



Alternative energy and natural resources in determining environmental sustainability: a look at the role of government final consumption expenditures in France

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Abstract

The global community is concerned about several environmental changes. Climate change, desertification, destruction of tropical rainforests, erosion of coastal ecosystems, soil resource loss, overfishing, species extinction, and loss of biodiversity are all contributing factors. Many commentators contend that these issues make up a cumulative, sustained human impact on the environment that has profoundly changed the surface of the Earth. We explore the effects of alternative energy sources, natural resources, and government consumption expenditures on French environmental sustainability from 1990 through 2018 under the environmental Kuznets curve (EKC) framework. We apply advanced econometric methodologies for empirical analysis. Our long-run estimates indicate that alternative and nuclear energy, natural resources, and government final consumption expenditures are negatively associated with CO₂ emissions, while economic growth is positively related to CO₂ emissions. CO₂ emissions are negatively correlated with the square root of economic growth (EKC), thereby supporting EKC. As economic growth increases, environmental sustainability deteriorates. Eventually, EKC will make a positive contribution to environmental improvement. Future research directions, research limitations, and policy implications are discussed.

Keywords Alternative energy · Environmental sustainability · Government expenditure · EKC · France

Introduction

Conserving energy reduces demand and lessens negative environmental impacts since most of our energy comes from non-renewable fossil fuels. Besides preserving resources, energy conservation saves money and improves the environment. The development of our energy systems has been

influenced by various environmental concerns, from air quality problems to acid rain. These diverse environmental considerations influence and modify investments and other actions to provide secure, affordable energy. With the growing concern about climate change due to greenhouse gas (GHG) emissions, 60% of which are produced by the energy sector, the potential impact of climate change policies on the energy sector is increasing. Energy and environmental policies are inextricably linked, creating a pressing need to understand how to promote synergies. Addressing climate change requires investments in clean energy and removing existing high-emission assets. Path dependence and lock-in are potential consequences of long-lived infrastructure. Keeping temperatures below 2 °C will require a faster transition away from these assets than natural infrastructure replacement (Zakari et al. 2022; Zakari and Khan 2021).

The energy sector is the largest contributor to the production of heat-trapping GHG emissions through the combustion of fossil fuels. Additionally, the combustion of fossil fuels produces air pollution, one of the most important environmental concerns worldwide, when economic and public health damages continue to mount in all countries. Energy

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is a vital resource for economic growth and development. However, it presents critical challenges to the production and use of energy (Khan et al. 2021; Khan and Hou 2021a; Tawiah et al. 2021). There are opportunities to work together to develop solutions to these challenges at the nexus of air pollution and greenhouse gas emissions in several contexts. A significant step in this direction is the interplay between reducing air pollution and GHG emissions when this interplay is not always positive. It is clear that many countries want to address these dual priorities, but the approach may not be straightforward. This issue plays out in very different contexts in China and the USA, illustrating how each country deals with the case (Khan et al. 2021; Khan et al. 2021; Khan and Hou 2021b).

It has been reported that many countries have been tightening air quality regulations to reduce air pollution such as particulate matter, sculpture dioxide, and mercury emissions. In addition to reducing our GHG emissions, compliance with these regulations will also reduce our carbon footprint. You will also find information about the channels by which these co-benefits are achieved, taking into account the experience of the European Union, the USA, and Canada and the experience of other regions (Khan et al. 2021; Lyu et al. 2021; Yang and Khan 2021). A significant amount of the carbon dioxide emissions may be reduced or increased due to other factors, such as coal- and gas-fired electricity generation economics and future expectations concerning carbon dioxide emissions. It is important to highlight the benefits of multipollutant strategies that incorporate an integrated approach (Khan et al. 2021; Zahoor et al. 2021; Zakari et al. 2021).

In 2019, France put its target of reaching net zero greenhouse gas emissions by 2050 into law and updated its energy transition framework through a new National Low-Carbon Strategy and ten-year Energy Transition Strategy (Khan et al. 2021; Taghizadeh-Hesary et al. 2022; Zakari and Khan 2022). Despite several reforms underway, France's transition to clean energy has suffered substantial delays, and implementation continues to be challenging. To accelerate its energy transition, the French government's plan for economic recovery following the crisis of Covid-19 in the nineteenth century and its 2030 investment plan will help it drive progress in sustainable mobility, retrofitting existing buildings, and investing in hydrogen. Many of the numerous recommendations in France 2021 address ways to support the country's efforts to address energy and climate challenges.

To achieve its targets, for France, to meet its climate change targets, it must accelerate the critical components of its energy transformation. The country has played a decisive role in guiding international efforts to tackle climate change. According to a new report released by the International Energy Agency, the government must make crucial decisions about its future energy mix (Bilal et al.

2022; Khan et al. 2022; Zakari et al. 2022). French governments are not deploying technologies and solutions for producing low-carbon energy fast enough to reach their energy and climate targets, according to the 2021 Energy Policy Review. The IEA calls for increased policy actions and investments to achieve its energy and climate goals. Historically, France has shown a strong leadership role in raising the global climate targets. With its involvement in the framework of the European Union and, more importantly, in the historic 2015 Paris Agreement, it played a leading role. It has done so in line with the principles of the Paris Agreement (Hassan et al. 2022; Khan et al. 2022, c; Zhang et al. 2022).

A climate law was enacted in France, one of the first countries globally, and the French government is working toward reaching net zero emissions by 2050 as soon as possible. Throughout France, green finance has been promoted, and a new approach to budgeting aligns the budget and national expenditure goals concerning climate change and the environment. Among the most ambitious clean energy transition plans around the globe is the program for government investments in 2030 and economic recovery, both of which offer a range of retrofitting buildings and promote low-carbon transportation (Arslan et al. 2022; Khan et al. 2022; Zakari et al. 2022). It is expected that the French government will have to make important decisions in 2022 to ensure the country meets its goal of being net-zero emissions by 2050, in particular concerning plans to modernize the nuclear fleet. Throughout the UK, the government must also gratify its ambitions and implement new policies to push clean energy across the economy in the coming years. By 2030, the EU wants to cut emissions by 55%.

The French are at a crossroads, as they have to decide how to design their future energy system to achieve net-zero emissions by 2050. The government of France aims to halve France's final energy consumption. It could be done by investing much more in nuclear power, energy efficiency, and renewable energy between 2012 and 2050. The National Low-Carbon Strategy of France emphasizes energy efficiency. The residential and service sectors have seen the most improvements in efficiency over the past two decades, and building codes and product regulations have been adopted more stringently (Liu et al. 2022; Zahoor et al. 2022; Zhang et al. 2022). There was a slight decline in renovation rates, though, and only a few savings were made in the transportation sector. France still relies heavily on hydroelectric power plants constructed generations ago for almost half of its renewable energy output. Promote flagship programs, streamline permits, and align regional and national goals. The federal government hopes to help speed up solar and wind power progress. The initiative is worthwhile. However, the prospects of success are less specific unless policies are more persistent and consistent.

