thus promote the evolution of dynamic capabilities at the company level. Other factors, such as the financial system, institutions, human capital, and technology transfer, also help these processes become effective by facilitating them. Hence, Figure 1, based on the fundamental principles of green growth and dynamic capabilities theory, considers companies, policies, and the environment as a co-evolutionary system that interacts through continuous learning and adaptation.

The G-8 countries, in particular, have shown some upward trends in green growth, albeit at different rates, as shown in Figure 2. The UK and France have shown a marked increase in supporting green growth, especially recently, while Canada has shown the most stable trend in green growth. On the other hand, while France appears to be in the best position, Russia still ranks lowest among this group of countries in terms of green growth performance. However, the most striking point in Figure 2 is that the green growth trends of these countries in general show a continuous and steady increase. This situation can be interpreted as an indication that green growth policies in G8 countries are effective. In this context, the successful implementation of policies can be interpreted as meaning that steady progress can be made towards sustainability goals. The G8 countries are a good example in this regard.

The study thus extends the frontiers of environmental and economic sustainability in the literature by viewing green growth from the dynamic capability perspective. In this respect, it provides an instance of how these two important concepts in the literature can be handled together. While dynamic capabilities theory has been examined at the firm level to provide

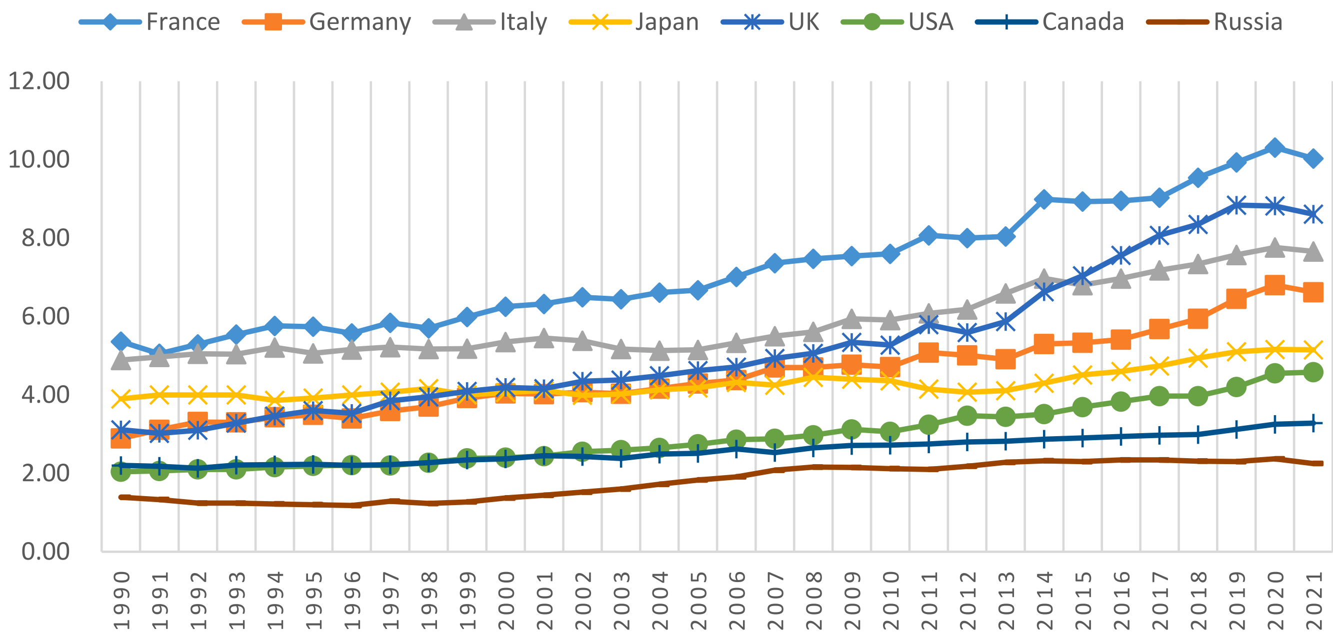

FIGURE 2 | Green growth trend in the G-8. *Source:* Authors' computations using OECD statistics.

competitive advantage, this study takes the theory to the macro level and shows how it can be used to help countries achieve their sustainable development goals. This aspect of the study strengthens the link between theory and practice and brings a new perspective to the green growth literature. A unique empirical analysis of how dynamic capabilities shape countries' sustainable development attainment using the G-8 scenario was provided by assessing the integral roles of notable capabilities indicators like green energy supply, green technology investments, energy efficiency, and environmental policy stringency. Thus, it fills the existing gap in the literature and provides concrete data-driven insights for SDG policymakers and stakeholders.

Following this background introduction, the remaining part of the study continues with a review of the relevant literature in Section 2, followed by the methodology discussion in Section 3. The results of the empirical analysis were presented and discussed in Section 4, while Section 5 wraps up the study with recommendations.

2 | Literature Overview

The empirical literature that considers the practices that are in line with the goal of sustainable development is quite extensive. The determinants of environmental pollution, the environmental impacts of clean energy, and the environmental damages of growth are among the most researched topics. However, green growth in particular refers to a new generation, environmentally friendly approach to growth that has emerged within the scope of sustainable development goals. Hence, green growth studies constitute a relatively new and less-researched aspect of the voluminous empirical literature of environmental research. A synopsis of the current green growth-oriented empirical literature is presented in Table 1.

Considering the literature review, most existing studies have shown that GE, GI, and EE positively affect green growth. Although different samples are used in existing studies, the variables used in the model are largely similar. This situation is insufficient in terms of evaluating the diversity of green growth determinants. The variables used can be differentiated, and a different perspective can be brought to green growth processes. However, it is noteworthy that the estimators used are second-generation dynamic estimators. In this respect, the existing literature is multifaceted. Furthermore, the literature has focused on the positive and significant impact of renewable energy consumption. The difference between this study and the existing literature is that it focuses on renewable energy supply rather than renewable energy consumption. This allows for the evaluation of the impact of green energy supply as one of the most effective factors in green growth processes.

Another innovation in this study is the control for important variables that have been ignored in the relevant literature, such as the environmental policy stringency index. This control allows the effectiveness of green growth policies to be observed while scrutinizing the question of whether these factors (green technology and energy productivity) drive green growth among the G-8 countries. Besides, considering that the dynamic capability perspective is explored from a macroeconomic perspective in this study, it is also important to note that adopting the concept of energy productivity is quite beneficial within the scope of the study rather than efficiency. Energy efficiency mainly reveals the technical link between energy input and physical output, such that less energy use gets the same task done, unlike energy productivity, which is mainly an economic concept that measures the levels of economic value produced per unit of energy consumed. Although the empirical literature on green growth has begun to increase, more research is needed to examine the impact of micro-level change processes on green growth from the prism

TABLE 1 | Summary of current literature.

