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MODELLING OF SUSTAINABLE DEVELOPMENT IN A REGION

DISSERTATION THESIS

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ANNOTATION

Sustainable development demands an ambitious effort to integrate social, economic and environmental dimensions as well as development objectives. Achieving these objectives also suggests reuniting the planning of many agencies, actors and other institutional design. This dissertation thesis aims to support these efforts with modelling interactions among sustainable development objectives and their indicators at the EU country and regional level. To model the interactions, the thesis applies a nexus approach and uses panel cointegration and vector error correction models to examine causalities among the sustainable development indicators. The results indicate existence of short- and long-run bidirectional causalities between social, economic and environmental dimensions. These findings have potentially vital implications for sustainable development policy in both old and new EU countries.

KEYWORDS: sustainable development, sustainable development goals, sustainable development indicators, nexus approach, causality, European Union

ANOTACE

Udržitelný rozvoj vyžaduje ambiciózní úsilí o integraci sociálních, ekonomických a environmentálních rozměrů i rozvojových cílů. Dosažení těchto cílů rovněž předpokládá sjednocení plánování mnoha agentur, aktérů a institucí. Cílem této disertační práce je podpořit toto úsilí modelováním interakcí mezi cíli udržitelného rozvoje a jejich ukazateli na úrovni zemí a regionů EU. K modelování těchto interakcí disertační práce používá nexus přístup a ke zkoumání kauzálních souvislostí mezi ukazateli udržitelného rozvoje využívá panelové kointegrační modely a modely vektorové korekce chyb. Výsledky naznačují existenci krátkodobých a dlouhodobých obousměrných kauzálních vztahů mezi sociálními, ekonomickými a environmentálními dimenzemi. Tato zjištění mají potenciálně zásadní důsledky pro politiku udržitelného rozvoje ve starých i nových zemích EU.

KLÍČOVÁ SLOVA: udržitelný rozvoj, cíle udržitelného rozvoje, indikátory udržitelného rozvoje, nexus přístup, kauzalita, Evropská unie

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LIST OF SYMBOLS AND ABBREVIATIONS

AIC	Akaike information criterion
ARDL	Autoregressive distribution lag
BRIC	Brazil, Russia, India, and China
BRICS	Brazil, Russia, India, China, and South Africa
CADF	Cross-sectionally augmented Dickey-Fuller
CB	Convention on biological diversity
CD	Cross-section dependence
CEE	Central and Eastern European countries
CEs	Cointegration equations
CGE	Computable general equilibrium
CIPS	Cross-sectionally augmented Im–Pesaran–Shin
CO2	Carbon dioxide
CPI	Corruption development index
CRW	Combustible renewables and waste
DAC	Development Assistance Committee
DOLS	Dynamic ordinary least squares
DPD	Dynamic panel data
DPTF	Dynamic panel threshold framework
EAP	Environmental Action Plan
EC	Energy consumption
ECT	Error correction test
EDU	Education
EKC	Environmental Kuznets curve
EMP	Employment
EU	European Union
FDI	Foreign direct investment
FGM	Female genital mutilation
FMOLS	Fully modified ordinary least squares model
GDP	Gross domestic product
GFC	Gross fixed capital formation

GHG	Greenhouse gas
GLS	Generalized least squares
GMM	Gaussian mixture model
GNI	Gross national income
GNP	Gross national product
HDI	Human development index
HE	Heating energy
IAEG	Inter-agency and Expert Group
ICT	Information and communication technology
ILO	International Labour Organization
INEQ	Inequality
LM	Lagrange Multiplier
MDG	Millennium development goals
MW	Municipal waste
NCDs	Non-communicable diseases
NEXP	Net export
NUTS	Nomenclature of Territorial Units for Statistics
ODA	Official Development Assistance
ODS	Ozone-depletion substances
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary least squares
PCA	Principal component analysis
POVR	Risk of poverty
POVRST	Risk of poverty after social transfers
PPP	Purchasing power parity
PRFE	Panel regression with fixed effects
R&D	Research and development
RFID	Radio-frequency identification
SC	Schwarz criterion
SDG	Sustainable development goal
SE4All	Sustainable energy for all

STI	Share of tertiary industry
STIRPAT	Stochastic impact by regression
UAE	United Arabic Emirates
UK	United Kingdom
UN	United Nations
UNGA	United Nation General Assembly
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nation Children Fund
UNSC	United Nation Statistical Commission
UR	Unemployment rate
US	United States
USD	US dollar
VAR	Vector autoregression
VECM	Vector error correction model
WCP	Waste charging policy
WHO	World Health Organization

Introduction

Sustainable development is a concept that is presumed to reunite economic, social as well as ecological changes which was initiated during 1980. In the same way, it is also seen as an axiom used commonly from time to time to emphasize the vision of the future by many scholars. Their aim is to get rid of current problems that the occupant of the earth is facing today. Common among them are continuous depletion of natural resources, CO2 (carbon dioxide) emissions, environmental degradation, gender inequality and unequal distribution of wealth. Undoubtedly and in the present days, sustaining economic development in agreement with the sustainable development concept has been an important issue. In spite of this, it is difficult to get one specific definition for the concept. The definition by Brundtland Commission (Brundtland, 1987) is often used as "*meeting the needs of present without comprising the ability of future generations to meet their own needs*". The definition embraces two features: the first one deals with the concept of 'needs' especially the world poverty. The other feature is an issue of limitation levied by the state of technology along with social organization on the environment to placate the present and future needs.

The sustainable development concept is enormous and multidimensional in scope or in nature, since it consists of the three pillars such as environmental, social, and economic. These pillars must be unified to achieve the aim of sustainable development. For instance, the environmental aspect alone deals with limiting all the human activities to carrying capacity of the ecosystem (which includes energy, materials water and land) happening in the area and stress on the quality of human life (like air quality and human health). Economic pillar concerns with effective utilization of resources to promote operational profit as well as maximize market value. It also emphasizes on substitute natural for manmade resources by adopting strategies like reuse and recycle. The social pillar deals with ensuring the social well-being to the population by matching the need of individuals with the need for the group (implying equity), creating public consciousness and cohesion as well as involvement and used of local labors and firms. All these activities confirm the complex nature of managing the concept.

In addition to the issues raised above, it is alleged that the there is no single approach but several approaches in dealing with sustainable development (Sartori et al., 2014). Particularly, the method is usually base on the field which is applied. For instances, fields like ecology, engineering, economics and management have different approaches regard modelling of sustainable development as an approach to evaluate sustainable development (Sala et al., 2015). Consequently, the outcome from these modelling methods are mostly used for decision making as well as formulation of policies for the countries, regions, and global sustainable application (Hacking and Guthrie, 2008). But the approaches to the modelling of sustainable development have not been devoid of several challenges specially the traditional macro-economic approach models (Daly & Farley, 2011). Subsequently, and to solve these bottlenecks of traditional models, several literatures on modelling of sustainable development have re-emerged and most all of them still have some gaps. The common among them are the top-down modelling approaches. These models have the ability to assist the national scale, of macro-framework (economic variables) analysis of the influences and responses across range of sectors. The bottom-up models also help in comprehensive assessment technological impact on sectoral level. These two modelling approaches are usually used together to stimulate complementary analyses at the sectoral segment and they are branded as hybrid model (Van Vuuren et al., 2009). Another model is an input-output model which serves as a descriptive instrument for a national economy. It provides the basis for several advance models. But it is static and does not consider long-term dynamics (Herbst et al., 2012). Again, the bottom-up optimization and simulation models are also employed in sectoral-based planning because has a limited scope and it usually lack feedback loops with the other sectors of an economy (Herbst et al., 2012). Another model that seems good for sustainable development are multi-agent models. As these models remain experimental, they are usually too sensitive to experimental settings, which limits their application (Boulanger 2005). I must also note that no one model is perfect and, therefore, no one can satisfy all the requirement for modelling sustainable development as emphasized by (Nicholson, 2007).