This study addressed the first important question of how alternative and nuclear energy will affect the sustainability of the environment in France. As part of our efforts to build a CO₂-neutral global economy, it is crucial to decarbonize all sectors that depend largely on fossil fuels today. Heating, industrial processes requiring combustion, and transportation, especially heavy-duty, maritime, and air transportation, are some of the many examples. Around 10% of the entire world's electricity is generated by nuclear energy. It has a relatively low carbon footprint and is the second-largest source of low-carbon power in the world after hydropower. Nuclear technology can also be used for nonelectric applications to reduce carbon footprints. The shift from coal-fired plants to alternative energy sources, such as wind, solar, and natural gas, will reduce CO₂ emissions from the power sector because air pollution and carbon dioxide for these plants are much greater than in coal plants. At the moment, switching from coal-fired power generation to gas-fired power generation is likely the most attractive fuel choice since gas emits less CO₂ emissions (370 kg/MWh) than coal (820 kg/MWh). Despite this, gas is not a carbon-free fuel, and CO₂ emissions will still be present even though they have been substantially reduced. It is important to shift to lower and zero-carbon fuels as much as possible to reduce CO₂ emissions. China released its Air Pollution Prevention and Control Action Plan in 2013, which aimed to reduce the share of coal in the total power generation from 79% in 2011 to below 65% by 2017 (from 79% in 2011). The plan is expected to have a large positive impact on the overall environment. There is the potential to reduce coal consumption from the current level of over nine billion tons to under three billion tons, potentially resulting in cumulative CO₂ emissions reductions that are on the order of 7.2 trillion tons over time. Several sectors can potentially lower their emissions of greenhouse gases, including chemical and industrial processes, clean energy systems, and transportation, by using hydrogen instead of fossil fuels. As it is today, most of the hydrogen in France is produced by steam methane reforming, which is a very energy-intensive process that causes a great deal of CO₂ emissions per year, comparable to the combined emissions of the UK and Indonesia. There are several ways nuclear energy can be used to produce hydrogen efficiently, without emitting any CO₂ emissions, and as a source of electricity and heat.

The Earth has numerous components, such as sunlight, the atmosphere, water, land, minerals, plants, and animals. It is possible to safeguard natural resources through natural heritage programs or by protecting them through nature reserves. Biodiversity and geo-diversity are often found in particular ecosystems (such as the rainforest in Fatu-Hiva) and are usually documented as such. Another important question addressed by this study is how natural resources might influence the sustainability of the French environment.

French resources include iron ore, salt, sulfur, bauxite, zinc, uranium, arsenic, etc. Aside from that, the country also has an extensive timber and fishing industry and a considerable amount of renewable energy. A surprising thing about France is that it only has limited reserves. Large amounts of natural minerals across the country have been depleted due to heavier mining during the industrial revolution, which played a huge role in transforming France into what it is today. It is estimated that France has significant coal, iron ores, bauxite, and uranium reserves. However, they are of shallow depths and difficult to extract, making them unsuitable for steel production. It is a pity that the iron ores in this region are of low quality. The uranium ores are very rare.

It should be noted that there are virtually no petroleum deposits in the Pyrenees, and the natural gas reserves discovered in 1951 at Lacq in the Pyrenees are now almost exhausted. Despite its great development, hydroelectric production cannot meet France's demands. Furthermore, France's high-quality soils make up nearly half of the country's surface, which has resulted in a surplus in agriculture, which has enabled it to become an important food exporter.

The study also considers how final consumption expenditure by the French government and the economic growth of this country influence environmental sustainability. Apart from tax revenues, government expenditures were about 61.78% of GDP in 2020. There has recently been an increase in government spending in the current economic crisis that affects many countries. Spending by the government involves a variety of economic variables and the country's prosperity. The quality of the environment is significantly influenced by government spending. This study investigates how interconnected capital, government expenditure, and the environment are. The literature has failed to examine the relationship between public spending and the environment, while public expenditure may significantly impact the environment. Spending by governments affects the environment both directly and indirectly. Redistribution of government expenditures is more likely when government expenditures increase.

Consequently, there is a higher level of income equality and increased environmental quality. It is expected that large government groups will only demand the environment if it is a luxury good. Economic growth may result in increased pollution levels due to four mechanisms, including scale, growing environmental pressures, composition increased in human capital, intense activities over physical capital intensive industries that are more harmful, technique because of improved labor efficiency, and income increasing income increases demand environmental quality.

Efforts to create an environment conducive to nuclear and alternative energy in France are completely ignored in current literature. This paper explores the effects of alternative energy sources, natural resources, and government consumption expenditures on French environmental sustainability

from 1990 through 2018 under the environmental Kuznets curve (EKC) consideration. France has not yet studied such multiple interactions for ecological sustainability, government spending, and economic growth. The French economic records over the study period include historic recessions and financial crises, such as the financial crisis of 2009, the nuclear disaster of Fukushima in 2011, and the Eurozone crisis in 2013. Our analysis is based on fully modified least squares (FMOLS) and generalized linear model (GLM) using Newton-Raphson and Marquardt steps for the long-run estimations. Moreover, we also apply robust least square and the generalized method of moments (GMM) for robustness checking. For analyses of GMM, we use liner estimation with one weight update with Bartlett kernel Newey-west fixed weighting matrix.

Following is an outline of the remainder of this paper. A literature review is provided in “[Literature review](#)” section to help position the paper. In “[Methodology](#)” section, we provide comprehensive information on the study’s data, theoretical background, and methodology. In “[Results and discussion](#)” section, we present the findings derived from the empirical evaluation of our model. The conclusion and policy recommendations in “[Conclusion and policy recommendations](#)” section are shown.

Literature review

Natural replenishment of renewable resources is what constitutes sustainable energy. It includes sun, wind, rain, tides, waves, and geothermal heat. The use of fossil fuels far exceeds the replenishment of renewable energy. Some renewable energy sources are not sustainable. Biomass sources, for instance, are not sustainable at current exploitation rates. In addition to electricity generation, renewable energy supplies heat/cooling for air and water, transportation, and electric energy for remote areas (off-grid). Almost 30% of humanity’s global energy consumption comes from solar and wind. Traditional biomass, however, accounts for just 8% of energy consumption. Solar water heating makes up more than 4% of energy consumption, and electricity makes up over 6% (Nunez 2015). Among the technologies available are solar, wind, and micro-hydro power options and hybrid electric and solar systems. Several small solar electric systems are available today that can be used to produce electricity for households and small businesses. To significantly reduce GHGs emissions, a hybrid energy system that combines nuclear energy and renewables can be developed.

Transitioning to sustainable energy sources, such as wind, solar, biofuels, hydro, and others with low or zero carbon footprints is the central goal of the energy transition (IEA 2020). Nathaniel and Abdul (2020) examined the

relationship between renewable energy and environmental footprint for Southeast Asian countries from 1990 to 2016. They concluded that environmental degradation is reduced due to the use of renewable energy. The study by Wang et al. (2020) analyzed the ecological footprint of the G-7 countries from 1980 to 2016. Danish et al. (2020) examined how renewable energy increases the energy supply to Brazil, Russia, India, China, and South Africa (BRICS). They confirm the ecological footprint reduction of renewable energy using FMOLS and DOLS. Sharif et al. (2020) revisited Turkey’s ecological footprint. In addition, the long-term environmental impact of renewable energy consumption is reduced when using the quantile autoregressive distributed lag model (QARDL). Elshimy and Khadiga’s (2019) findings confirm that renewable energies minimize carbon footprint.