Author(s)	Sample and analysis period	Method	Findings
Anwar et al. (2024)	Selected Fragile Countries 1996–2019	Panel Quantile Regression	GT and FD positively affect GG.
Chhabra et al. (2024)	Emerging Economies 2000–2020	DCCE	An increase in RE increases GG.
Sohag et al. (2021)	OECD 1980–2016	CS-ARDL	RE and TI positively affect the GG.
Hussain et al. (2022)	High-GDP Countries 2000–2020	CCEMG-AMG	They found that GT increases GG and EC reduces GG.
Mohsin et al. (2022)	ECOWAS 1990–2018	DEA	The increase in Re and R&D increases GG.
Yao et al. (2023)	BRICS 1990–2020	CS-ARDL	Tourism promotes GG in the long and short term.
Luo and Zhang (2022)	China 1990–2018	Meta frontier SBM model	ER has a positive effect on GG.
Su and Gao (2022)	China 1993–2020	NARDL	ET, ER, and FI positively affect GG.
Gorji and Martek (2023)	40 countries 2010–2021	FGLS	The contribution of RE sectors to GG.
Dźwigoł et al. (2023)	AB 2000–2020	GMM	The increase in re and EE increases GG.
Khan et al. (2023)	OECD 1990–2020	MMQR	EE, RE, and GT GG positively affect.
Appiah et al. (2024)	Sub-Saharan Africa 1996–2018	Quantile regression	Some IQ indicators increase GG
Anwar et al. (2024)	Selected Fragile Countries 1996–2019	Panel Quantile Regression	GT and FD positively affect GG.

Abbreviations: DEA, Data Envelope Analysis; EC, Energy Consumption; ECOWAS, West African States Economic Community; EE, Energy Efficiency; ER, Environmental Regulation; ET, Environmental Technology; FD, Financial Development; FI, Financial Innovation; GG, Green Growth; GT, Green Technology; IQ, institutional quality; RE, Renewable Energy; TI, technological Innovations.

of how they relate to country-level policy structures and implementations in order to enhance sustainable development. Most existing studies on dynamic capabilities theory have been examined at the firm level in terms of the search for competitive advantage, but this study broadens the perspective to the macro level to show how these capabilities facilitate countries' sustainable development agenda. Thus, it strengthens the theory-practice link and brings a new perspective to the growing green growth literature.

3 | Data, Methods, and Theoretical Framework

This study analyzes the green growth processes of G-8 countries[1] in the context of the dynamic capabilities theory that supports sustainable development. The model is estimated using annual data for the period 1990–2021. The independent variables considered are the factors that ensure growth with the aim of zero emission, in line with Sustainable Development Goals (SDGs). Green growth is defined as an environmentally friendly and sustainable economic growth in line with the SDG-8 mandates. The study leverages the OECD indicators for green growth among member nations. We adopted the environmental and resource productivity aspects of the green growth signal. Utilizing this proxy offers some advantages, as observed by the OECD. Firstly, it helps to measure the dynamics of green economic expansion in terms of natural resources efficiency. Secondly, the indicator covers production facets of environmental degradation, which are often neglected in economic modeling, in contrast to the common consumption-based pollutant emission measures that dominate the existing literature. By this, the idea of the scrutiny relies on how much of energy-related carbon pollution is exerted for every unit of economic expansion that we create.

In line with the dynamic capability theory, we selected certain factors that reflect business capacities to adapt to changing environmental conditions and the capacities to restructure their resources to attain a sustainable competitive edge on an aggregate level. Firstly, we considered the level of green energy supply (GES) as a major capability indicator, especially in the face of the growing need for energy transition to an environmentally friendly form of energy. Green energy supply reduces carbon emissions, minimizes dependence on fossil fuels, and thus serves as an effective factor for the foundation of sustainable growth. In this context, the increase in renewable energy sources should directly support sustainable growth by improving environmental quality. The literature has generally focused on renewable energy consumption and mainly reveals that renewable energy has a positive effect on growth (Apergis and Payne 2010; Bilgili et al. 2016). But then, the new shift in the argument would be about how green the economic growth is in this context? Hence, the impacts of GES on GG were scrutinized by examining the proportion of renewable energy production within the G-8 total energy generation capacity.

Besides the levels of green energy supply, the amount of Green technology (GT) was also examined. GT is expected to enhance capability by supporting sustainable growth through innovation in an environmentally compatible manner. It should also increase efficiency in production processes, reduce resource use, and consequently lower emission rates. In this context, the number of environmental patents among the G-8 countries was adopted as a tool for scrutinizing GG. Romer's (1990) endogenous growth theory argues that technological innovation is the source of long-term growth, and it has also been observed that innovations made in an environmentally compatible manner generate both economic and environmental benefits (Costantini and Mazzanti 2012).

Furthermore, considering that there are variations in the levels of efficiency in energy technologies, coupled with the differences in regulations across countries, we controlled for these two key factors. The quest for higher energy efficiency (EP) remains pivotal to attaining sustainable development. This is because better EP enables lower energy consumption per unit of output, thus leading to reduced costs and improved environmental quality as a result of less carbon emissions from the lower energy use. Ang (2007) showed that energy intensity is of critical importance in economic growth and emission reduction. Paramati and Mo (2017) have also observed that energy efficiency has a long-term reducing effect on carbon emissions.

The level of strictness of environmental policies (EPI) was also controlled for in the model. The EPI encapsulates policy frameworks that are implemented to curb pollution, including taxes, emissions trading systems, and other green incentives by governments to reduce environmental pollution. The theoretical assertion of the hypothesis established by Porter and van der Linde (1995), maintained that strict environmental regulations have a positive effect on innovation and productivity in the long term. The major presupposition, however, was that such policies are well-designed. Hence, there is a need for empirical investigation to properly understand whether EPI produces expected environmental gains. Albrizio et al. (2017) found that strict environmental policies increase energy efficiency and the adoption of clean technologies. Additionally, the OECD (2020) report shows that strict environmental policies play a decisive role in reducing emissions and promoting green innovation. Hence, we control for this factor. The adopted EPI index shows the degree to which environmental policies explicitly or implicitly place a price on polluting or environmentally damaging behavior. The index varies between 0 and 6, with 0 implying not strict, and the highest degree of strictness follows consecutively up to level 6. Table 2 provides variable descriptions.

TABLE 2 | Indicators and descriptions.

Variable and symbol	Measurement and definition	Database
Green growth (logGG)	GDP/energy-related CO_2 emissions (Production-based CO_2 productivity, US dollars per kilogram, 2015)	OECD statistics
Green technology (logGT)	Number of environmental patents (Percentage)	OECD statistics
Green energy supply (logGES)	Percentage of renewable energy production in total energy (Percent)	OECD statistics
Energy productivity (logEP)	Energy productivity, GDP per unit of TPES (US Dollar, 2015)	OECD statistics
Environmental policy (logEPI)	En. Pol. Stringency Index (0↓–6↑)	OECD statistics (Kruse et al. 2022; Botta and Kozluk 2014)

3.1 | Model and Empirical Procedure

We adopted the model estimated in Yao et al. (2023), Gorji and Martek (2023), and Kazi et al. (2021) as follows:

$$\mathrm{LogGG}_{i,t} = \beta_0 + \beta_1 \mathrm{LogGT}_{i,t} + \beta_2 \mathrm{LogGES}_{i,t} + \beta_3 \mathrm{LogEP}_{i,t} + \beta_4 \mathrm{LogEPI}_{i,t} + u_{i,t} \quad (1)$$

The natural logarithmic transformations of all variables were used. In the equation, i stands for horizontal cross-section, and t stands for years. In the model, β is the constant term, $\beta_1, \beta_2, \beta_3, \beta_4$ are the coefficients of independent variables and u_{it} is the error term. In Equation (1) the level of green growth (GG) is determined by green energy supply (GES) and green technology (GT) while controlling for energy efficiency (EP) and the variations in environmental policy stringency (EPI) level.