This dissertation thesis is designed to integrate indicators from all the three dimensions of sustainable development, namely social, economic, and environmental. An in-depth understanding of these dimensions and their interactions is vital for handling economic, social as well as environmental problems. This dissertation thesis uses the vector error correction model (VECM) to model interactions among sustainable development indicators in EU 28 countries at both the national and regional level. This dissertation thesis adopts a nexus approach to investigate causal relationships among sustainable development indicators. First, multivariate cointegration is applied to verify the existence of these relationships, and then short- and long-run Granger causality tests are conducted to confirm the main hypothesis on the existence of the economy-society-environment nexus. Hence, synergies and trade-offs of different sustainable development dimensions can be leveraged in sustainable development policies.

This dissertation thesis aims to propose an economy-society-environment nexus model to examine interactions among sustainable development goals and indicators at national and regional EU levels. The remainder of this dissertation thesis is organized as follows. Chapter 2 introduces the concept of sustainable development, its goals and indicators, and interactions among sustainable development goals and indicators are discussed. Chapter 3 present the state-of-the-art methods used in modelling sustainable development. Chapter 4 presents the main aim and specific objectives of the dissertation thesis. Chapter 5 outlines the used research methodology and econometric models, including the data that will be used for empirical studies. Chapter 6 presents empirical results of the proposed sustainable development models. Chapter 7 presents the limitations of the models and outlines several future research directions. Chapter 8 demonstrates the theoretical contributions of the dissertation thesis and Chapter 9 concludes with a summary of the main findings.

1. Sustainable Development Goals and Indicators

1.1 Sustainable Development Goals

Sustainable development denotes the means of human development whereby resources that is exploited, aims at meeting human needs, at the same time ensuring the sustainability of natural system and protecting environmental condition (Smith et al., 1998). It is associated with diverse issues of socio-economic development and environmental problems with an objective of assessing the needs of humanities and sustain them. Brundtland commission, who coined the definition for the term, stress the idea that the next generation should have the same magnitude of well-being opportunities as the present generation. Impliedly, sustainable development is seen as the non-diminished in terms of human welfare. This can be determined through the nature of analysis as well as the level of human utility, earning likewise consumption (Imperatives, 1987).

Historically, the concept of sustainable development was coined or brought up in the World Charter for Nature (Westing, 1987). It was designed to address our common future (WCED, 1987) and later expanded to 40 chapters of Agenda 21 of the earth summit which was held in 1992. There was the initial attempt to bring together the two main contrasting embodiments: which involves ensuring lasting economic growth and efficiently safeguarding our environmental as well as our natural resources which has a limit (Schlesinger & Meadow-Orlans, 1972). Taking into considering the UN World Summit on Social Development of 1995 held in Copenhagen, the importance of creating global social sustainable development was emphasized and, eventually, the social pillar was developed. In 2002, during the summit of sustainable development conference in Johannesburg, the social development pillar was incorporated it into the already developed two pillars (environmental and economic). Further, another step was a Rio+20 conference tagged as “the future we want” (Un-Habitat, 2012). Much emphasis was made on how to promote green economy using sustainable development as well as eradicate poverty. Thereafter, quantitative sustainable development indicators were also developed to monitor the progress made in sustainable development goals (SDGs). These indicators were enshrined in Agenda 21 (chapter 40). The indicators served as a guard to assess whether the countries or the regions were on the right part of designing a sustainable world. From then, numerous indicators have been created at all levels. At present, the SDGs and its indicators have become the key pillar for the UN member countries, and they are used to design agenda as well as policies to be use from post 2015 to 2030. It should be also noted that the current indicators are the expanded form of Millennium Development Goals (MDGs) which were accepted in the year 2000 and expired in 2015 (Noinaj et al., 2012). The Open Working Group drafted the goals and eventually UN General Assembly accepted the goals and indicators in July 2014 (Brenner & Schmid, 2014). Finally, the UN General Assembly officially approved it at the 68th session of the UNGA in September 2014. These goals and indicators were finally implemented in 2015. Impliedly, the world community adopted the 2030 SDGs in September 2015 comprises 17 goals and 169 indicators. Again, from the goal 1 to goal 6 SDGs were created based on core agenda of MDGs and the goal 7 to 17 were new goals set (Brenner & Schmid, 2014). Now, the goals and its indicators were created to function as a transformative agenda that stress on integration as well as balance among social, economic, and environmental ambitions. Subsequently, they have become an important part of new international development framework for all countries. These have had a major effect on national development planning effort after the year 2015. It has also become necessary for all the countries to choose their national targets and again assess their own priorities like their level of aspiration regarding the scale and pace of the transformation. The countries and regions have also integrated their own national SDG strategies, and these must be at the center the national effort. Analogously, the SDGs show broader, integrated, complex likewise challenging agenda to implement than the MDGs. This is applicable to all the countries on the globe especially for the both the developing and developed countries. The timeframe for attaining these goals consist of medium and long term which most of the goals as well as the targets are in accord with the 2030-time limit. Moreover, and currently, most governments face a problem of selecting the realistic as well as ambitious national targets. They are also exposed to a task of setting a cost-effective and fitting pathway that will facilitate achieving these goals.

Besides, and in brief, sustainable development also implied attaining and maintaining economic growth through other factors of socio-economic development. One of its purpose is to provide the maximum demand of human needs and enhance their living condition in line with financial resources that will support environmental conservation (Imperatives, 1987). The idea of the sustainable development concept also transcends beyond it meaning and many assumptions in different nations. The government, policy makers, economists, researchers and other world institutions for instance, the World Bank, the World Trade Organization and International Monetary Fund have branded sustainable development by acknowledging the both living condition (thus its economic part) and its environmental part.

However, the basic aim of the concept is the integration of economic, social and environmental issues in decision making as well as policy making in all aspect of development dimension (Phimphanthavong, 2012) Consequently, it can also be inferred from the above ideas that, the concept depends on two main objectives: firstly, it aims at sustaining an economy that fairly meets the needs of people without much exploitation of resources input or ejecting excessive waste emission of the environment. Secondly, sustaining the human institutions that guarantee the security as well as opportunity to foster social interaction together with spiritual growth. These are bound to promote the understanding of the numerous dimensions of sustainable development as well as its complex interactions and enhance policies based on attaining sustainable development objective. Apart from these and more so, the integration signifies the inclusion of traditional sectors of economic and government activity comprising economic planning, natural resources, energy, industry education agriculture and environment. Many studies confirm that the wealthy benefit from economic growth and the rest of the population are not spared by cost of resource depletion, environment degradation and social stress, etc. (Greiner, 2011; Van Hoa & Feng, 2013).

Besides, United Nations also believe that sustainable development does not only place emphasis on economic growth, but it recommends a transformation in the content of growth to ensure its significance as well as equitable impact (Imperatives, 1987). In other words, this transformation is needed in all countries as a means of ensuring preservation of stock of ecological capital, minimizing level of venerability to economic crisis, and environmental problems.

The global sustainable development goals for 2030 have been one of the unique and greatest promises made by the world leaders in 2015. It is an updated version of previous goals set (MDGs). The aim of the goal is to change the world or the planet by making it fairer, safer and protect the environment by including everyone or leaving no one behind. The leaders and institution such as United Nations decided to rely on these goals to attain the fairer and unique world in the year 2030.

The goals include the following SDGs:

SDG1 – Poverty reduction

Poverty reduction remains the first goal to achieve sustainable development. The world poverty reduced from 1990-2015 by 26% (from 36% to 10%). Although it was a laudable achievement by the world leaders and its institutions, the pace of the reduction has slightly slowed down in the last decade. More than 700 million people are still living in extreme poverty today. They are struggling to satisfy most of basic demands such as access to clean water and sanitation and good healthcare. Again, most the people dwell on less than 1.90 dollars a day especially in Sub-Saharan Africa. Also, not all the people who have secured some jobs can be assured of decent living. Impliedly, about 8% of employed workers together with their families live in extreme poverty globally in 2018 (Kwilinski et al., 2020). Therefore, the goal is intended to solve these problems. Once more the goal is that by the year 2030, the poor and the venerable have equal right access to economic resources and other basic services.