Grossman and Krueger (1991) presented the basic concept of environmental quality by examining greenhouse gas emissions and economic development. They then describe how economic growth is a key element of a vibrant environment defined in the EKC model. As a result, economic development is at the expense of environmental degradation (Uddin and Gow 2016). The economic growth and environmental quality of Europe between 1997 and 2014 are studied by Elshimy and Khadiga (2019). The EKC hypothesis confirms economic growth by incorporating panel mean groups (PMG-ARDL). For 35 Asian countries since 1991, Arshad Ansari et al. (2020) examined the ecological and material footprint hypothesis. The researchers produce mixed results in their study of the existence of EKC using ecological footprint and PMG methodologies. However, Southeast Asian countries appear to hold EKC (Bekun et al. 2021). East, South, and Southeast Asia do not participate. Baz et al. (2020) examined Pakistan’s ecological footprint from 1971 to 2014. According to the study, economic growth stimulates ecological footprints. There are also similar results (Ahmad et al. 2021, 2020; Alola et al. 2019, 2019; Arshad Ansari et al. 2020; Khan and Hou 2020; Nathaniel and Khan 2020).

Throughout this study, we come across a few pieces of research discussing the impact of government expenditures on the environment and how such expenditure strategies affect the state of the domain. Halkos and Paizanos (2013) empirically examine government expenditures’ effects on the environment. The researchers used sulfur dioxide emissions (SO₂) and CO₂ emissions as proxies for the quality of the environment. They concluded that expenditures by the government are related to the environment’s quality in several ways. Moreover, Leppänen et al. (2015) found that the transition from 1995 to 2009 in the Russian government expenditures was related to climate change. Their research uses temperature as a proxy for environmental conditions (Fatai Adedoyin et al. 2021). According to their results, government expenditures toward protecting the environment hurt the planet’s overall temperature. Sasana et al. (2019)

suggested that economic development might worsen air quality and health issues and the absence of quality materials in the environment. The impact of public expenditure policies on the environment is examined in classic literature (Gufta et al. 1995). The study's findings suggest that governments should decrease environmentally harmful subsidies. We should support agriculture sector subsidies and encourage donations of environmentally friendly equipment for the energy sector to maintain, capitalize, and conserve it. Generally, all of these studies use different indicators to proxy environmental factors.

There is a responsibility on behalf of companies to establish environmentally sustainable practices, but these practices do not need to conflict with the company's objectives to be successful. Environmental sustainability, when done correctly, should align profit with people and the planet, as well as people with each other (Ethics 2022). Unrestricted consumption has been shown to have a significant impact on human welfare. As our economy grows, so does our energy use, and as a result, our environment becomes more polluted, and our natural resources are depleted. But for a business to succeed and be sustainable, that does not mean it cannot be innovative and innovative. Growth is tethered to sustainability in some way. New jobs are created by companies involved in the field of renewable energy. There is an opportunity to use less energy and plastic in production to increase profits. The corporate cost-benefit analysis must consider the impact of the environment in assessing cost-benefit costs, but achieving this alignment is an investment in a future economy that will flourish to achieve this alignment (Freedman 2018). There are certain instances in which ESG (Environmental, Social, and Governance) and sustainability are used interchangeably, like when benchmarking is concerned and data is disclosable to the public. As a term for many green concepts and corporate social responsibility, sustainability is an umbrella term that encompasses a wide spectrum of topics. In contrast, ESG has become the preferred term for investors and the financial world. Although sustainability efforts may have been at the forefront of the industry's beginnings, it has evolved to encompass ESG practices, performance, reporting, and opportunities available to investors. By analyzing ESG-related data, investors can determine what their risk-adjusted returns are. With the focus on all three pillars of measurement and disclosure of performance, companies have gained an advantage in this area (Goodland and Rockfeller 1996).

Since climate change is an all-encompassing problem, carbon emissions are measured using various mathematical models and theories. Carbon dioxide emissions have been investigated using many methods in recent years. For analyzing affluence and technology through regression, three of the most discussed ideas in the literature are EKC,

STIRPAT, and the Logarithmic Mean Divisia Index (LMDI). According to Sarkodie et al. (2020), a study looked at household consumption expenditure, GDP per capita, and energy efficiency in Kenya to determine the validity of the Kuznets curve theory. Rauf et al. (2018) also show that the Belt and Road economies initiative shows evidence of EKC. Using data from 1980 through 2014, Eyup Dogan and Ilhan Ozturk examined carbon dioxide emissions and real income, non-renewable energy use, and renewable energy use in the USA. Ozturk (2017) studied carbon dioxide emissions, replacement energy consumption, foreign direct investment, and fossil fuel consumption across nine Latin American nations. Using 25 OECD nations as an example, Kahia et al. (2019) analyzed gross domestic product to per capita carbon emissions and renewable and non-renewable energy use. Sarkodie et al. (2020) examine associations between climate change and human capital in China. According to the EKC hypothesis, economic development and environmental degradation have a U-shaped curve (Panayotou 1994). EKC measures environmental pressure by measuring carbon dioxide emissions. The ecological footprint was employed by Ulucak and Bilgili (2018) to measure environmental degradation. Their research identified three types of economies: low, middle, and high. The EKC hypothesis was confirmed.

Methodology

Theoretical framework

It has been extensively discussed in previous studies how environmental sustainability, renewable energy consumption, and economic growth all play into each other (Bekun et al. 2021; Ike et al. 2020; Ikram et al. 2020; Khan et al. 2018; Khezri et al. 2022; Nathaniel et al. 2021; Pata 2021; Vural 2020; Yang et al. 2020). This study attempts to examine the impact of alternative and nuclear energy consumption on the notions of environmental sustainability, natural resources, government expenditures, and linear and nonlinear effects of economic growth in France. Natural resources like sunlight, wind, and water provide most of the green energy. These energy sources provide an abundant supply of energy and are the antithesis of carbon-emitting fossil fuels that have powered the world for 150 years. A nuclear power plant is the world's most environmentally friendly energy source. Nuclear power is considered to be a very clean source of energy. Nuclear energy offers many pros and cons to consider, including the fact that there are fewer emissions and greater efficiency with nuclear energy (Spring Power and Gas 2018). Population growth and climate change are among the factors contributing to increased pressure on scarce natural resources. Water supply and watershed quality are declining as household, industrial, and agricultural

demands grow. As a result, watersheds and irrigated lands are falling in quality and function.

Additionally, deforestation, overgrazing, salinization, and soil erosion are rising. Therefore, natural resources are diminishing rapidly, affecting the poor, who rely upon these resources to generate most of their income (Van der Elst and Williams 2018). Using public funds, the government sets limits on pollution and enforces drinking water standards. Moreover, some businesses are limited in terms of their environmental impact by the government.

Economic growth will impact the country's real output as a result of the increase in economic activity. Consequently, increasing production and consumption is likely to increase environmental costs. Global warming, non-renewable resource consumption, pollution, and habitat losses are among the environmental impacts of economic growth. All forms of economic growth do not cause environmental damage. As real incomes rise, individuals can devote resources to ecological protection better. Economic growth can also lead to less pollution if technology improves. The theory of economic growth and the environment holds that it worsens the climate to a point, but once the post-industrial economy takes over, it enhances it (Pettinger 2020). There may be a Kuznets curve for some visible pollutants, but this may be less true for less visible and diffuse impurities.

In contrast, economic growth does not reverse the trend toward consumption and reduction of non-renewable resources. If pollution is reduced in one country, corrosion may be exported elsewhere, e.g., by importing coal from developing countries. Often, environmental policies focus on immediate problems while ignoring long-term issues (Stern, 2004).