The Dynamic Capabilities Theory, which forms the basis of this study, was originally developed at the firm level, as previously explained (Teece et al. 1997). However, with the subsequent development and updating of the literature, it has also been adapted to the macro level in the context of national innovation systems, sectoral transformation, and green growth strategies (Fagerberg 2018; Teece 2018). In this context, long-term structural changes such as environmental sustainability, green transformation, and the circular economy require institutional capacity, technology accumulation, and policy alignment at the country level, going beyond the firm level.

Therefore, at this stage, the representation of dynamic capabilities applications through macro indicators is included in the literature.

The variables included in the model were determined by evaluating indicators that could represent them at the macro level based on the DC theory. In the literature on dynamic capabilities, sensing represents the ability of economic actors to recognize technological opportunities, environmental risks, and new market needs at an early stage (Teece 2007). At the macro level, this capability can be assessed in terms of a country's knowledge production infrastructure, R&D ecosystem, and technological awareness of environmental issues. Particularly in the sustainable development literature, environmental patents are considered a generally accepted measure of green innovation, environmental technological competence, and knowledge-based sensing capacity (Johnstone et al. 2010; Popp 2019). In this regard, the use of environmental patents as the macro dimension of the dynamic capabilities theory is theoretically consistent. Seizing ability refers to the conversion of perceived opportunities into concrete investments, policy preferences, and resource allocation (Teece 2007). Renewable energy represents countries' clean energy levels and is therefore used as an effective tool in sustainable development goals. In this context, renewable energy is evaluated as a macro indicator in environmentally friendly growth strategies. In the literature, renewable energy investments are considered alongside dynamic policy capacity, green industry strategies, and sustainable development orientations (Aghion et al. 2016; Marques and Fuinhas 2012). The energy efficiency variable, on the other hand, can be associated with transforming capacity in Teece's study. According to transforming capacity, existing production structures, technological infrastructure, and institutional arrangements are restructured in the long term (Teece 2014). Energy efficiency is an environmentally friendly representative of green transformation processes. Increases in energy efficiency are directly related to technological diffusion, institutional adaptation, and long-term sustainable growth (Filippini and Hunt 2015; IEA 2023).

To start the empirical procedure, the correlation relationship between the variables was investigated first, and thereafter, we proceeded to carry out a CD test. This test represents an important pre-test for making estimations in panel data analysis. Determining the presence of cross-sectional dependency is one of the first steps in determining the coefficient estimator. In this context, Breusch and Pagan (1980) "CDLM" test is utilized to determine the presence of CD. The Breusch and Pagan (1980) CDLM test is derived from the squares of the pair-wise correlation coefficients of the error terms. It is also considered to produce efficient results when the cross-sectional dimension (N) is relatively smaller than the time dimension (T) ($N<$T) (Pesaran 2004, 4–5). The equation of the CDLM test statistic is as follows:

$$\mathrm{CD}_{\mathrm{LM}} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T\hat{p}_{ij}^{2} \tag{2}$$

P_{ij} in the equation denotes the sample estimate for the pair-wise correlation coefficients of the error terms.

Additionally, determining the heterogeneity of slope coefficients is as critical as CD. It constitutes an important step in long-run estimation in panel data analyses. This test was developed by Pesaran and Yamagata (2008). The equations used to investigate the heterogeneity of slope coefficients are as follows:

$$\dot{\Delta} = \sqrt{N}\left(\frac{N^{-1}S\% - k}{\sqrt{2k}}\right) \text{ ve } \dot{\Delta}_{\mathrm{adj}} = \sqrt{N}\left(\frac{N^{-1}S\% - 1}{\sqrt{\frac{2k(T-k-1)}{T+1}}}\right) \tag{3}$$

The Equation (2) works better for small observations, while the third equation is used for larger observations. The initial screening conducted indicated the possibility of CDs; as such, the selection of the CADF test, which is a second-generation unit root test, is justifiable. The CADF test is a test developed by

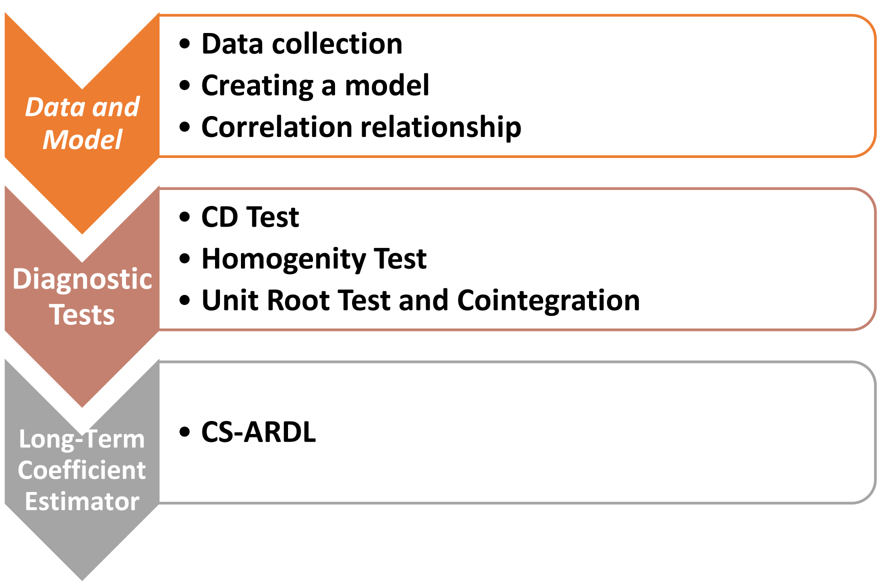

FIGURE 3 | The analytical procedure.

Pesaran (2007) as follows: in Equation (4), and a lag term represents the new notations in Equation (5).

$$\Delta Y_{it} = \pi_i + \theta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \Psi_i \Delta \bar{y}_t + \mu_{it} \quad (4)$$

$$\Delta Y_{it} = \pi_i + \theta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \sum_{j=0}^{p} \Psi_{ij} \Delta \bar{y}_{t-j} + \sum_{j=1}^{p} \delta_{ij} \Delta y_{i,t-j} + \mu_{it} \quad (5)$$

In the equation, $\bar{y}_{t-j}$ and $\Delta y_{i,t-j}$ denote the lagged level averages as well as the first difference for horizontal cross-sections.