SDG2 – Zero hunger

The initial assessment from 15 years ago indicated that there was a decline in the number of people living in extreme hunger. The trend has changed nowadays as almost 820 million people usually sleep with hunger and out of this 138 million are exposed to acute hunger (Nations, 2021). This is caused by man-made wars, climate change as well as economic crises. These billions of people living at the brink of starvation call for immediate attention to assist them with food supply, likewise humanitarian relief in the effected regions. Once more, the global food production as well as agriculture system must also be transformed by increase food supply and agriculture production. This could be done by improvement in investment together with international cooperation in agriculture research, technology development as well as working together with plant and livestock gene banks to increase agriculture production capacity. This will help nourish people who are going through starvation.

SDG3 – Ensure healthy lives and promote well-being for everybody

This is one of the important goals of sustainable development. Presently, the world is burdened with variety of disease including HIV, Ebola, and most recently COVID-19. All these diseases are subverting the world economy by killing billions of people on the globe. Although significant effort has been made to curtail the impact of these diseases, wider range of strategies are needed to get rid of the prevalence of these disease and boast the health issues. In addition, the continue support for the health system thus both (in fund and other services) are creating an easy access to physicians, ensuring good sanitation could also provide some shield or save millions of people's life. Some the major aim of the goal is to end the epidemics of AIDS, malaria, tuberculosis, hepatitis, communicable diseases and water-borne diseases by the year 2030. Other objectives to support the goal are as follows: (1) attain universal health coverage consist of financial risk protection, (2) ensure access to important health care services as well as safe, quality likewise affordable necessary medicines and vaccines for everyone, and (3) reduce the number of deaths and illnesses associated with water, air and soil pollution and hazardous chemicals by the year 2030, is also support goal (Nations, 2021).

SDG4 – Ensure inclusive and quality education

Education is regarded as one of the instruments that can bring people out of poverty. Consequently, much progress has been made towards creating an access to education as well as increase in school enrolment rate especially for girls at all levels of education. This is not withstanding, about 260 million children on the globe have been drop out of school (Nations, 2021). This represents much proportion of the population of both child and adolescent globally. Impliedly, they do not satisfy the minimum proficiency conditions in reading and mathematics. This situation has been aggravated by the temporary closure of schools as a result of the recent re-surface of COVID-19 pandemic on the globe. Subsequently, it is endangering the hard-won improvements attained by promoting global education. Therefore, among the key sub-goals set are; ensuring that all girls as well as boys complete free, equitable, quality primary and secondary education by acquiring the relevant and learning concept by year 2030, safeguards all girls and boys to have access to quality early childhood development and pre-primary education which lay foundation for primary education by year 2030, make sure that there is equal access for all men and women to affordable quality vocational, technical and tertiary education especially university and finally make sure that all learners acquire the knowledge and skills required to enhance sustainable development especially, human right, sustainable lifestyle, culture of peace and non-violence, appreciation of culture diversity and gender equality by the year 2030.

SDG5 – Gender equality

This goal does not only provide the basic human right, but it serves as an essential foundation for a prosperous, peaceful and sustainable world. Much progress has been achieved in this field (goal) for past ten years. For example, more girls are enrolled in schools; many women are now occupying parliamentary positions, few girls coerced into early marriages and more laws have been made and modified to advance the course of gender equality. In spite of these achievements there remains many challenges in attaining this goal. The common among them are physical assault and sexual violence inflicted on women by their decisive or ultimate partners. Also, fewer women are represented in political position or levels. Hence, eradicating all form of violence against women in both public and private domains particularly sexual, trafficking and other forms of exploitation is an important objective. Again, prohibition of harmful practices like the child, early and forced marriage as well as female genital mutilations is another goal. Promoting and strengthened sound policies, enforcement of legislation to enhance gender equality as well as empowerment for all women and girls is another goal.

SDG6 – Access to clean water and sanitation for everybody

Generally, some amount of progress has been made in this area. However, in rural settings about billions of people still lack this basic service. For instance, it estimated that about one out of three people in the world do not have access to safe drinking water. Again, every two out of five people do not own hand-washing facilities particularly with soup and water. Also, over 673 million people keep on practicing open defecation (Nations, 2021). In effect, a goal has been set to accomplish universal and equitable access to safe, affordable drinking water for everyone by year 2030. Again, to have access to adequate and equitable sanitation and hygiene as well as end open defecation is another goal set for the year 2030. Significantly increase water-use efficiency across all sectors and adopting sustainable withdrawals as well as supply of freshwater to deal with water scarcity could considerably decrease the number people suffer from water scarcity. Another goal is to develop more international cooperation as well as capacity-building to assist the developing countries in water and sanitation related issues consisting of water efficiency, water harvesting, wastewater treatment, desalination of water and recycling and reuse technologies by the year 2030.

SDG7 – Energy

Regarding this goal, some effort has been made with the result indicating that energy is turning to be sustainable as well as extensively accessible. The energy situation in the developing countries is now improving. Creating renewable energy in those regions is gaining an impressive ground in the electricity sector. This is not withstanding, as more attention must be focused on promoting an access to clean and safe cooking fuels likewise technologies for the people especially in Sub-Saharan Africa. Consequently, it will help solve the predominant problems facing 840 million people living in those regions with electricity (Nations, 2021). As a result, the following sub-goals have been set; making sure there is universal access to reliable, affordable as well as modern energy services by the year 2030, There should be a significant rise in the share of renewable energy in the global mix for next decade, promote international cooperation to stimulate access to clean energy research and technologies such as renewable energy, energy efficiency, and enhance investment in infrastructure by the year 2030.

SDG8 – Promoting economic growth

Promoting inclusive economic growth implies enhancing progress, creating decent work for all and improving living standards. However, attaining this goal has been hijacked by the recent global virus COVID-19. Since it has held the global economy to standstill from later part 2019 to date, many jobs losses have been escalated most countries. Impliedly, industrial production has come to disruption, the prices of commodities have dropped. The impact once more is instigating changes in financial marked, impeding already tepid economic growth and worsening the heightened risks emanating from other factories. Before the coming of this virus, the previous forecast provided an evidence of employment will either remain stagnant or decline for the subsequent period. Again, the world needs new 470 million created jobs to off-set the remaining unemployment from 2016 to 2030 (Nations, 2021). Besides, the global gender gap hovers around 23 percent without commonly accepted strategy to combat it. Therefore, how to liberate the world economy from these crisis remains a big question to the world leaders, institutions, businesses and everybody. The following sub-goals have been designed to support the main goal; attaining full employment as well as decent work for all men and women especially for young people, person with disabilities and equal pay for the work of equal value by the year 2030; develop and implement policies that will ensure sustainable tourism which will create jobs, enhances local culture and product by the year 2030, and finally, promote global resource efficient consumption & production and decouple economic growth from environmental degradation in line with the ten-years framework of sustainable consumption and production with the developed countries taken an initial step is also a another goal.

SDG9 – Resilient infrastructure and building a sustainable industry

Creating an inclusive and sustainable industry could let loose the dynamic and economic drivers that generate employment as well as income. Yet this is not the case of developing regions as the established infrastructure has some gaps. Especially, most of the developing countries lack basic infrastructure such as electric power, water and good sanitation, communication technology and motorable roods which is affecting productivity. To achieve resilient infrastructure, building a sustainable industry and creating innovation, SDG9 implores us to develop and promote trade and ensure that resource put into efficient use. Accelerating the development of the least developed regions especially their manufacturing sector will lay the foundation for the 2030 objective. Impliedly, the impact of these developments will boost investment in scientific research and innovation. Again, technology and innovation remain the key to find a long and lasting remedy for economic and environmental problems.