Model specification

This paper explores the effects of alternative energy sources, natural resources, and government consumption expenditures on French environmental sustainability from 1990 through 2018 under the environmental Kuznets curve (EKC) consideration.

$$CO_2_t = \beta_0 + \beta_1 ALTER_t + \beta_2 NATURAL_t + \beta_3 GOVER_t + \beta_4 GDP_t + \beta_5 GDPS_t + \varepsilon_t \quad (1)$$

Where β_0 in the intercept, β_1 to β_5 are coefficients of ALTER (alternative and nuclear energy), NATURAL (natural resources), GOVER (government consumption final expenditures), GDP (economic growth), and GDPS (square root of GDP, EKC). CO_2 (CO_2 emissions, proxy for environmental sustainability) is the dependent variable, t reflects the time series (1990 to 2018), and ε is the error.

Data sources

This study examines the effects of alternative energy sources, natural resources, and government consumption expenditures on French environmental sustainability from 1990 to 2018 using the EKC as a measurement tool. The amount of CO_2 emissions per capita is expressed in metric tons. Carbon dioxide is a greenhouse gas emitted as a by-product of the combustion of fossil fuels. As a result of the explosion of solid, liquid, and gaseous fuels, carbon dioxide is released into the atmosphere. This percentage represents the amount of energy used as alternative and nuclear energy. A clean energy source is an energy source that is non-carbohydrate and does not emit carbon dioxide during the process of generation. In addition to hydropower and nuclear power, it also includes geothermal power, solar power, and geothermal power. Natural resource rents are calculated as a percentage of GDP. It is estimated that the total natural resources rent equals the sum of the rents received by oil companies, natural gas companies, coal companies, mineral companies, and forest companies. The total government final consumption expenditures are calculated based on current dollar exchange rates. All current government expenditures, including employee compensation, are included in government final consumption expenditures. Government military expenditures are excluded from the analysis as they are part of government capital formation. The data are collected from the World Development Indicators (WDI) for the annual time series.

Econometric modeling

Unit-root tests

To make trends stationery, testing at the unit root level can decide whether trending data should be first added or subtracted from deterministic time functions before regressing on them. The theory of economics and finance sometimes suggests that there is an equilibrium relationship between non-stationary time series variables in the long run. Our study is based on the Dicky-Fuller (1997) and Phillips and Perron (1988) unit root tests, which we applied to our sample time series to check their unit root properties. Following the requirements of Dicky-Fuller (1997) and Phillips and Perron's (1988) unit root tests, we have recalculated the estimation properties by considering constant, without constant, and trend, and with continuous and trend. As a standard Dicky-Fuller's (1997) ADF, the following tests were performed:

$$\Delta y_t = c + ay_{t-1} + \beta_t + \sum_{j=1}^k d_j \Delta y_{t-j} + \varepsilon_t \quad (2)$$

Δy_t represents the change in the values over time, and Δy_{t-j} represents the first-differenced lag to deal with serial correlation in the errors over time.

Johansen co-integration test

Using a process known as co-integration, we analyze time series for the presence of long-term correlations. Cointegration is a concept that was first introduced in 1987 by Nobel laureates Robert Engle and Clive Granger. Engle and Granger (1987), the Johansen Test (1991, 1995), and the Phillips-Ouliaris Test are three of the most popular tests used for co-integration. Johansen’s co-integration test is especially noteworthy because it considers the entire variables endogenously, and it can produce more than one co-integrating relation Johansen (1991, 1995) as follows:

$$y_t = A_1 y_{t-1} + \dots + A_p y_{t-p} + \beta x_t + \varepsilon_t \tag{3}$$

Where y_t is non-stationary k -vector, βx_t is the deterministic trend of d -vector, and ε_t approaches to random error vector.

Long-run estimates and robust long-run analysis

The study moves from examining the co-integration of the variables to a more important step of the empirical analysis: the long-run estimates that determine whether the study variables are trending in the long run. In this study, we apply fully modified least squares (FMOLS) presented by Phillips and Hansen (1990) and generalized linear model (GLM) using Newton-Raphson and Marquardt steps for the longer estimations. We computed dispersion using Pearson Chi-Square, convergence achieved after one iteration, and coefficient covariance computed using observed Hessian. Literature (Khan et al. 2021, b; Khan and Hou 2020) demonstrates that many widely used econometric approaches are based on FMOLS, and GLM long-run estimates. In general, the benefit of these methodologies resides in their ability to eliminate problems of endogeneity among regressions and their ability to deal with the issue of autocorrelation. Moreover, we also apply robust least square and the generalized method of moments (GMM) for robustness checking. For estimations of GMM, we use liner estimation with one weight up a date with Bartlett kernel Newey-west fixed weighting matrix. Standard errors and covariances are computed using an estimate weighting matrix while constantly adding to the instrument list. An advantage of the GMM approach is that we only need a moment condition to begin the analysis. We do not need anything to be log-linearized. It does not matter whether there are non-linearities. Heteroscedasticity and distributional assumptions are robust

against the model (Nelder-Wedderburn 1972; Stroup 2012). Clustering contributes to the literature of all four advanced econometric approaches.

Results and discussion

Table 1 summarizes the results of the descriptive analysis and the corresponding correlation coefficient matrix for various aspects of the French economy, including CO₂ emissions, alternative and nuclear energy, natural resources, government final consumption expenditure, and economic growth. There is a considerable overlap between the mean, median, maximum, and minimum values of all these variables, which indicates that these variables have a normal distribution. As a measure of the level of volatility and fluctuation among these variables, the standard deviation represents this level of volatility and instability. There was, therefore, the greatest degree of change in the behavior of government final consumption expenditure during this period. Using pairwise correlation matrix, it was possible to determine the negative association between alternative and nuclear energy sources, CO₂ emissions, and natural resources. There is also a negative correlation between government final consumption expenditures, economic growth, and CO₂ emissions in the government sector (Bekun et al. 2022; Caglar et al. 2022). However, alternative and nuclear energy are positively related to government final consumption expenditures and economic growth. Figure 1 demonstrates the data trend in the raw form.

In Table 2, we present the results of the unit root tests for the two-dimensional functions ADF, and PP with all the options of without constant and trend, with constant, and with constant and movement. As such, all the variables of ADF at the level, such as CO₂ emissions, alternative and nuclear energy, natural resources, government

Table 1 Descriptive analysis

Variables	CO ₂	ALTER	NATU- RAL	GOVER	GDP
Mean	0.749902	1.651810	– 1.257380	11.65482	4.494741
Median	0.771847	1.653012	– 1.284770	11.68803	4.528161
Maximum	0.812976	1.704564	– 0.963065	11.83766	4.656425
Minimum	0.662038	1.581962	– 1.438622	11.42922	4.335960
Std. Dev.	0.047090	0.030467	0.110085	0.144901	0.116438
CO ₂	1.0000				
ALTER	– 0.8378	1.0000			
NATU- RAL	0.5738	– 0.7858	1.0000		
GOVER	– 0.8092	0.7714	– 0.6952	1.0000	
GDP	– 0.7662	0.7187	– 0.6594	0.9942	1.0000