Subsequently, the test developed by Westerlund (2007) was used to investigate the existence of a long-run relationship between the variables after the CD was confirmed. The CS-ARDL approach of long-run coefficient estimation was later followed in the study. This estimator takes CD into account and is used in the presence of heterogeneous slope coefficients. The estimator has also been confirmed to be more consistent in the presence of CD and heterogeneous coefficients than the results obtained through some other contemporary approaches like the MG, PMG, and AMG estimators (Onifade and Alola 2022). The CS-ARDL estimator is based on the calculation of dynamic joint correlated effects.

$$W_{i,t} = \sum_{I=0}^{p_w} I, i\, W_{i,t=1} + \sum_{I=0}^{p_z} \beta\, I, i\, Z_{i,t-1} + \varepsilon_{i,t} \quad (6)$$

In the presence of CSD, Equation (6) is used to represent an ARDL model. The equation used to calculate the long-run coefficients and the average group estimator following (Chudik et al. 2016) are as related from Equations (7–10). Figure 3 captures the analytical procedure of the empirical investigations.

$$\bar{\pi}\mathrm{CS}-\mathrm{ARDL}, i = \frac{\sum_{I=0}^{p_z} \widehat{\beta I}, i^{p^w}}{1 - \sum I = 0} \widehat{\gamma I, i} \quad (7)$$

and at the same time:

$$\hat{\bar{\pi}}\, M, G = \frac{1}{N} \sum_{i=1}^{N} \hat{\pi} i \quad (8)$$

$$\Delta W_{i,t} = \vartheta_i \left[W_{i,t} - \pi_i Z_{i,t} \right] - \sum_{I=0}^{p_{w-1}} \gamma I, i \Delta_I W_{i,t-1} + \sum_{I=0}^{p_z} \beta I, i \Delta_I Z_{i,t} + \sum_{I=0}^{p_x} \alpha' I, i \bar{X}_t + \varepsilon_{i,t} \quad (9)$$

Also;

$$\hat{T}_i = -\left(1 - \sum_{I=1}^{p_w} \widehat{\gamma I}, i\right) \quad (10)$$

4 | Results

4.1 | Preliminary Analysis

First, the correlation relationship between the variables was investigated in Table 3. According to the correlation table, there is a close relationship between energy efficiency and green growth. The relationship between these two variables is at the expected level and can be supported theoretically. Table 4 shows the results of two important diagnostic tests required for the coefficient estimator namely, the CD test and the slope homogeneity test results.

The statistics in the Table 4 indicate that the null hypothesis is rejected for both the CD test and the homogeneity test. In this context, it is concluded that the estimated model contains CD

TABLE 3 | Correlation relationship between variables.

	logGG	logGT	logGES	logEP	logEPI
logGG	1				
logGT	0.1582	1			
logGES	0.3462	0.3344	1		
logEP	0.8820	0.1455	0.2131	1	
logEPI	0.7587	0.5289	0.4763	0.7401	1

TABLE 4 | CD and homogeneity test results.

	CD test		Homogeneity test		
Test	**Statistic**	***p***		**Delta**	***p***
LM	52.92	0.003***		15.985	0.000***
LMadj	8.315	0.000***			
LMCD	3.795	0.000***	Adj.	17.734	0.000***

Note: The notations *** denotes significance at 1% significance level.

TABLE 5 | Unit root results.

	Level		F. Difference	
	Constant	Cons + trend	Constant	Cons + trend
Variables	***Z*[t-bar]/(*p*)**	***Z*[t-bar]/(*p*)**	***Z*[t-bar]/(*p*)**	***Z*[t-bar]/(*p*)**
logGG	−2.79 (0.003***)	−1.39 (0.082*)	—	—
logGT	−1.82 (0.034**)	−3.19 (0.001***)	—	—
logGES	2.40 (0.992)	0.37 (0.644)	−6.15 (0.000***)	−5.49 (0.000***)
logEP	1.16 (0.879)	2.15 (0.984)	−5.18 (0.000***)	−4.52 (0.000***)
logEPI	−2.24 (0.013**)	0.00 (0.503)	—	—

Note: Lag length is 1. *, **, *** denotes significance at 10%, 5%, 1% significance level.

and the slope coefficients are heterogeneous. Since the model estimated in this study contains CDs, the CADF test, which is a second-generation unit root test, was utilized.

Since the model includes CD, the CADF test is used. The test results as reported in Table 5 indicate that lnGES and lnEP variables are stationary at I(1) level. On the other hand, other variables are stationary at the level. The test developed by Westerlund (2007) was used to investigate the existence of a long-run relationship between the variables. This test can be used both in the presence and absence of CD. In the presence of CD, the results of the bootstrap option are considered (Westerlund 2007).

The second-generation cointegration test is used to investigate the cointegration relationship between variables, and the results are presented in Table 6. Since the model includes CD, bootstrap probability values are taken into account. The *p* value indicates the existence of cointegration. After the cointegration is verified, the coefficient estimate is made. CS-ARDL is used as the long-run coefficient estimator in this study. This estimator takes CD into account and is used in the presence of heterogeneous slope coefficients.

TABLE 6 | Panel ECM co-integration test.

	Statistics	asym *p*	Bootstrap *p*
g-tau	−5.787	0.000***	0.000***
g-alpha	−14.556	0.000***	0.000***
p-tau	−6.632	0.000***	0.000***
p-alpha	−20.080	0.000***	0.000***

Note: The notations *** denote significance at 1% significance levels. The fixed option is used. Bootstrap was run as 1000.

4.2 | Long-Run Discussions

Since the model includes CD, the second-generation coefficient estimator CS-ARDL is used. We analyze the link between green growth and the identified determining factors. The CS-ARDL supplies the impacts of these factors on green growth for both the short-run and long-run scenarios as reported in Table 7.

It was observed in the short run that only the amount of green technology (GT) and the level of energy efficiency (EP) significantly affect green growth within the G-8 countries. In the short term, it has been observed that the only factors significantly influencing green growth in G8 countries are the amount of green technology (GT) and the level of energy efficiency (EP). It has been found that variables that are statistically significant in the short term are similar to those that are significant in the long term. A 1% increase in green technology in the short term increases the dependent variable by 0.060%. This observed result is in the expected direction and supports the literature, as is the case in the long term (Mensah et al. 2019; Suki et al. 2022; Hussain et al. 2022). A 1% increase in energy efficiency increases green growth by 0.70%. This finding is in the desired and expected direction, as observed in the literature. Therefore, it parallels the literature (Dźwigoł et al. 2023; Dong et al. 2023). Green technology and energy efficiency are inherently environmentally friendly variables. Although the positive effects of these variables vary by country and time, in this study, considering the sample countries, the positive effects are as expected and support the literature.

TABLE 7 | CS-ARDL results.

Variables	Coefficients	Standard error	*p*
Short run results			
d.logGG	−0.3193	0.0695	0.000***
logGT	0.0597	0.0279	0.032**
logGES	−0.0039	0.0703	0.955
logEP	0.7062	0.1063	0.000***
logEPI	−0.0104	0.0233	0.655
Ect	−1.3193	0.0695	0.000***
Long run results			
logEPI	−0.0075	0.0198	0.703
logEP	0.5388	0.0746	0.000***
logGES	−0.0002	0.0477	0.955
logGT	0.0435	0.0205	0.034**
Model statistics	R^2: 0.52 CD statistics: −3.40 *p*-value: 0.000		

Note: Lag length is set as 1. ** and *** represent 5% and 1% significance level.