SDG10 – Reduce inequalities

This implies that the issue of inequalities must be dealt with both within and among countries. Generally, and currently, inequality (of several domains) continue to exist within and among countries. In other words, there has been much social protection extension globally, yet the rate of people with disability likelihood of facing danger of health expenditure on average, is five times more than people without disability. Again and although some progress has been made to reduce inequality, yet some element of inequality remains prevalent in income inequality, preferential trade status enjoyed by low income countries, refuges and immigrant, people with disabilities, older people and children who are usually at risk are left behind. Therefore, the goal set progressively and sustain income growth of the bottom 40 percent of the population at a rate higher than the national for the year 2030. Once more, another sub-goal is to empower and enhance the social, economic as well as political inclusion for all regardless of age sex ethnicity religion, disability origin or economic/other status by the year 2030.

SDG11 – Sustainable cities and communities

This implies building an inclusive city, safe, resistant as well as sustainable. The world is transforming to become an urbanized. It is believed that over half of the world population now dwell in the urban centers and as a result it is predicted that it will increase up to 60 percent by the year 2030. Though cities and urban centers serve as powerhouse for economic growth and subsequently contribute about 60 percent of global gross domestic product (GDP), but they produce about 70 percent of global carbon emissions. These cities/urban centers are also burdened with problems like inadequate infrastructure (poor waste management system, poor water and sanitation system), growing number of slums dwellers, unplanned urban sprawl and worsening air pollution. For example, it is estimated that about ninety percent of people living in urban centers breathe unsafe air and this has caused 4.2 million deaths (Nations, 2021). Therefore, a goal is set for the year 2030 to ensure an access to safe, affordable and sustainable transport for all. At the same time retrofit roads and its safety including expanding public transport by considering the needs of women, children, persons with disability and older people. The goal will abate the adverse per capita environmental impact of the cities/urban centers notably paying particular attention to waste management and air quality by the year 2030.

SDG12 – Promoting responsible consumption and production

The world consumption and production that tends to shape the global economy, by relying on the how we put the natural environment and resources into use. Ill-advised and unreasonable use of these resources create a destructive effect on the planet. It is believed that ensuring both economic and social development in the last century have not been devoid of environmental degradation. This is destroying the systems which our future survival would depend. Notably and every year, it is estimated that about 1.3 billion tons of food produced costing 1 trillion go rotting in bin of consumers and retailers (Nations, 2021). This is due to lack of transportation as well as bad harvesting practices. Once more, the world could save about 120 billion dollars per year if people worldwide decide to use energy efficient bulbs (Nations, 2021). Sustainable consumption and production lay much stress on the putting less resources into prudent use and at the same time expand its benefit. Impliedly, decoupling economic growth from environmental destruction, promoting resource efficiency and the same time ensuring sustainable lifestyle.

SDG13 – Climate action

It is alleged that the last years observed one of the warmest years in the past decades. The amount of CO2 emissions as well as greenhouse gases in the atmosphere have steadily increased. All the activities are causing climate change which is affecting every region on the globe. Impliedly, it is changing weather pattern, stimulating the rise of sea level, disrupting or holding national economy to standstill and affecting lives. Therefore, it has become very necessary to save lives and protect livelihood by taken immediate and urgent actions to deal with the CO2 emission and climate change. Hence, this is what the goal intends to solve. Therefore, the following objectives have been set to support, strengthening and integrating climate change measures into national policies and strategies: creating awareness on the issue through education, and raising both human and institutional capacity on climate change mitigation, adaptation as well as early warning.

SDG14 – Oceans

Another goal is to conserve and sustain the use the oceans, seas and marine resources. The benefits derive from the oceans, seas and marine resources have been very important to mankind on the globe. Most of the food, the water we drink are gotten from ocean and waters. It also regulates the oxygen in the air. Therefore, a cautious management of the oceans and its resources will also pave the way for the sustainable future. Besides, there has been a continuous damage to our coastal waters as a result of pollution. Again ocean acidification is imposing an adverse impact on the proper function of the ecosystem as well as biodiversity. The aquatic life is exposed such a danger. Consequently, being careful and protect our ocean should be our key objective or focus. Also, already protected areas of the ocean must be efficiently controlled as well as resource, and laws should be enacted to minimized overfishing, acidification and pollution. The goal is set to prevent as well as considerably reduce marine pollution of all kinds, especially from land-based to other activities such as marine debris likewise nutrient pollution for the year 2025.

SDG15 – Ensure sustainable forests, stop and reverse land degradation and stop biodiversity loss

Human survival depends much on nature. Nature provides us with food, feed, oxygen, control our weather patterns and pollinate our crops. Unfortunately, it is under intensive stress as a result of human activities. Human activities have changed above 75 percent of earth surface, pushing wildlife as well as nature to a smaller brim or ridge of the globe. The refusal to restore and protect the plant and animal species will affect our economies, food securities health, livelihood and quality of life globally. Human activities and climate change contribute to deforestation and desertification. This also hinders the achievement of sustainable development. Hence, this objective has been set to support SDG15: to make sure that the conservation of ecosystem and biodiversity are maintained to promote the capacity that will be beneficial to sustainable development by the year 2030.

SDG16 – Ensuring peace, justice and strong institutions

Conflict, insecurity, weak/poor institutions likewise access to justice have been the greatest bane impeding the achievement of sustainable development. It is being declared that about 70 million people flee as a result of wars, persecution and conflict in 2018 (Nations, 2021). And it is the highest ever recorded in the past 70 years. In dealing with these, some objectives have been outlined: substantial mitigating of unlawful financial and arms flows, fight all forms of organized crime and strengthened retrieval likewise return of stolen national assets by the year 2030 and also help to provide legal identity for all especially birth registrations by year 2030.

SDG17 – Revive the global partnership

Reviving global partnership is believed to be a key to promote sustainable development since it operates on the principle of ensuring all-inclusive partnership. Impliedly, developing a strong global partner will set a strong background to achieve sustainable development. The goal operates on the ensuring inclusive partnership starting from local regional national and global levels. This is usually base on the principle value, shared vision as well as shared goods. This intends to put people likewise plant at the center.

1.2 Sustainable Development Indicators

During the 46th session from 5th to 6th March 2015, the UN Statistical Commission (UNSC) outlined the road map for developing and implementation of SDG indicators as well as monitoring framework for the subsequent years after 2015. Realizing the enormous nature of the task (SDG indicator agenda), the UNSC created an institution "Inter-agency expert group" to deal with SDG indicators. It also set up national statistical offices to act as onlooker, then regional and international organization and agencies were also entrusted to devise a proposal which was used as indicators to monitor sustainable development goals at global level. It took over 18 months for detail assessment of views and comments from experts in the UN civil society, business, academia and offices before these developed indicators were implemented.

Consequently, new SDG indicators have become a backbone for monitoring the progress of SDGs at all level especially, local, regional, national and global. Apart from the indicators acting as a management tool or report cards for assessing the progress of sustainable development, it has also assisted ensuring accountability of the institutions involve in achieving the SDGs (Schmidt-Traub et al., 2015). Hence, here I intend to unfold the original global monitoring 100 indicators (their complete list is available in the Global indicator framework for the SDGs[1]) together with 17 SDGs which it intends to address. Again, the potential institutions responsible for the proper functioning of the indicators will be acknowledged.

Sustainable development indicators for SDG1 – Poverty reduction

Multidimensional poverty

The indicator is used to provide detailed evaluation of the level of poverty and deprivation. It uses tools like materials deprivation, income and work. The UN Development Programme presents multidimensional poverty through the Human Development Report Office by considering three main elements, namely health (nutrition and child mortality), education (school enrolment years of schooling), and living standard (access to water, electricity, cooking fuel, etc.) (Malik, 2013). A household is classified as poor if it experiences one or more of these deprivations on weighted average (Mauro et al., 2018). In addition to the above, other indicators incorporate the following into multidimensional poverty: housing, social protection, quality of education and internet access (Alkire & Samman, 2014).