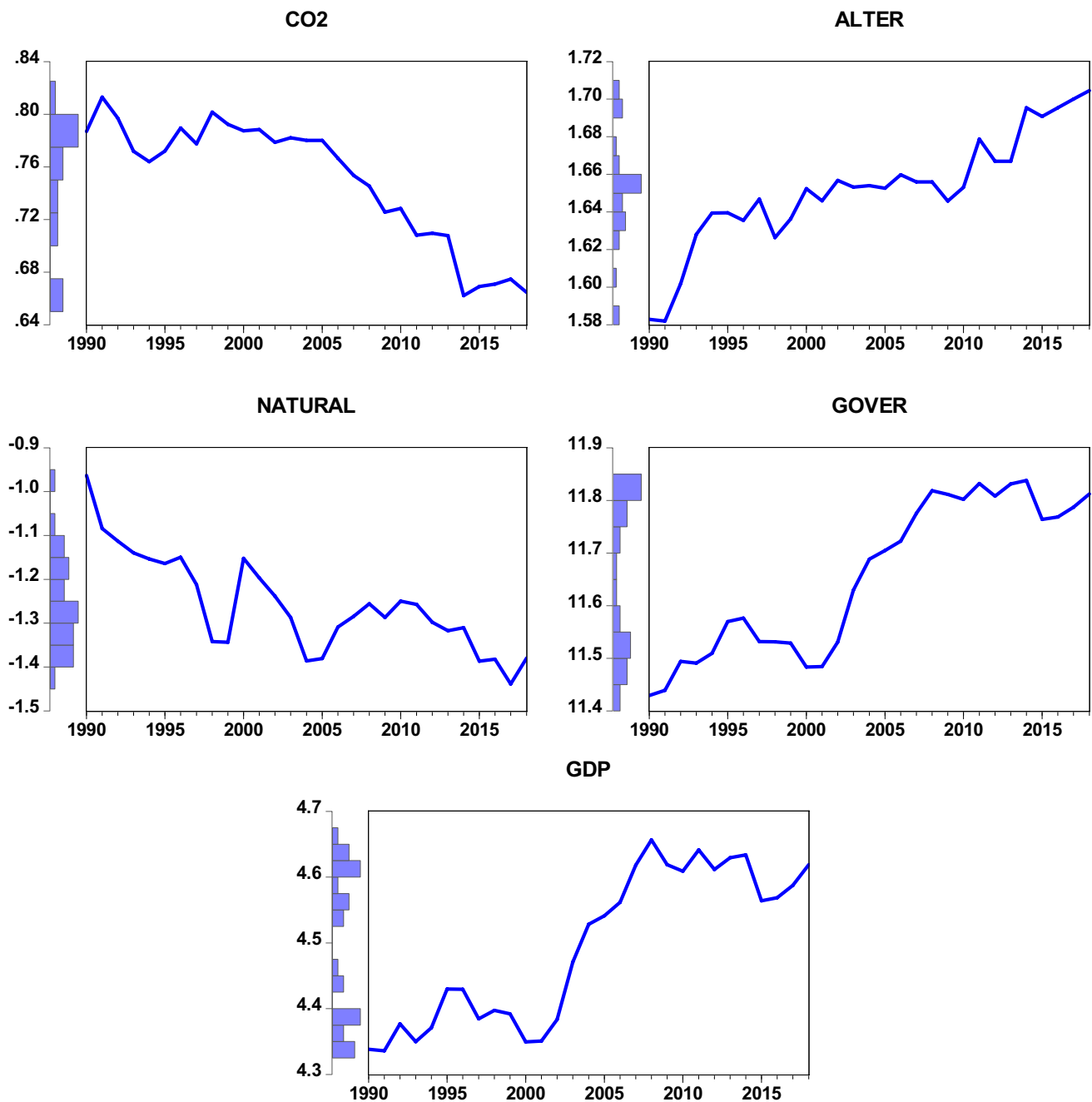


Fig. 1 Raw data multiple graphs

final consumption expenditures, economic growth, etc., are not stationary. At first difference, all these variables are static. It has been found that CO₂ emissions have a significant level of 1%. Various levels of significance are associated with alternative and nuclear energy, natural resources, government final consumption expenditures, and economic growth. At the level of PP, CO₂ emissions are stationary without any constants or trends and significant at the level of 10% significance. Natural resources are

also stationary at the level of 10% significance. The use of alternative and nuclear energy, government final consumption expenditure, and economic growth are not stationary. At the first difference, all of these variables are stationary. CO₂ emissions, alternative and nuclear energy, and natural resources are all significant at a 1% significance level. The government's final consumption expenditure and economic growth are significant at 1%, 5%, and 10% significance levels.

Table 2 ADF and PP unit-root tests

	ADF At level	CO ₂	ALTER	NATURAL	GOVER	GDP
With constant	t-Statistic	0.0290	− 1.5204	− 2.8415	− 1.2795	− 1.0211
	Prob.	0.9537	0.5077	0.0654	0.6240	0.7315
With constant & trend	t-Statistic	− 2.0426	− 3.0442	− 3.3169	− 2.1076	− 2.5255
	Prob.	0.5537	0.1387	0.0849	0.5188	0.3141
Without constant & trend	t-Statistic	− 1.5570	2.1653	1.0192	1.9882	1.4488
	Prob.	0.1105	0.9907	0.9146	0.9865	0.9598
ADF at first difference						
		d(CO ₂)	d(ALTER)	d(NATURAL)	d(GOVER)	d(GDP)
With constant	t-Statistic	− 6.5506***	− 4.7596***	− 4.9957***	− 3.7573**	− 4.1921**
	Prob.	0.0000	0.0008	0.0004	0.0087	0.0031
With constant & trend	t-Statistic	− 6.4915***	− 4.6884**	− 4.9205**	− 3.7317*	− 4.1306*
	Prob.	0.0001	0.0048	0.0026	0.0372	0.0159
Without constant & trend	t-Statistic	− 5.7322***	− 5.1777***	− 4.9846***	− 3.4397**	− 3.9764***
	Prob.	0.0000	0.0000	0.0000	0.0013	0.0003
PP at level						
		CO ₂	ALTER	NATURAL	GOVER	GDP
With constant	t-Statistic	0.4023	− 1.6287	− 3.0063*	− 1.1807	− 1.0713
	Prob.	0.9794	0.4552	0.0465	0.6683	0.7127
With constant & trend	t-Statistic	− 2.0106	− 3.0076	− 3.7691*	− 1.6854	− 1.7739
	Prob.	0.5705	0.1479	0.0338	0.7309	0.6902
Without constant & trend	t-Statistic	− 1.8653*	2.1161	1.8378	1.7582	1.3373
	Prob.	0.0601	0.9898	0.9815	0.9781	0.9506
PP at first difference						
		d(CO ₂)	d(ALTER)	d(NATURAL)	d(GOVER)	d(GDP)
With constant	t-Statistic	− 6.5506***	− 5.9708***	− 5.9263***	− 3.7098**	− 4.1401**
	Prob.	0.0000	0.0000	0.0000	0.0098	0.0035
With constant & trend	t-Statistic	− 6.4915***	− 5.9475***	− 5.8648***	− 3.6768*	− 4.0666*
	Prob.	0.0001	0.0002	0.0003	0.0417	0.0183
Without constant & trend	t-Statistic	− 5.6851***	− 5.1777***	− 5.4187***	− 3.3971**	− 3.9746***
	Prob.	0.0000	0.0000	0.0000	0.0015	0.0003

*** Significant at the 1%; ** significant at the 5%; * significant at the 10%

As a result of the mixed integration test results from both the ADF unit root test and the PP unit root test, we present the Johansen co-integration test results in Table 3. Here, the null hypothesis is rejected at the 1% significance level because there can only be one co-integrating equation. As a result, we can explain that our study variables CO₂ emissions, nuclear energy, natural resources, government final consumption expenditures, and economic growth have a long-run relationship and movement together during the study period in France.