This observation was also valid in the long run. Specifically, a 1% increase in the level of energy efficiency boosts green growth by approximately 0.54% in the long run. This supports the growing arguments for the significant role that increased efficiency plays beyond the literal growth in energy supply and utilization (Dźwigoł et al. 2023; Khan et al. 2023). The EP's positive impact in both the short and long term is an expected outcome. This result can be interpreted as the G-8 countries strengthening both growth and sustainability as they increase energy efficiency in production and consumption. Energy efficiency investments reduce costs in the short term and support sustainable growth by increasing competitiveness. The G-8 countries (the US, Germany, Japan, Canada, France, Italy, the UK, and Russia) are generally high-tech countries that are well-established in optimizing energy conversion processes. Energy efficiency investments in these countries are attractive not only from an environmental perspective but also in terms of economic performance (e.g., Industry 4.0 applications, building insulation, smart grids). Besides, countries such as Japan and Germany, in particular, have made efficiency gains in energy-intensive sectors compatible with economic growth through technological innovations. In this regard, energy efficiency standards in the industrial sector need to be tightened to increase the impact of energy efficiency. Energy-saving technologies in buildings should be widely adopted. Energy management should be improved through digitalization and smart grids. This will ensure that the expected impact of energy efficiency continues to be achieved.

Furthermore, green technology (GT), a 1% increase in the variable, enhances green growth among the G-8 countries by approximately 0.0435%. These empirical findings are in line with the results observed in the green growth literature (Hussain et al. 2022; Anwar et al. 2024; Khan et al. 2025), and further draw our attention to the importance of green technology in the global sustainability quest. The positive impact of GT on green growth in the long and short term is an expected finding. G-8 countries can be said to be pioneers in eco-friendly innovation and green patents (especially Germany and Japan). Green technologies play an important role in both reducing carbon emissions and creating new market opportunities (e.g., electric vehicles, renewable energy equipment, energy-efficient products). Prioritizing green technologies in R&D incentives, strengthening green patent protections, and increasing university-industry collaborations in this direction will trigger and accelerate green growth. Furthermore, green technology transfer mechanisms should be widespread within the G-8. This will spread the impact of green growth to broader areas.

However, the evidence obtained showed that both environmental policy (EPI) and green energy supply (GES) are not significant drivers of green growth in the understudied G-8 economies. While this seemingly appears unconventional, there are possible underlying explanations for this evidence. Both factors are found statistically insignificant for green growth in both short- and long-term scenarios. This situation may be due to the fact that green energy generation investments produce long-term results, and their effect on short-term growth may be delayed. The lack of a significant effect of the EPI may be due to the limited impact of marginal increases on growth, given the strictness of current environmental policies in G-8 countries. Another potential reason for these insignificant effects of both environmental policy stringency and green energy supply on green growth is the economic context of these countries in terms of their current advanced economic structure. Most of these G-8 economies are already decoupling their growth from environmental degradation using innovative approaches. This position has been reaffirmed by the observed significant roles of their energy productivity coupled with green technology. As such, their green growth may now be primarily driven more by technological innovations, productivity, and services, rather than by policy stringency or energy supply changes.

Additionally, some of the notable G-8 countries still have a production and consumption structure dependent on fossil fuels. The presence of fossil fuel-based energy policies in some countries (e.g., Russia, the US, and Canada) continues to limit the effectiveness of environmental measures. Therefore, the lack of meaningful short-term effects of these variables can be explained by delayed effects or the success of policy implementation. IEA (2023) has noted that the increase in renewable energy still accounts for a low proportion of total energy supply. Besides, the cost of renewable energy technologies (especially storage and infrastructure) can be high, particularly in the initial stages, which limits their positive contribution to growth in the short term. Continuing to use traditional methods to avoid the costs of these investments also limits the long-term impact. In countries such as the US and Canada, where energy supply is heavily reliant on fossil fuels, the green energy transition is progressing much more slowly than in Europe. Therefore, a statistically significant relationship may not have been found for the panel as a whole. In this regard, it is essential that G-8 countries shift their energy subsidies from fossil fuels to green energy in order to increase the share of renewable energy. At the same time, it is important to invest in energy storage technologies.

Although a positive correlation was established between green growth and the environmental stringency index in the preliminary analysis, the subsequent detailed long-run investigation reveals that there is a lack of significant EPI effects. This outcome may stem from the fact that environmental policies' impacts are generally observable over the long term. For instance, policy strategies like carbon taxes or emissions trading systems reveal the effects of technological adaptation and sectoral transformation over time, and this can trigger growth. When G-8 countries are evaluated, they exhibit heterogeneous characteristics in terms of the strictness of their environmental policies. For example, while strict environmental standards prevail in Germany, regulations in the US are more flexible at times. Therefore, this existing heterogeneity may have affected the panel results. At the micro level, some firms view strict environmental policies as a "cost-increasing burden" and seek to avoid this cost, while others view them as an "opportunity for innovation." This situation may reduce statistical significance. The strictness of environmental policies prevailing in G-8 countries is not the only critical factor; their implementation effectiveness and stability are also crucial. Designing strict policies in a predictable and long-term manner that sends clear signals to markets can increase their effectiveness. Furthermore, policy harmonization (e.g., carbon pricing alignment between the EU, the US, and Japan) can further enhance the positive impact on growth.

Lastly, looking at the short-run details, when the coefficients are greater than 1, it means that when there is a deviation in the equilibrium, a fluctuating path is followed while returning to the long-run equilibrium. The overall model performs well, given the model's significant p-value and an acceptable R^2 statistic. Further diagnostic statistics on variables, as seen from the VIF report in Table A1 of the appendix, also show that there is no potential multicollinearity that could create any bias for the CS-ARDL estimates. Additionally, the error correction coefficient (ect) follows the expected negative sign (−1.3193) and is found to be statistically relevant. Thus, it indicates that in case of any deviation from equilibrium, the systems return to equilibrium. However, since the coefficient exceeds 1, it reflects that a fluctuating path is followed by the system while returning to the long-run equilibrium.

5 | Conclusion, and Country-Specific Policy Recommendations

Dynamic capabilities theory focuses on the capacity of firms and countries to adapt to changing environmental conditions, innovate, and use resources efficiently. From a sustainable development perspective, developing these capabilities can enable economies to achieve environmental sustainability and economic growth simultaneously. This study investigates the green growth dynamics of G-8 countries within the framework of sustainable development. The relationships between the variables are observed with the help of the CS-ARDL estimator. Empirical findings show that green technology and energy efficiency measures are significant positive drivers of green growth in the G-8 countries. Meanwhile, the level of environmental policy stringency and the amount of green energy supply portend an overall insignificant influence on green growth among the sampled countries.

Empirical findings show that green growth, as a reflection of dynamic capabilities, is strongly correlated with factors such as green technology supply and energy efficiency. This emphasizes that G-8 countries need to improve their dynamic capabilities by not only boosting their overall investments in green technology but also emphasizing more strategic approaches to stimulate research for enhanced energy efficiency levels in order to achieve sustainable development goals.