Existence of risk reduction strategies for climate-related and other disasters

Almost all the cities and population in the world have not been totally liberated from natural disasters particularly climate change, population growth as well as urbanization with its adverse effects. The problem is that the poor are the least resilient and most vulnerable to climate-related and other (social, economic, and environmental) disasters. The indicator evaluates losses, lives lost as economic cost relating to urbanization and rural setting as a result of natural disaster (Below et al., 2009). It also assesses losses in connection with extreme climate events such as storms, flood, extreme temperature, draught, and wildfires (Vos et al., 2010). Finally, it deals with the non-climate event but with the geophysical events like earthquakes volcanic eruptions,

[1] https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework%20after%202021%20 refinement_Eng.pdf

and tsunamis. The economic aspect concerns with tracing the crop and animals' losses in relation to both climate and non-climate events. Therefore, to effective disaster risk reduction, preventions are needed to curtail the economic and social impact of natural disasters. With the economic and agricultural dimension of disaster real-time remote sensing, technology could be utilized to monitor the systems. Impliedly, it could be used in the areas prune to these disasters as well as development of new resistant varieties to easy adaptation (Mitchell et al., 2013).

Percentage of eligible population covered by national social protection

Having access to sufficient social protection is regarded as a fundamental right stated in the Universal Declaration of Human Rights, yet over half of the population in the world lack social protection coverage. Therefore, the indicator is used to measure proportion of the population protected by the social network. The ILO includes 10 elements as a broad social security coverage, such as medical care, protection for disability, protection against poverty old age, unemployment, employment injuries social exclusion, maternity and children (Ocampo & Gómez-Arteaga, 2016).

Sustainable development indicators for SDG2 – Zero hunger

Population below the minimum of dietary energy consumption

This indicator deals with the percentage of the population who are suffering from hunger or deprivation (caloric) (Q. Zhang & Li, 2014). The MDG indicator rely on these parameters: (1) three-year moving averages quantity of food available for human consumption or consumption per person per day, (2) the level of inequality in terms of access to food, and (3) the minimum dietary demand for average person-expressed/in kilocalories per day. Therefore, the indicator assesses an important part of food security of a population.

Crop harvesting gap (actual harvest as % of potential production)

This indicator monitors the yield gap particularly for the major commodities. For instance, comparing the actual yield with the yield harvested under perfect condition. This is serving as a benchmark for productivity in terms of farming under rainfall agriculture and irrigation agriculture. This difference between crops productivity under rainfall agriculture management results from biophysiological domain such as climate venerability affecting risk, economic and environmental condition. Therefore, this indicator works efficiently only when it is combined with other indicators (Dobermann & Nelson, 2013).

Sustainable development indicators for SDG3 – Ensure healthy lives and promote well-being for everybody

The percent of children covered totally by vaccination

Almost every country on the globe currently has a specific period of vaccines to be administered. On the global level, WHO entreats all children to receive vaccines against haemophilius influenza, measles, Bacillus Calmette-Guérin, polio, rubella, rotavirus, hepatitis B, diphtheria-tetanus-pertussis, pneumococcal and adolescent girls are also to be vaccinated against human papillomavirus (Souter, 2012). Apart from these, WHO recommends each country to include additional vaccines like tetanus and yellow fever (Autran et al., 2009). Hence, the indicator evaluates the proportion of the population who had received the immunization at the appropriate age as authorized by the national schedule or without national schedule the WHO schedule takes the dimension (Autran et al., 2009).

The possibility of dying between ages 30 and 70 as a result of non-communicable diseases and suicides

Generally, non-communicable diseases (NCDs) account for about 38.48 percent of persons between 15 to 49 deaths and 79.35 percent deaths for age from 50 to 69 (Hotez et al., 2016). They comprise diseases such as respiratory diseases, cardiovascular diseases, diabetics and cancer, which have caused the death of many people on the globe. Suicides account for 5.4 percent of death of persons with ages between 15to 49 and 1.79 percent for age 50 to 69 (Misganaw et al., 2012). Therefore, this indicator is used to evaluate the premature death resulting from non-communicable diseases and suicide.

The proportion of the population without financial support for health care

The main component of the universal health coverage is financial affordability as well as transparency in seeking or soliciting for preventive and therapeutic service. It is important that the global determination to eradicate extreme poverty and promote social inclusion are not threatened by improving expenditure to use required by heath service so that it will enable the least well-off to afford important health service (Agyepong et al., 2016). Based on this, the monitoring framework for SDG3 must incorporate a global monitoring indicator on financial protection or support for the health care.

Sustainable development indicators for SDG4 – Ensure inclusive and quality education

The primary education completion rate for boys and girls

The primary completion is assessed by gross intake ration that is the total number of new entrants who get to the last grade of primary education according to the international classification of education (Isced, 2012). Unmindful of the age relative to the population of the theoretical entrance age to the last grade of the primary. It is also regarded as a programme structured to provide pupils with basic skills in reading, writing and mathematics together with elementary understanding of subjects like geography, social science, history, art, natural science and music (Isced, 2012). A higher gross intake ratio to last grade demonstrate a high degree of completion of primary education.

The secondary school completion rate for boys and girls

This is computed by dividing the total number of students in the last grade of secondary school minus repeaters in that grade by the total numbers of children of official completing age. It shows the dropout rates within secondary school as well as the transition rate between primary to secondary school through its denominator to the total number of children of official completing age. The secondary school completion measure is vital because the dropout rate is more in lower secondary school. It is also the ages where the actual as well as opportunity cost of education raises and at the same time educational system tend to provide high-quality institution. Gender differences as zeal to school for girls is strongly influence by income as well as the broader cost of education than the case for boys. Impliedly, the families, feel reluctant to finance in girl's education especially if the investment will not contribute an equivalent and direct economic benefit to them (Force, 2013).

The tertiary enrollment rates for men and women

The indicator deals with the total enrollment in tertiary education irrespective to the total population of the five-year age group in transit from secondary school. This is expressed in percentage. The tertiary education enrollment rate provides an evidence of quality of labour force within a particular country or region. In other words, if there is a wider gap between the enrollment in tertiary education and employment in tertiary education and unemployment rate provide a sign that the economics is not able to absorb it trained graduate or the graduate from tertiary education do not meet the required skills impacted to them do not meet the demand of the job market (Owens, 2017).

Sustainable development indicators for SDG5 – Gender equality

The number of cases of sexual and gender-based violence against children and women are investigated and sentenced

The sexual and gender-based violence is an overarching issue and keep on spreading. It is usually ending in impunity. The indicator was created as a measure against violence against women and children. Impliedly, it has to deal with peace and security, determine how the police and justice system handle and manage violence against woman as well as children. This three process-monitoring, investigating and sentence are all necessarily interlinked. Monitoring implied, confidence we have in system, investigating connotes commitment to the legal set up especially by the police as well as other security agencies and sentencing provide an evidence of justice been achieved. Therefore, this indicator, represents a good intermediary for wider measure of the quality of rule of law (Heidari & Moreno, 2016).

The percentage of girls and woman from 15-49 years who have undergone FGM

The widespread hurtful traditional practices especially the practice of female genital mutilation (FGM) is measured as a percentage of women aged (15 to 49) who avail themselves positively to survey inquiring "if they themselves have been cut". FGM implied all procedures involving partial or total removal of the external female genitalia or other injury to the female genital organs without medical reason. The practice does not offer any health benefit. The practice depicts deep-rooted gender inequality and classified among the highest form of discriminatory against women (Powell & Mwangi-Powell, 2017).