Following the analysis of the co-integration degree, we estimated this study’s long-run estimates using FMOLS, GLM, robust least squares, and GMM regressions in Tables 4 and 5. Our long-run estimates indicate that alternative and nuclear energy, natural resources, and government final consumption expenditures are negatively associated with CO₂ emissions. In contrast, economic growth is positively associated with CO₂ emissions. In France, the square root of economic growth, EKC, is also negatively correlated

Table 3 Johansen co-integration test.

Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	Critical value	Prob.
None**	0.741374	85.40922	69.81889	0.0017
At most 1*	0.601010	48.89514	47.85613	0.0398
At most 2	0.443438	24.08702	29.79707	0.1968
At most 3	0.263563	8.265625	15.49471	0.4374
At most 4	0.000202	0.005460	3.841466	0.9404
	Eigenvalue	Max-Eigen statistic	Critical value	Prob.
None*	0.741374	36.51407	33.87687	0.0237
At most 1	0.601010	24.80813	27.58434	0.1089
At most 2	0.443438	15.82139	21.13162	0.2355
At most 3	0.263563	8.260164	14.26460	0.3529
At most 4	0.000202	0.005460	3.841466	0.9404

** Significant at the 5%; * significant at the 10%

Table 4 Long-run results

Variables/Methods	Coefficient	Std. Error	t-Statistic	Prob.
FMOLS				
ALTER	− 0.774138*	0.345774	− 2.238858	0.0351
NATURAL	− 0.141774*	0.069370	− 2.043745	0.0526
GOVER	− 0.986933*	0.435373	− 2.266867	0.0331
GDP	5.007529**	1.603211	3.123437	0.0048
GDPS	− 0.452799**	0.123352	− 3.670772	0.0013
GLM				
ALTER	− 0.668048*	0.296209	− 2.255329	0.0241
NATURAL	− 0.120811*	0.055583	− 2.173502	0.0297
GOVER	− 1.039104**	0.365771	− 2.840857	0.0045
GDP	5.125867***	1.342148	3.819152	0.0001
GDPS	− 0.456445***	0.103300	− 4.418609	0.0000

*** Significant at the 1%; ** significant at the 5%; * significant at the 10%

Table 5 Robust long-run estimates

Variables/Methods	Coefficient	Std. Error	t-Statistic	Prob.
Robust least squares				
ALTER	− 0.661481*	0.312285	− 2.118193	0.0342
NATURAL	− 0.085454	0.058600	− 1.458252	0.1448
GOVER	− 1.151655**	0.385624	− 2.986475	0.0028
GDP	5.581773***	1.414993	3.944734	0.0001
GDPS	− 0.491162***	0.108907	− 4.509918	0.0000
GMM				
ALTER	− 0.601793*	0.333299	− 1.805565	0.0835
NATURAL	− 0.092116	0.059333	− 1.552518	0.1336
GOVER	− 1.069187**	0.285899	− 3.739743	0.0010
GDP	5.202729***	1.122467	4.635085	0.0001
GDPS	− 0.459616***	0.089082	− 5.159484	0.0000

*** Significant at the 1%; ** significant at the 5%; * significant at the 10%

with CO₂ emissions, which is evidence for the validity of the EKC hypothesis. This result explains that alternative and nuclear energy, natural resources, and government consumption final expenditures improve environmental sustainability. As economic growth develops, environmental sustainability begins to deteriorate. However, in the process, EKC starts contributing positively to ecological improvement.

A 1% level of significance is statistically significant in the case of alternative and nuclear energy. Under the negative relationship between alternative and nuclear energy and CO₂ emissions, a 1% acceleration in the alternative and nuclear energy sector will reduce the CO₂ emissions in France by 0.774138% (FMOLS) and 0.668048% (GLM).

Among the major environmental concerns that nuclear power raises are the creation of radioactive wastes such as mill tailings, used reactor fuels, and other radioactive wastes associated with nuclear power production. The materials can remain radiation-emitting for thousands of years, and they can potentially harm human health. Nuclear reactors are not responsible for air pollution or carbon dioxide emissions when operating, as is the case with fossil fuel-fired power plants. Despite this, there is a large amount of energy taken up by mining, refining, and making reactor fuel to do these. In addition to the large amounts of metal and concrete found in nuclear power plants, these materials are also manufactured with onerous quantities of energy. It is possible that the emissions from burning those fossil fuels could be associated with the electricity emitted by nuclear power plants if the fossil fuels are used to mine and refine uranium ore or if fossil fuels are used during the construction of nuclear power plants. Figure 2 demonstrates the interrelationship among the variables.

Natural resources have a negative coefficient value and are statistically significant at 1%. The negative dynamics between natural resources and CO₂ emissions explore that a 1% acceleration in natural resources may decrease the CO₂ emissions or improve the environmental sustainability in France by 0.141774% (FMOLS) and 0.120811% (GLM). The findings from this study indicate that natural resources are being extracted, processed, and used in a manner that causes environmental problems such as contamination of air, land, and water, destruction of ecosystems, and consequently, biodiversity has decreased. It is a well-known fact that exploitation, exploration, mining, and processing of natural resources have resulted in many types of damage to the environment. Environmental disturbances are deforestation, destruction of native flora and fauna, pollution of air, water, and land, instabilities of soil and rock masses, desertification, and climate change. As a result of environmental destruction, many arable lands, trees, and crops worth money have been lost. Because natural resources must be exploited to obtain them, most of the damage caused by their exploitation is inevitable. As a result, both the government and the natural resources industry must be involved in taking preventative and remedial measures that can minimize the damages caused by their exploitation.

Regarding the final expenditures for government consumption, the coefficient value is negative and statistically significant at 1% (FMOLS) and 5% (GLM). The negative dynamics between government consumption final expenditures with CO₂ emissions explore that a 1% increase in government final consumption expenditures may decrease the CO₂ emissions of France by 0.986933% (FMOLS) and 1.039104% (GLM). Environmental protection is a public expenditure on the part of the government which involves several spending on the part of the government. In addition to these categories, the government's expenditures on environmental