Based on the findings, energy productivity promotes green growth. The positive findings obtained in this context are in line with expectations. In this context, any development aimed at increasing energy efficiency is an investment in sustainable development, and it is therefore appropriate to promote energy efficiency, particularly in the industrial, residential, and transportation sectors. This study thus suggests some evidence of green growth gains from energy efficiency investments in these countries, especially in areas like Industry 4.0 applications, building insulation, and smart grids. It is recommended that developed and high-tech economies like Germany and Japan, alongside the other understudied G-8 countries, should further integrate energy efficiency with digitalization (IoT, artificial intelligence) for greater green growth outcomes. Other energy-intensive economies in the group, like the US, which consumes a substantial share of the world's energy, should allocate more budget to energy-efficient infrastructure to leverage the efficiency channel for higher sustainable growth outcomes.

The green technology indicator also demonstrates a positive impact on green growth, similar to energy efficiency. G-8 countries account for a large portion of global green technology production and R&D spending (e.g., Germany's environmentally friendly engineering solutions, Japan's efficient transportation systems). The sample group countries are developed countries that are actively working toward achieving sustainable development goals. Therefore, they prioritize investments in this area, and the empirical results align with expectations. However, the impact is relatively low (0.04%). This result can be interpreted as indicating that technologies are still limited in terms of widespread adoption or effective use. Here, economies of scale and policy incentive mechanisms are critical for the technology's impact to become more pronounced. To make the impact of green technologies more evident in G-8 countries, we recommend that a joint green technology pool or G-8 internal green innovation collaborations be established. This would increase the impact on green growth. Additionally, streamlining patenting processes and ensuring access to financing would expand the impact of green technology.

It is noteworthy that the evaluated indicators show consistent effects in the short and long term. In this context, the green energy supply and environmental policy rigidity index do not have a significant effect on green growth in either the long or short term. This outcome is plausible since green energy investments produce long-term results, and their effect on short-term growth may be delayed. Also, given the strictness of current environmental policies in G-8 countries, the EPI's unconventional roles may be due to the limited impact of its marginal increases on growth. This is further complicated by fossil fuel-based energy policies in some of the G-8 countries (e.g., the US, Russia, and Canada), and this continues to limit the effectiveness of environmental stringency measures. Green energy supply (GES) is a crucial input in environmental sustainability policies. In this context, the lack of meaningful short-term effects of GES indicates the need for more stable investment and subsidy policies. We recommend more priority to be given to green energy transition policies (e.g., carbon pricing), especially in energy-exporting countries among the G-8, such as Russia and Canada. This would foster green growth policies. EPI policies should be prioritized and strengthened not only through agreements on paper but also through oversight and penalties. In countries such as France and Italy, making local governments more active in the implementation of policies will increase effectiveness. It should be noted that when the error correction coefficient is evaluated, the system's ability to return to equilibrium in the long term demonstrates the sustainability of green growth strategies. Thus, demonstrating the applicability and scope of environmentally friendly policies such as the circular economy and long-term climate commitments.

The findings of the study reveal that energy efficiency and green technology are the variables that contribute most to green growth in G-8 countries. However, it also points to the need for policy continuity, investment stability, and implementation capacity for these contributions to be effective. Even policies that appear ineffective in the short term may have the potential to bring the system into balance in the long term when combined with effective policies. Therefore, policymakers should establish long-term strategies, investment-focused incentives, and national-international coordination, taking structural characteristics into account.

Overall, following the dynamic capabilities theory, the G-8 governments can enhance their national green growth and overall sustainability performance by sensing, seizing, and transforming strategically. In their sensing approach, it is recommended that they strategically identify areas of emerging environmental risks and properly monitor green technological trends in order to fully harness green market opportunities. They can leverage data-driven monitoring strategies as well as stakeholder engagement. As for seizing, the authorities of the G-8 need more policy strategies for green industrial development. They can achieve this by providing more fiscal incentives and other supports to investors. The governments also need to provide more enabling environments that support private investors in green innovation. The G-8 authorities can achieve this by a transformative approach within the DC framework through the continuous strengthening of their various institutions, expansion of infrastructures, and regular training of their officials. By so doing, the public sector capabilities will be improved with better capacity for regulations that can promote overall green growth and actualization of SDG-8 objectives.

6 | Limitations and Future Study Directions

This study contributes to the literature in many ways, but it has some limitations. The first limitation is data constraints. Secondly, the impact of these variables on green growth has only been evaluated specifically for G8 countries. Another limitation is that green growth and dynamic capabilities are represented through observable macro-level indicators such as green technology patents, energy efficiency, and renewable energy supply. While these measures are widely used in the literature, they may not fully reflect the multidimensional and firm-level nature of dynamic capabilities and the diffusion and adoption processes of green technologies. This study attempts to explain the relationship between dynamic capabilities and the macro-level green growth process through specific variables. Hence, future research could expand the relationship between dynamic capabilities and the green growth process in various directions. Expanding the sample to include developing economies or conducting comparative analyses between developed and developing country groups would provide a comparable analysis. Combining firm-level or sectoral data could provide deeper insights into how dynamic capabilities translate into green growth outcomes at different aggregate levels. Additionally, future studies could investigate the interplay between the rigidity of environmental policy, green technology, and energy efficiency to better capture policy-technology complementarities. They could also conduct country-specific assessments using alternative econometric approaches, such as country-specific estimators.

Author Contributions

Şeyma Bozkaya: conceptualization, writing – original draft, methodology, formal analysis. **Stephen Taiwo Onifade:** conceptualization, writing – original draft, methodology, editing and correspondence.

Acknowledgments

Open access publishing facilitated by Vaasan yliopisto, as part of the Wiley - FinELib agreement.

Funding

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data for this present study are sourced from the Organization for Economic Co-operation and Development—OECD, (https://www.oecd.org/).

Endnotes

[1] The G-8 countries (the US, Germany, Japan, Canada, France, Italy, the UK, and Russia). (https://2009-2017.state.gov/e/eb/ecosum/2012g8/faqs/index.htm#:~:text=The%20G8%20consists%20of%20the,Russia%20and%20the%20United%20Kingdom).

References

Aghion, P., A. Dechezleprêtre, D. Hémous, R. Martin, and J. Van Reenen. 2016. "Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence From the Auto Industry." *Journal of Political Economy* 124, no. 1: 1–51. http://www.nber.org/papers/w18596.

Albrizio, S., T. Kozluk, and V. Zipperer. 2017. "Environmental Policies and Productivity Growth: Evidence Across Industries and Firms." *Journal of Environmental Economics and Management* 81: 209–226. https://doi.org/10.1016/j.jeem.2016.06.002.

Ambrosini, V., and C. Bowman. 2009. "What Are Dynamic Capabilities and Are They a Useful Construct in Strategic Management?" *International Journal of Management Reviews* 11, no. 1: 29–49. https://doi.org/10.1111/j.1468-2370.2008.00251.x.

Ang, J. B. 2007. "CO_2 Emissions, Energy Consumption, and Output in France." *Energy Policy* 35, no. 10: 4772–4778. https://doi.org/10.1016/j.enpol.2007.03.032.