Percentage of women from 20-24 years (or 18) forced in early marriage

The indicator traces the number of occurrences of child marriages, as defined by UNICEF. The practice is a violation of basic right and likely to create long life harm. It is been asserted that most girls who are betrothed to early marriages abandoned formal education also experience high risk of pregnancies (Delprato et al., 2017; UNICEF, n.d.). The child brides impose a high risk of exploitation, abuse likewise family and friend separation which do not auger well for both health and well-being.

Sustainable development indicators for SDG6 – Access to clean water and sanitation for everybody

The total number of the population using safety managed sanitation services in both rural and urban setting

The indicator assesses the percentage of the urban and rural dwellers using managed drinking water services as prescribed by the WHO/UNICEF Joint Monitoring Programme. The indicator has been revised beyond the previous MDG "basic drinking water" indicator by integrating quality and safety water available for people to use. Households are perceived to have access to safety managed drinking water service when they get water from a basic source within their area or premises. The term safety managed is proposed to deal with a high threshold of service particularly for water, protecting supplies, and safeguarding that the water is safe for drinking (Supply et al., 2015). Lack of safe drinking water originates illnesses as well as mortality. Economically, inadequate access to water creates a big problem in the household which demand much commitment of human resources to fetch water.

Water resource management sustainability

The integrated water resources management aims to put together the development and management of water land likewise other related resources to exploit equitable and social welfare, without causing any destruction to important ecosystem (Paul et al., 2018). It is an important component of a wider water resources management which is composed of protection of the water-related ecosystem, water use efficiency as well as water scarcity (covered across the framework) (Grizzetti et al., 2016).

The proportion of total water resources used

The indicator evaluates the stress on water by defining it as the total volume of underground water and surface water abstracted (withdrawn) from their source for human consumption (especially in agriculture, industry sector, or municipality) relative to the annual renewable water resources in percentage. The indicator demonstrates whether a country withdraws more than its sustainable supply of fresh water sources. It can be used to measure or trace progress in the sustainable integrated as well as transparent management of water resources (Howarth, 2018).

Sustainable development indicators for SDG7 – Energy

The percentage of population having access to electricity

This indicator assesses the proportion of the population depending basically on non-solid fossil fuel for cooking as set by the sustainable energy for all (SE4All) framework report (Angelou et al., 2013). At present, available source of data consisting of (WHO global household energy database together with the IEA world energy statistics and balances) only provide binary tracking of access (either the household does have access to energy or do not have access to energy). Based on this initial step, the SE4All global tracking framework is applying this simple indicator to assess modern cooking solution.

The rate of primary energy intensity improvement

The indicator is used to represent energy efficiency as one of the pillars of SE4All. It can be utilized to measure the pace to which economic growth is decoupling from energy uses, which has been a major requirement for sustainable energy likewise decoupling. Energy efficiency is described as ratio between the gross consumption of energy and GDP. Particularly, the gross energy consumption is reported across five major sources of energy; nuclear renewable solid fuel/biomass, oil and gas. Therefore, the indicator is expressed as the compound annual growth rate of energy intensity (which is measured in PPP terms) (Angelou et al., 2013).

The share of renewable energy

This indicator deals with the share of renewable energy consumption. The composites of renewable energy are solar, bioenergy, wind, hydropower, geothermal as well as marine sources. Again, other forms of energy mix comprise electricity, transportation likewise cooking / heating fuel. Hence, this indicator aims at significantly increasing the share of renewable energy in the global energy mix (Uğurlu, 2019).

Sustainable development indicators for SDG8 – Promoting economic growth

Growth in GDP per capita

The indicator deals with the annual growth rate of real GDP per capita. It is evaluated as a percentage of annual growth based on the constant local currency. The indicator aims at ensuring at least growth in GDP with respect to national circumstances especially for developing countries through 2030. However, it appears to be a necessity to supplement this indicator with several others within SDG8 because GDP is reportedly unrelated to other economic performance indicators and wellbeing measures. In fact, GDP growth itself hinders the SDGs related to environment and reduction of inequalities (Coscieme et al., 2020).

Youth employment rate in both formal and informal sector

The indicator the youth rate of employment describes the percentage of the youth labour force who are employed. Again, young people are the people between the ages 15 and 24. The labour force could be defined as all the people or persons within the above group and presently available for work and are actively looking for work. In other words, the sum of those employed and unemployed. The youth employment in both sectors (formal and informal) must be reported and must be done separately according to the two sectors (formal or informal) (Elder, 2009).

Rectification or enactment and enforcement of the fundamental ILO labour standards and compliance in law and practice

The ILO key convention deals with major labour standards based on promoting opportunities for decent as well as productivity work. In other words, women and men will be able to work in conditions s as equity, security, non-discriminatory freedom and dignity. The above indicator tracks countries enactment of labour law as well as compliance with the eight fundamental ILO conventions. These comprise the following issues: elimination of all forms of forced labour, freedom of association likewise collective recognition of the right to collective bargaining, minimum age of labour as well as getting rid of worst form of child labour, eradicate discrimination in terms of employment and occupation including ensuring equal remuneration (Maupain, 2013).

Diversity, innovation and upgrade for economic productivity

The indicator emphasizes attaining higher economic growth by relying on diversification, as well as technological innovation producing high value added and increasing capital and labour productivity. This indicator can also be assessed using the change in GDP with respect to per employed person. The aim is to evaluate the change in productivity of an economy. Apparently, technological progress interacts also with environmental quality (Sinha et al., 2020).

Full employment and decent work with equal pay

The indicator stresses on attaining full productive employment as well as decent work for all. This concerns not only women but also young people with disabilities and, at the same time, the objective is to ensure equal pay for equal work by the year 2030 (Nhamo et al., 2018).

Sustainable development indicators for SDG9 – Resilient infrastructure and building a sustainable industry

Access to transport infrastructure

An access to easy connection, reliable road throughout the years are deeming important for the developmental process which comprises an access to market, inputs, education and reliable health services. The indicator intends to measure the share of the population who live within reach of roads that are reliable as well as passable in all year round. By choice, the road should have pavement that will facilitate an easy access to heavy vehicles and buses (Dobermann & Nelson, 2013).

Share of population involved (expenditure) in research and development

In the field of sustainable industry, technology and innovation are the main drivers of economic growth and development. Success or progress in this area demands both trained staff and public/private spending absorbed in research and development (R&D). Therefore, the indicator either tracks the total number of persons (technicians and other supporting staff) working in the R&D area or the share of R&D expenditure in GDP. Again, the indicator does limit itself to research in technology, diffusion and adaptation but it also aimed at achieving many SDGs.

Sustainable development indicators for SDG10 – Reduce inequalities

GNI share of the richest 10 percent or Palma ratio

This indicator concerns the level of inequality. Its emphasis is on from top to the bottom end of the income distribution. Impliedly, the indicator measures the changes from the top to the bottom of income distribution. It initially monitors the income of richest 10 percent of the population (Palma ratio) or gross national income (GNI) and divide by the poorest 40 percent of the total population share of income distribution or GNI (Palma, 2011).

Sustainable development indicators for SDG11 – Sustainable cities and communities

The proportion of population of urban centers living in slum or informal settlement

The indicator assesses the percentage of the urban population living in slums or informal settlement proposed by UN-Habitat. It is calculated by taking the number of people living in slums of the cities divided by the total population of the city (Fox, 2013). Besides, UN-Habitat has designed a criteria use to describe a household as living in slums and among them are: sufficient living area (not more than two people living in a room), access to basic sanitation (access to excreta disposal system, either private or public), and access to basic water (impliedly, sufficient amount water for use by the family at an affordable price) (Hacking & Guthrie, 2008).