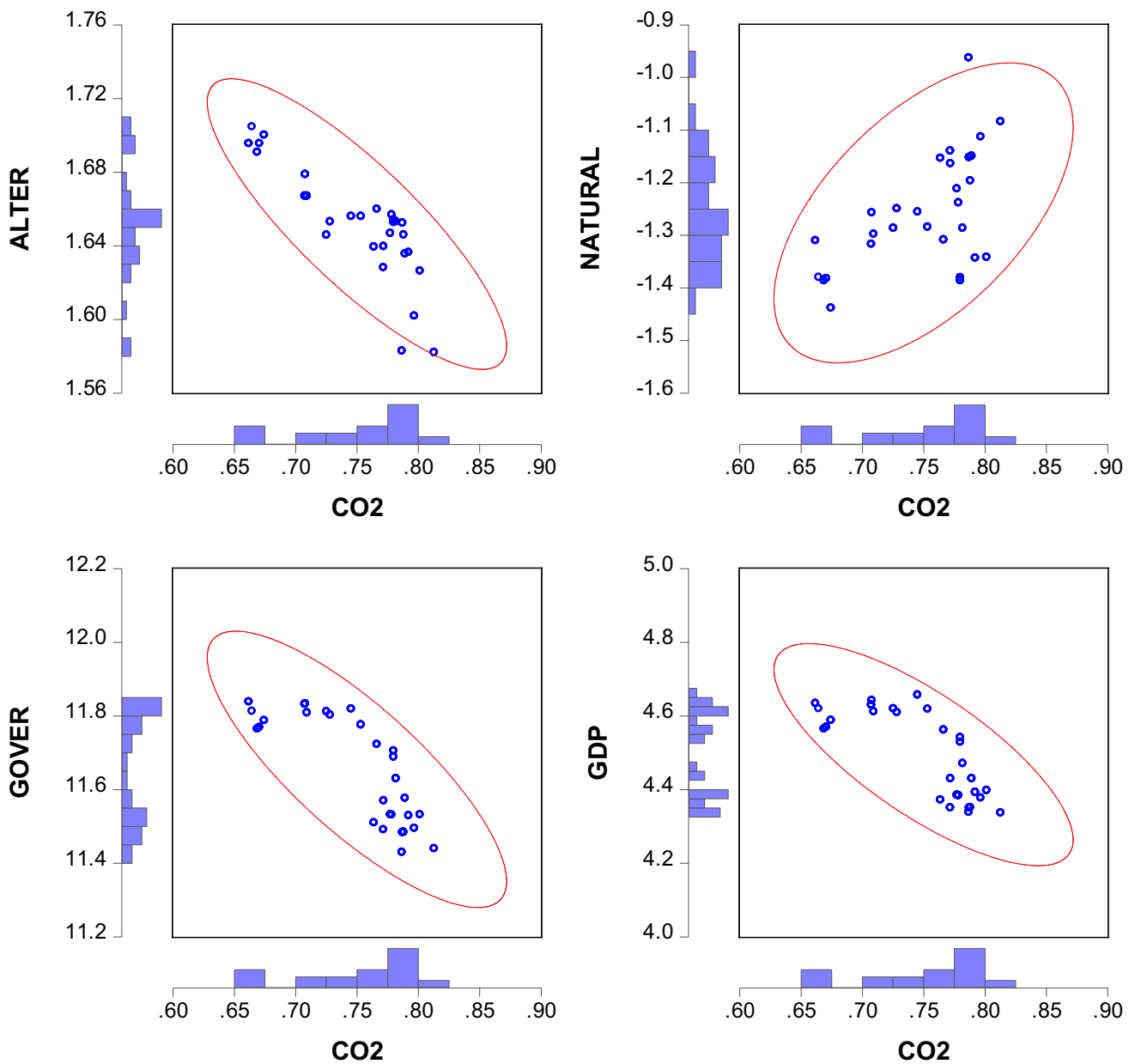


Fig. 2 First vs. all multiple graphs

matters have also been included. These include waste and wastewater management, pollution reduction, protection of biodiversity and landscapes, as well as scientific research concerning environmental protection. These findings suggest that government environmental funds could be allocated toward oil windfalls and introducing environmental taxes and green policies. In this way, we could tackle some of the pressing environmental issues. Additionally, this research also highlights that the government's spending on environmental awareness and education programs may improve both living standards and the quality of life, which, in turn, may lead to the advancement of sustainability in the environment.

Finally, GDP growth at 5% (FMOLS) and 1% (GLM) is positive and statistically significant. Economic growth and CO₂ emissions are positively correlated, explaining that a 1% increase in economic growth may increase CO₂ emissions or degrade the environmental sustainability of France by 5.007529% (FMOLS) or 5.125867% (GLM). This outcome implies that the economy's growth will be compromised without protecting the environment, and the protection of the environment will be undermined without economic growth. There are limits on the planet's economic growth due to its natural resources. Depending on the degree of resource substitution, technological progress, and structural

factors changes, these limits may differ. The results of economic growth are surprisingly both positive and negative in terms of their impacts on the environment, including the increased use of non-renewable resources, pollution levels, global warming, and potential losses of habitats. Despite this, not all types of economic growth hurt the environment. In the EKC's U-shape, those living in higher-income societies face greater environmental degradation, which increases as income increases and declines when income exceeds. This suggests that air pollution is caused by growth, and growth can alleviate the threat. The negative coefficient value of the square root of economic growth implies that a 1% further

increase in economic growth reduces the CO₂ emissions by 0.452799% (FMOLS) and 0.456445% (GLM). There has been increasing evidence that the EKC hypothesis predicts that per capita income and pollutants have an inverted-U relation over time. Specifically, as income increases, environmental pressure rises to a certain level; then, it declines. As can be seen from Table 5, the long-term robustness analysis seems to have similar results. Figure 3 demonstrates the lower triangular matrix showing the interrelationship among the variables.

The results of the pairwise Granger causality test are presented in Table 6. The results demonstrate that a