Anwar, A., N. T. T. Huong, A. Sharif, N. Kilinc-Ata, M. Çitil, and F. Demirtaş. 2024. "Is a Green World Real or a Dream? A Look at Green Growth From Green Innovation and Financial Development: Evidence From Fragile Economies." *Geological Journal* 59, no. 1: 98–112. https://doi.org/10.1002/gj.4844.

Apergis, N., and J. E. Payne. 2010. "Renewable Energy Consumption and Economic Growth: Evidence From a Panel of OECD Countries." *Energy Policy* 38, no. 1: 656–660. https://doi.org/10.1016/j.enpol.2009.09.002.

Appiah, M., S. T. Onifade, and B. A. Gyamfi. 2024. "Pathways to Sustainability in Sub-Sahara Africa: Are Institutional Quality Levels Subservient in Achieving Green GDP Growth?" *Journal of the Knowledge Economy* 16, no. 1: 2366–2390. https://doi.org/10.1007/s13132-024-01774-7.

Ayres, R. U., and U. E. Simonis. 1993. *Industrial Metabolism: Restructuring for Sustainable Development*. UN University Press.

Bilgili, F., E. Koçak, and Ü. Bulut. 2016. "The Dynamic Impact of Renewable Energy Consumption on CO_2 Emissions: A Revisited Environmental Kuznets Curve Approach." *Renewable and Sustainable Energy Reviews* 54: 838–845. https://doi.org/10.1016/j.rser.2015.10.080.

Bleady, A., A. H. Ali, and S. B. Ibrahim. 2018. "Dynamic Capabilities Theory: Pinning Down a Shifting Concept." *Academy of Accounting *and Financial Studies Journal* 22, no. 2: 1–16. https://www.researchgate.net/publication/325257001.

Botta, E., and T. Kozluk. 2014. *Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach*, OECD Economics Department Working Papers, No. 1177. OECD Publishing. https://doi.org/10.1787/5jxrjnc45gvg-en.

Breusch, T. S., and A. R. Pagan. 1980. "The Lagrange Multiplier Test and Its Applications to Model Specification in Econometrics." *Review of Economic Studies* 47, no. 1: 239–253. https://doi.org/10.2307/2297111.

Chhabra, M., M. Agarwal, and A. K. Giri. 2024. "Does Renewable Energy Promote Green Economic Growth in Emerging Market Economies?" *International Journal of Energy Sector Management* 18, no. 6: 1836–1851. https://doi.org/10.1108/IJESM-08-2023-0023.

Chudik, A., K. Mohaddes, M. H. Pesaran, and M. Raissi. 2016. "Long-Run Effects in Large Heterogeneous Panel Data Models With Cross-Sectionally Correlated Errors." In *Essays in Honor of Man Ullah*, 85–135. Emerald Group Publishing Limited. https://doi.org/10.2139/ssrn.2552907.

Costantini, V., and M. Mazzanti. 2012. "On the Green and Innovative Side of Trade Competitiveness? The Impact of Environmental Policies and Innovation on EU Exports." *Research Policy* 41, no. 1: 132–153. https://doi.org/10.1016/j.respol.2011.08.004.

Dong, K., J. Zhao, and F. Taghizadeh-Hesary. 2023. "Toward China's Green Growth Through Boosting Energy Transition: The Role of Energy Efficiency." *Energy Efficiency* 16: 43. https://doi.org/10.1007/s12053-023-10123-7.

Dźwigoł, H., A. Kwilinski, O. Lyulyov, and T. Pimonenko. 2023. "The Role of Environmental Regulations, Renewable Energy, and Energy Efficiency in Finding the Path to Green Economic Growth." *Energies* 16: 3090. https://doi.org/10.3390/en16073090.

Eisenhardt, K. M., and J. A. Martin. 2000. "Dynamic Capabilities: What Are They?" *Strategic Management Journal* 21: 1105–1121. https://doi.org/10.1002/1097-0266(200010/11)21:10/113.0.co;2-e.

Fagerberg, J. 2018. "Mobilizing Innovation for Sustainability Transitions: A Comment on Transformative Innovation Policy." *Research Policy* 47, no. 9: 1568–1576. https://doi.org/10.1016/j.respol.2018.08.012.

Filippini, M., and L. C. Hunt. 2015. "Energy Demand and Energy Efficiency in the OECD Countries: A Stochastic Demand Frontier Approach." *Energy Journal* 36, no. 2: 1–27. https://www.jstor.org/stable/41323322.

Gorji, A. A., and I. Martek. 2023. "The Role of Renewable Energy as a 'Green Growth' Strategy for the Built Environment." *Buildings* 13, no. 5: 1356. https://doi.org/10.3390/buildings13051356.

Hart, S. L., and G. Dowell. 2011. "A Natural-Resource-Based View of the Firm: Fifteen Years After." *Journal of Management* 37, no. 5: 1464–1479. https://doi.org/10.1177/0149206310390219.

Helfat, C. E., S. Finkelstein, W. Mitchell, et al. 2007. *Dynamic Capabilities: Understanding Strategic Change in Organizations*. Blackwell.

Helfat, C. E., and M. A. Peteraf. 2003. "The Dynamic Resource-Based View: Capability Lifecycles." *Strategic Management Journal* 24, no. 10: 997–1010.

Hussain, Z., B. Mehmood, M. K. Khan, and R. S. M. Tsimisaraka. 2022. "Green Growth, Green Technology, and Environmental Health: Evidence From High-GDP Countries." *Frontiers in Public Health* 9: 816697. https://doi.org/10.3389/fpubh.2021.816697.

International Energy Agency. 2023. *Energy Efficiency 2023*. IEA. https://www.iea.org/reports/energy-efficiency-2023.

Johnstone, N., I. Haščič, and D. Popp. 2010. "Renewable Energy Policies and Technological Innovation." *Environmental and Resource Economics* 45, no. 1: 133–155. https://doi.org/10.1007/s10640-009-9309-1.

Kazi, S., H. Shaiara, H. Shawkat, and O. Normah. 2021. "Innovation, Militarization, and Renewable Energy and Green Growth in OECD Countries." *Environmental Science and Pollution Research* 28, no. 27: 36004–36017. https://doi.org/10.1007/s11356-021-13326-6.

Khan, K. A., A. Hamid, A. Sharif, Q. R. Syed, and A. Anwar. 2025. "Impact of Adaptation Technologies and Green Energy on Environmental Quality: Evidence From G8 Economies." *Gondwana Research* 139: 230–242. https://doi.org/10.1016/j.gr.2024.11.016.

Khan, S. A., Z. Yu, I. L. Ridwan, R. Irshad, P. Ponce, and M. Tanveer. 2023. "Energy Efficiency, Carbon Neutrality and Technological Innovation: A Strategic Move Towards Green Economy." *Economic Research-Ekonomska Istraživanja* 36, no. 2. https://doi.org/10.1080/1331677X.2022.2140306.

Kruse, T., A. Dechezleprêtre, R. Saffar, and L. Robert. 2022. *Measuring Environmental Policy Stringency in OECD Countries – An Update of the OECD Composite EPS Indicator*, OECD Economics Department Working Papers, No. 1703. OECD Publishing. https://doi.org/10.1787/90ab82e8-en.