The percentage of land use rate to population growth rate

It is believed that cities are anticipated to absorb between two and three billion or more people by the year 2050. Even if they manage to control the population or not, they have done sustainably through efficient gain from agglomeration. Agglomeration will create concentration, compactness, and connectivity which result in prosperity and sustainability. Consequently, over halve of area of cities are expected to form part of already existing urban centers in the year 2030 (Elmqvist et al., 2013). This will provide an opportunity to make future city extra productive and sustainable. Yet, many cities have forgone these benefits and have tend to become expensive, growing carelessly at faster than the population and indiscriminately gripping the land which could have been used for agriculture purpose and ecosystem services. Hence, as a solution to land use efficiency, the indicator was designed to benchmark and monitor the links between land use and population growth in the urban centers.

Urban air pollution level

The fast growing of urban centers results in rising air pollution in most of our cities particularly in developing countries. It is asserted that more than six million premature deaths per year will be caused by urban ambient air pollution by the year 2060 (Landrigan, 2017). Subsequently, it has much economic and health implication. Therefore, the post-2015 framework consists of this indicator was proposed to track the mean urban air pollution, particular attention should be given to the level of particulate matter in cities.

Sustainable development indicators for SDG12 – Promoting responsible consumption and production

Responsible management of chemicals and waste

The indicator puts emphasis on creating an environmentally efficient management of chemicals and waste throughout their life cycle in agreement with the established standards set by international frameworks, such as Montreal protocol, Basel convention, and Rotterdam Convention. This should also lead to significantly curtail chemicals and waste emission to the air, water as well as soil so that their adverse effects on human health and environment can be reduced. Complementary instruments should be implemented to reduce waste disposal by integrating municipal services, service providers and appropriate funding schemes ensuring financial sustainability of the services (Rodić & Wilson, 2017).

Substantially reduce waste generation

This indicator emphasizes significant reduction of waste generation by using technique such as prevention, reduction, recycling as well as reuse. The problem associated with this indicator is that there is not enough availability of data for the recycling rate globally (Pujara et al., 2019).

Remove market distortions that encourages waste consumption

The indicator tends to resolve inefficiency of fossil-fuel subsidies that creates wasteful consumption by getting rid of market distortion that are in line with national circumstances. These distortions can be reduced, among others, by restructuring of taxation as well as phasing out the harmful subsidies if they exist to strengthen the environmental impact (Magrini et al., 2020).

Sustainable management and use of natural resources

The indicator aims to attain sustainable management as well as use of natural resources particularly by promoting prudent use of domestic material consumption, domestic material consumption per capita likewise domestic material consumption per GDP. To decouple GDP growth and domestic material consumption, more developed countries outsource material-intensive production (Barbier & Burgess, 2019).

The frequency of disclosure of natural resource right of holdings

The indicator investigates whether resources-based rights and registry of right holders between governments and business, contracts and licenses regarding extraction of resource exploration & production, agriculture and forestry operations are timely published. Failing to disclose or keeping all the information secret tend to result in mismanagement, creating power imbalance, incompetence and breeds corruption. Hence, disclosure serves as a precursor for coordination as well as ensuring an effective management by the government agencies. In effect, it encourages the citizens to know their right in terms of environmental compliance and also fulfilled their social commitments. Another benefit regarding the disclosure of contract is that it creates transparency, provide incentive, and prevent government officials from their quest for self-interest over the population (Elmqvist et al., 2013).

The use of ozone-depleting substances

This indicator is used to evaluate the consumption pattern for ozone-depleting substances (ODS) monitored under the Montreal Protocol on substances that deplete the ozone layer. They will permit an implication to be drawn based on the amount of ODS being removed as a result of the Protocol (Meyer & Newman, 2020).

Sustainable development indicators for SDG13 – Climate action

The availability and implementation of transport as well as an intensive decarbonization strategy

Maintaining the global warming at a level of 2 degrees Celsius demands that countries prepare national deep decarburizations strategies to 2050 which must include all sources of greenhouse gas (GHG) emissions from energy, agriculture, forest, transport, industry, forest and other sectors. The strategies require transparent as well as detailed explaining how the countries intend to attain the deep emission cut, reduce energy consumption as well as decarbonize the power sector and electricity consumption particularly for transport as well as building sectors. Therefore, the indicator is proposed to evaluate the implementation of such strategies.

GHG emission in the agriculture, forest and other land use sector

The indicator describes the total net GHG emission-tons of CO2 equivalent in the agriculture, forest and other land use sector, split by gas (made of CO2, N2O and CH4) and by land is classified into forest land, croplands, wetland, settlement land, grassland and other lands. Based on the Intergovernmental Panel on Climate Change 2006, the rules were introduced for the national GHG inventory and the good practice guidance was presented for land use (Martínez & Mollicone, 2012).

The official financial support to combat climate change

The developed countries made a pledge at the Paris conference (as reported to the United Nations Framework Convention on Climate Change (UNFCCC)) to provide an amount of hundred billion dollars per year towards financing climate change strategy by the year 2020. This indicator was designed to track the climate financial contribution by the developed countries.

Sustainable development indicators for SDG14 – Oceans

The percentage of fish tonnage got within maximum sustainable yield

Maximum sustainable yield represents the largest yield (catch) which can be theoretically harvested from species stock over indefinite period under constant environmental conditions. It is mostly measured in tons (Finley, 2011). The indicator provides information about the magnitude of exploitation of fish resources and the progress towards sustainable management of fishes.

Sustainable development indicators for SDG15 – Ensure sustainable forests, stop and reverse land degradation and stop biodiversity loss

The yearly change in degraded or desert arable land (in percentage or hectors)

The Food and Agriculture Organization described the land degradation as a reduction in the condition of the land that affect inability to provide ecosystem goods and services as well as ensuring its functions for some period of time (Nachtergaele et al., 2011). The causes of land degradation are erosion loss of soil nutrients, salinization and sand dune encroachment. There has been improvement in data for land degradation due to advancement in technology such as digital mapping remote sensing and monitoring. The objective to this indicator is to halt all land degradation by the year 2030.

The red list index

The red list index relies on the list of threatened species to track the rate of extinction for marine and terrestrial species groups in the near future (impliedly from ten to fifty years) devoid of any conservation action. The downward trend of an index connotes a risk of species extinction is increasing. The index is employed to evaluate the progress made towards the Aichi Target 12 of the Convention on Biological Diversity as well as the MDGs (Butchart et al., 2007).

Sustainable development indicators for SDG16 – Ensuring peace, justice and strong institutions

Number of violent injuries and deaths

This indicator measures the occurrence of injuries and fatalities resulting from violence, such as assault (burning, abuse and beating) and arm robbery cases or violence but not emanating from self-inflicted injuries and expressed in terms of unit per 100,000 populations.

Enforcement of a national law or constitutional guarantee on the right to information

The indicator assists in measuring whether a country has a legal or policy framework which protect and promote access to information. Generally, public access to information assist in ensuring institutional accountability and transparency. Therefore, it is necessary to evaluate both the existence of such frameworks and the culture of secrecy or an institutional resistance to corruption (Peña-López, 2008).

The perception of public sector corruption

The public-sector corruption impedes the rate of development of an economy and even diverts' resources away for poverty eradication efforts as well as sustainable development. Actually corruption is difficult to measure due to the objective data trends which makes it incomplete to compare. Therefore, the Transparency International (the global civil society working to fight corruption) has subsequently developed the Corruption Development Index (CPI) (Rohwer, 2009). The CPI ranks countries by considering how corruption in public sectors in is perceived to be. Another mean of measuring corruption is drawing many corruption data from reputable institutions. The CPI usually uses the view from observers around the world, consisting of experts living, working in the countries and territories for the evaluation.

Sustainable development indicators for SDG17 – Revive the global partnership

The official private assistance as well as the net private development as percentage of GNI

The main target value for the Official Development Assistance (ODA) is the international commitment of 0.7 percent of GNI, together with additional commitment of 0.15-0.2 percent of GNI for least developed countries. In dealing with the recipient countries of the Development Assistance Committee (DAC) list, the indicator evaluates the amount of ODA received as a percentage of its GNI.