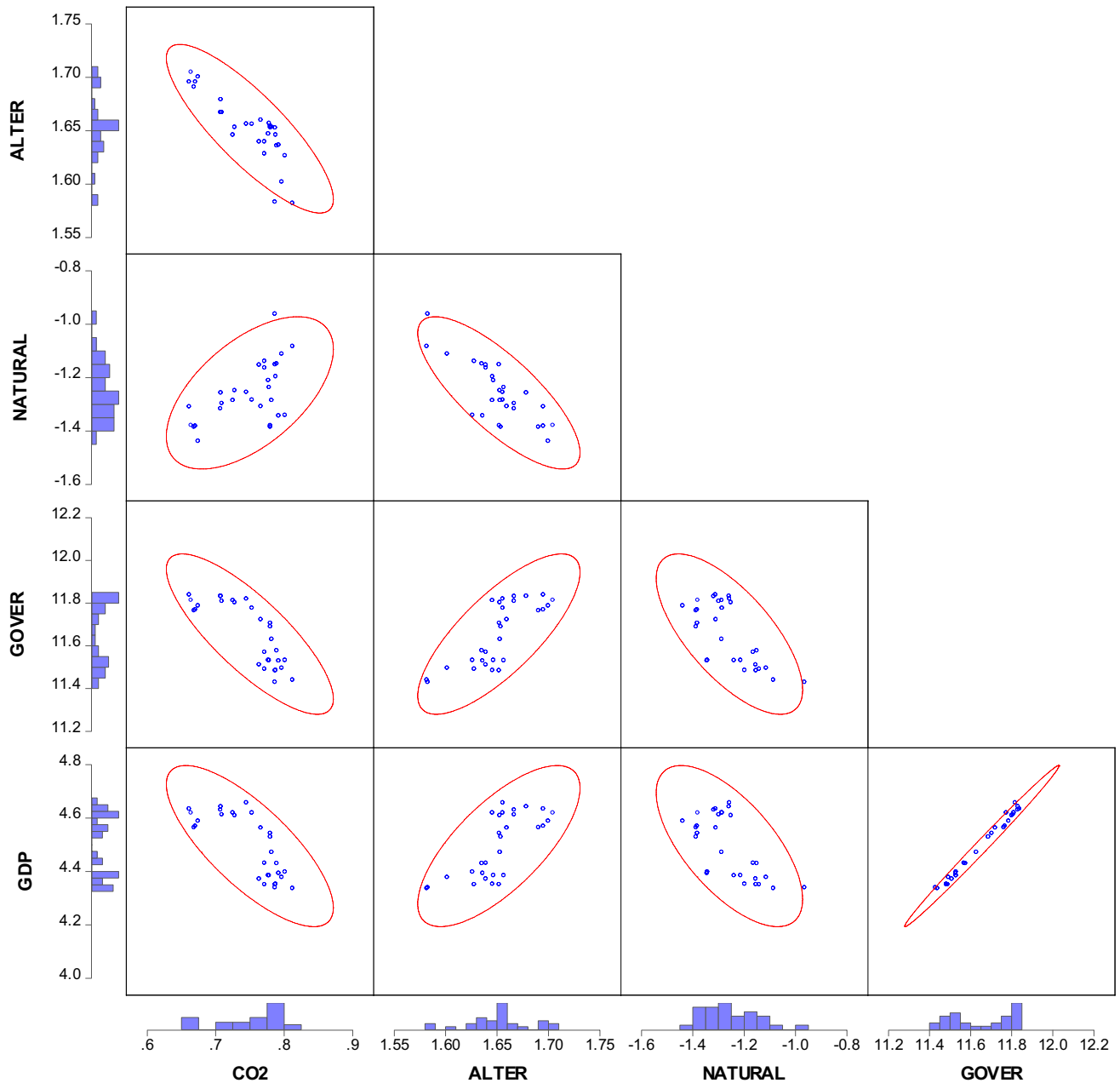


Fig. 3 Lower triangular matrix

Table 6 Pairwise Granger causality tests

Variables	CO ₂	ALTER	NATURAL	GOVER	GDP
CO ₂	–	0.01309 (0.9098)	1.88332 (0.1821)	6.04109* (0.0213)	5.47914* (0.0275)
ALTER	2.02442 (0.1671)	–	3.20336* (0.0856)	1.50043 (0.2320)	0.84796 (0.3659)
NATURAL	3.18997* (0.0862)	7.30697* (0.0122)	–	1.35591 (0.2552)	0.88436 (0.3560)
GOVER	0.36428 (0.5516)	0.11031 (0.7426)	0.21326 (0.6482)	–	0.00023 (0.9879)
GDP	0.06000 (0.8085)	0.70596 (0.4088)	0.95352 (0.3382)	0.45068 (0.5082)	–

*Significant at the 10%

unidirectional Granger causality prevails between CO₂ emissions and natural resources, general government final consumption expenditure and CO₂ emissions, and economic growth and CO₂ emissions. A bidirectional Granger causality exists between natural resources and alternative energy and nuclear energy sources in France during the study period.

Conclusion and policy recommendations

Resources that support current operations without compromising future generations' energy needs or climate are sustainable. A sustainable energy source can be recharged within a human lifetime and does not damage the environment long term. Solar energy, wind energy, wave energy, biomass energy, geothermal energy, and hydroelectricity are all examples of sustainable energy. Several renewable energy sources include wind, solar, and hydropower (Bekun et al. 2022; Caglar et al. 2022). Sustainable environmental management involves conserving natural resources and protecting global ecosystems to support health and well-being now and in the future. Environmental sustainability involves aspects such as the health of ecosystems over the longer term. Protecting food supplies, farmlands, and fishing stocks is a way to ensure the long-term productivity and health of resources (Bekun 2022). This paper explores the effects of alternative energy sources, natural resources, and government consumption expenditures on French environmental sustainability from 1990 through 2018 under the EKC consideration.

All the variables are transformed into their natural logarithms during the estimation process. The study applies advanced econometric methodologies for analysis, including FMOLS, GLM, robust least squares, and GMM as long-run estimates. Our long-run estimates indicate that alternative and nuclear energy, natural resources, and government final consumption expenditures are negatively associated with CO₂ emissions. In contrast, economic growth is positively related to CO₂ emissions. In France, the square root of economic growth, EKC, is also negatively correlated with CO₂ emissions, which is evidence of the EKC hypothesis's

validity. This result explains that alternative and nuclear energy, natural resources, and government consumption final expenditures improve environmental sustainability. As economic growth develops, environmental sustainability begins to deteriorate. However, in the process, EKC starts contributing positively to ecological improvement. The results of pairwise Granger causality demonstrate that a unidirectional Granger causality prevails between CO₂ emissions and natural resources, general government final consumption expenditure and CO₂ emissions, and economic growth and CO₂ emissions. A bidirectional Granger causality exists between natural resources and alternative energy and nuclear energy sources in France during the study period.

In 2030, the United Nations hopes everyone will access modern energy services. Renewable energy sources will be doubled in the global energy mix, and energy efficiency will have doubled. Aiming for these goals is ambitious. The challenge is that few countries have developed policies and regulations that will foster truly sustainable energy systems. These will provide secure, affordable, and sustainable energy to meet these objectives. This may enable policymakers in France to design policies about nuclear emissions and CO₂ emissions reductions based on the results. The long-run estimates elucidate the negative associations between alternative and nuclear energy sources and environmental sustainability in France. Nuclear energy reduces environmental pollution and helps mitigate environmental pollution. Unlike nuclear and renewable energy, natural gas does not seem to reduce emissions. Foreign direct investment and nuclear power contribute to reducing emissions. Policy analysts should consider that nuclear energy impacts both kinds of carbon emissions (Adewale Alola et al. 2021; Baloch et al. 2021; Fatai Adedoyin et al. 2021). In addition to meeting growing energy demands, nuclear energy can reduce energy import dependence. An aggregate measure of energy costs and CO₂ emissions might be connected because France has a lot of nuclear energy. In addition, nuclear energy could achieve sustainable development goals and design better environmental strategies. In addition, the French need to invest in nuclear energy and intensify it. A nuclear technology-based economy will undoubtedly contribute

to economic growth and social and environmental well-being. In addition to providing energy security and reducing pollution generated by conventional energy production, nuclear power offers lower costs.

Further, nuclear power would reduce energy import dependence. As globalization strengthens nuclear energy's benefits in reducing carbon emissions, policymakers should emphasize it more. Through globalization, nuclear energy could gain a bigger share, enabling international trade, foreign direct investment, and technology transfer.

Using natural resources sustainably means ensuring that social benefits are maximized and environmental impacts are minimized to strike a balance between these two dimensions. Natural resource policy is about the distribution of benefits and costs. Biodiversity protection is based on the same concerns. Different types of property rights can protect biodiversity values. All requests have winners and losers. When creating an effective property rights system, it is hard to ignore distributional issues, requirements for measuring progress, and timeframes for reaching objectives. All resource policy involves the difficult question of promoting equitable distributions, but biodiversity policy poses a complex question. Those outside a local area may be interested in protecting ecosystem services, but defensive efforts will fail unless these interests are aligned with local owners' objectives. Resources are protected effectively when the participants accept the rules and procedures. The regulation of natural resource systems can be difficult, and there are many opportunities for circumvention. They undermine rather than promote its evolution to a new form when they doubt the legitimacy of the property rights system due to their inability to accept its distributional outcomes. As a result of scarcity, rent-seeking is magnified, contributing to the erosion of legitimacy. Practices that promote sustainability include cutting fewer trees each year and planting new seedlings in deforested areas. The rapid growth of the human population demands that we reduce our depletion of forests, precious metals, and other natural resources as fast as possible.

The primary indicator of economic development is the increase in real GDP. Still, other indicators of economic growth are also needed, such as improved literacy levels, better infrastructures, a reduction in poverty, and higher standards of healthcare. As a policy for economic development, it could refer to improving macroeconomic conditions to provide for a stable economic climate characterized by low inflation and positive economic growth. Privatization, deregulation, lower taxes, and less regulation are all supply-side policies that should be used to stimulate private capital investment. Diversifying away from agriculture can help promote economic development by spending more on public goods such as education, transportation, and healthcare.

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