Lopez, M. V., A. Garcia, and L. Rodriguez. 2007. "Sustainable Development and Corporate Performance: A Study Based on the Dow Jones Sustainability Index." *Journal of Business Ethics* 75, no. 3: 285–300. https://doi.org/10.1007/s10551-006-9253-8.

Luo, S., and S. Zhang. 2022. "How R&D Expenditure Intermediate as a New Determinants for Low Carbon Energy Transition in Belt and Road Initiative Economies." *Renewable Energy* 197: 101–109. https://doi.org/10.1016/j.renene.2022.06.152.

Marques, A. C., and J. A. Fuinhas. 2012. "Is Renewable Energy Effective in Promoting Growth?" *Energy Policy* 46: 434–442. https://doi.org/10.1016/j.enpol.2012.04.006.

Mensah, C. N., X. Long, L. Dauda, et al. 2019. "Technological Innovation and Green Growth in the Organization for Economic Cooperation and Development Economies." *Journal of Cleaner Production* 240: 118204. https://doi.org/10.1016/j.jclepro.2019.118204.

Mohsin, M., F. Taghizadeh-Hesary, N. Iqbal, and H. B. Saydaliev. 2022. "The Role of Technological Progress and Renewable Energy Deployment in Green Economic Growth." *Renewable Energy* 190: 777–787. https://doi.org/10.1016/j.renene.2022.03.076.

OECD. 2011. *Towards Green Growth*. OECD Publishing. https://doi.org/10.1787/9789264111318-en.

OECD. 2020. *OECD Environmental Performance Reviews: Policies for Greener Growth*. OECD Publishing. https://doi.org/10.1787/9789264301061-en.

Onifade, S. T., and A. A. Alola. 2022. "Energy Transition and Environmental Quality Prospects in Leading Emerging Economies: The Role of Environmental-Related Technological Innovation." *Sustainable Development* 30, no. 6: 1766–1778. https://doi.org/10.1002/sd.2346.

Paramati, S. R., and D. Mo. 2017. "The Role of Financial Stability on Renewable Energy Consumption: Evidence From Developed and Emerging Market Economies." *Renewable Energy* 88: 125–134. https://doi.org/10.1016/j.renene.2015.10.010.

Pesaran, M. H. 2004. "General Diagnostic Tests for Cross-Sectional Dependence in Panels." https://ssrn.com/abstract=57250.

Pesaran, M. H. 2007. "A Simple Panel Unit Root Test in the Presence of Crosssection Dependence." *Journal of Applied Econometrics (Chichester, England)* 22, no. 2: 265–312. https://doi.org/10.1002/JAE.951.

Pesaran, M. H., and T. Yamagata. 2008. "Testing Slope Homogeneity in Large Panels." *Journal of Econometrics* 142, no. 1: 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010.

Popp, D. 2019. "Environmental Policy and Innovation: A Decade of Research." *International Review of Environmental and Resource Economics* 13, no. 3–4: 265–337. http://www.nber.org/papers/w25631.

Porter, M. E., and C. van der Linde. 1995. "Toward a New Conception of the Environment-Competitiveness Relationship." *Journal of Economic Perspectives* 9, no. 4: 97–118. https://doi.org/10.1257/jep.9.4.97.

Romer, P. M. 1990. "Endogenous Technological Change." *Journal of Political Economy* 98, no. 5, Part 2: S71–S102. https://doi.org/10.1086/261725.

Şahin, Ü. 2019. "Yeşil Ekonomi, Yeni İnsan Yayınevi 52, Yeşil Politika Serisi-2, Editörler: Ahmet Atıl Aşıcı - Ümit Şahin."

Sohag, K., S. Husain, S. Hammoudeh, and N. Omar. 2021. "Innovation, Militarization, and Renewable Energy and Green Growth in OECD Countries." *Environmental Science and Pollution Research* 28: 36004–36017. https://doi.org/10.1007/s11356-021-13326-6.

Su, Y., and X. Gao. 2022. "Revealing the Effectiveness of Green Technological Progress and Financial Innovation on Green Economic Growth: The Role of Environmental Regulation." *Environmental Science and Pollution Research* 29, no. 48: 72991–73000. https://doi.org/10.1007/s11356-022-20978-5.

Suki, N. M., N. M. Suki, S. Afshan, A. Sharif, M. A. Kasim, and S. R. M. Hanafi. 2022. "How Does Green Technology Innovation Affect Green Growth in ASEAN-6 Countries? Evidence From Advance Panel Estimations." *Gondwana Research* 111: 165–173. https://doi.org/10.1016/j.gr.2022.06.019.

Teece, D. J. 2007. "Explicating Dynamic Capabilities: The Nature and Microfoundations of (Sustainable) Enterprise Performance." *Strategic Management Journal* 28, no. 13: 1319–1350. https://doi.org/10.1002/smj.640.

Teece, D. J. 2014. "The Foundations of Enterprise Performance: Dynamic and Ordinary Capabilities in an (Economic) Theory of Firms." *Academy of Management Perspectives* 28, no. 4: 328–352. https://doi.org/10.5465/amp.2013.0116.

Teece, D. J. 2018. "Business Models and Dynamic Capabilities." *Long Range Planning* 51, no. 1: 40–49.

Teece, D. J., G. Pisano, and A. Shuen. 1997. "Dynamic Capabilities and Strategic Management." *Strategic Management Journal* 18, no. 7: 509–533. https://doi.org/10.1002/(ISSN)1097-0266.

UN. 2012. "United Nations: The World We Want." https://unsdg.un.org/sites/default/files/The-World-we-Want.pdf.

UNEP. 2011. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*. United Nations Environment Programme.

United Nations (UN). 2015. *Transforming Our World: The 2030 Agenda for Sustainable Development*. United Nations.

Wang, C. L., and P. K. Ahmed. 2007. "Dynamic Capabilities: A Review and Research Agenda." *International Journal of Management Reviews* 9, no. 1: 31–51. https://doi.org/10.1111/j.14682370.2007.00201.x.

WCED. 1987. *World Commission on Environment and Development: Our Common Future*. Oxford University Press. https://www.are.admin.ch/are/en/home/media/publications/sustainable-development/brundtland-report.html.

Weizsäcker, E. U., A. B. Lovins, and L. H. Lovins. 1998. *Factor Four: Doubling Wealth, Halving Resource Use*. Club of Rome. https://doi.org/10.1177/014459879701500608.

Westerlund, J. 2007. "Testing for Error Correction in Panel Data." *Oxford Bulletin of Economics and Statistics* 69, no. 6: 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x.

Yao, X., F. Durani, Q. R. Syed, H. H. Lean, and M. I. Tabash. 2023. "Does Tourism Promote Green Growth? A Panel Data Analysis." *Environment, Development and Sustainability* 27, no. 1: 2411. https://doi.org/10.1007/s10668-023-03972-w.

Appendix A

TABLE A1 | Further diagnostic checks (VIF).

Variable	VIF	1/VIF
LogEPI	2.41	0.414584
logEP	2.14	0.466885
logGES	1.29	0.774792
logGT	1.20	0.830974
Mean VIF	1.76	