Private net flow for sustainable development as share of GNI

The international private finance is essential for financing sustainable development. Especially, in private finance fund is used to support private sector development (particularly agriculture) and infrastructure. The prescribed indicator is used to monitor international private flows at market rate using the OECD DAC criteria which is made up of direct investment, bond lending (maturity >1 year), bank lending (maturity > 1 year) and some other flow (usually reported holdings of equities which is issued by firms' aid recipient countries) (Clements, 2020).

Mobilize financial resources for developing countries

The indicator stresses mobilizing financial resources for developing countries through FDI or uses FDI as a pivot for development assistance. FDI involves direct investment equity flow of one's economy by aggregating equity capital, investment of earnings as well as other capital. FDI portrays the net flows of investments between countries and is mostly divided by country GDP. Consequently, the indicator strongly supports the mobilization of additional financial resources for developing countries to stimulate the achievement of SDG17 by the year 2030.

Increase export of developing countries

This indicator is aimed to increase export especially in the developing countries so that this action is likely to raise their share in global market by double in the year 2030. The indicator evaluates the total export value of goods as well as service.

1.3 Interactions Among Sustainable Development Indicators

The interactions among sustainable development indicators deal with interdependencies between or among SDGs or indicators relating to the 2030 agenda. This in turn means for sustainable development that the increase / decrease in the value of one indicator influences the performance of either one or more other indicators (Assembly, 2015; Nunes et al., 2016). Since the inception of SDGs, their indicators were designed to link SDGs to effectively combat the problems facing humanity, such as poverty alleviation, protecting the planet as well as its resources, and ensuring human prosperity (Griggs et al., 2014; Le Blanc, 2015).

Recent literature observed that sustainable development indicators are in network interactions, such as the indicators of poverty, health, gender and inequality (with either beneficial or worsening effects). For example, co-beneficial interactions (i.e., rather than trade-off effects) were depicted for poverty in this specific network (Pham-Truffert et al., 2020). Inequality, on the other side, portrayed negative effects on the remaining indicators. In other words, SDG1, SDG3, SDG5 and SDG10 (impliedly, poverty, good health and well-being, gender equality and decent work and economic growth) demonstrate a close connection and that they have a potential to contribute to the overarching 2030 agenda of “leaving no behind”. Hence, they are classified as key indicators for sustainable development trajectories. The economic growth (SDG8) and food (SDG2) are also assumed to provide mutual benefits. Certain objectives can also affect other development areas. For example, food supply is very important to our lives. Our food system today consists of agricultural practice which destroys our land as well as other resources regarding the quantity diversity likewise quality. Again, growth involves creating job opportunities, the growth in business can impede other sustainable development goals which questions the traditional GDP growth measure.

The indicators of energy (SDG7), infrastructure (SDG9), cities (SDG 11) as well as climate change (SDG13) also highlight interactions with each other (Pham-Truffert et al., 2020). New infrastructure and industrialization demand energy but industrialized automation may lead to job losses (Messerli et al., 2019). Other bidirectional causalities exist among SDGs education (SDG4), water (SDG6), sustainable consumption and production (SDG12), ocean (SDG14), ecosystems (SDG15), peace and partnerships (SDG17) (Pham-Truffert et al., 2020).

Notably, research indicates that poverty, inequality, health and gender are predominant problems for sustainable development when unsolved, which impedes the achievement of sustainable development goal for the year 2030 (Pham-Truffert et al., 2020). However, with prudent handling of these indicators, a multiplicative effect on other indicators can be achieved and the achievement of the 2030 agenda can be substantially enhanced. Similarly, indicators of food and economic growth must also be cautiously approached since a rapid boost can unfold an unexpected effect and obstruct the attainment of the overall agenda. It also believed that indicators such land and terrestrial ecosystems and climate usually equally reinforcing each other; climate has an effect on the water which tends to influence energy and energy has an effect on climate. In that sense, their effect could be beneficial or disastrous (Pham-Truffert et al., 2020).

By narrowing the interactions to specific sustainable development indicators that appear to be strongly connected with the remaining indicators (Pham-Truffert et al., 2020), the following discussion highlights the most important interactions.

Interaction between poverty and other sustainable development indicators

Eliminating poverty by safeguarding the equal right to economic resources as well as access to services is believed to be commonly inseparable from other SDGs and their indicators. Getting rid of poverty must be perceived as ensuring wellbeing, welfare and freedom for each individual. Also, the understanding the concept of poverty transcends beyond income as the scope has transformed to become multi-causal likewise multi-dimensional concept of poverty which is depicted in both MDG and SDG goal number 1. Some theories of poverty as well as economic development usually emphasize a set of basic poverty dimensions. These consist of access to education, health services, shelter, energy, water, sanitation and human right likewise liberties, empowerment, human security, social inclusion, dignified livelihoods and opportunities to participate in trade as well as production activities (Nilsson, 2017).

By taking the tenet of leaving no-one behind into consideration, it is necessary to bear in mind that the interactions with poverty cannot be simply acknowledged as interaction with the goal of aggregate economic well-being but the major aim deals with welfare as well as freedom of each individual (Gewirth & morality, 1978). For instance, development strategies like industrialization, export-driven manufacturing, and value-adding activities in the food sector as well as natural resource extraction usually strengthen aggregate economic well-being. However, they contribute to poverty reduction when there are appropriate institutional frameworks that support the poor to exploit the opportunity and the benefit from development. Again, advancement in public health and rise in income is indivisible form poverty reduction as far as they make ones afford the services from public health, satisfy the basic needs such as shelter and nutrition.

Regarding the international dimension, protectionist policies in richer countries reacting to the popular anxiety of the effect of globalization on domestic jobs likewise industries basically limit the chances for export-led poverty reduction in lower-income countries. Moreover, assessing the level by which international trade has been able to minimize poverty mostly depends on the developed sectors. Additionally, the trade agreements are mainly aimed at both trade directions (between wealthier economies, emerging economies and poor economies). For example, Africa is usually not able to compete efficiently, on large scale supplier with both the emerging and developed economies (A. Zafar, 2007). Since poverty reduction has been one of the major

SDGs, it demands multilateral development institutions, bilateral corporation agencies as well as development plans, especially for lower-income countries. The institution should also have a strong treatise connecting poverty reduction with international trade as well as access to global markets.

Interaction between energy, carbon emissions, employment and education

The modern energy is vital to human development. The service provided by energy makes everything possible especially in the industrial world. Sustainable energy is an energy generated without an accompanied carbon emission or pollution-free. Impliedly, an attempt to increase energy access or expansion of renewable energy mix and ensure energy efficiency creates a simultaneous decrease in carbon emissions (Büchs & Schnepf, 2013). Therefore, the interaction between the energy and reduction of air pollution is regarded as reasonable. Again, this will not be sufficient to reduce or meet the quality of the environmental targets while demanding technology control and other measures. To safeguard that the world's poor have access to affordable, dependable and modern energy services assist by stimulating renewables as well as increasing energy efficiency will lead to price shocks and avoid universal access to modern energy supplies. Using renewables as well as energy-efficient technologies is capable of creating innovation and support local regional and national industrial likewise employment objectives. Applying the decarburization of the energy system by employing renewable and energy efficiency is bound to stifle economic growth in some countries. However, an immediate and substantial increase in renewable and energy efficiency is an important aspect of the effort to slow down global warming. Promoting energy access and boosting the share of forms of renewable energy like agriculture as well as forest based-bioenergy for health care, education and employment can have a positive effect on the income and equality and poor rural dwellers. Good governance can also be used to prevent conflict between objectives. For instance, policymakers should be cautious by ensuring that the price of energy remains affordable for the poor. Again, institutions as well as financial capacity must be sought locally, though foreign investment and development funding (advance rich countries to poor countries) are also needed or relevant to minimize inequalities. Also, attaining universal energy access is apt to provide an opportunity for employment and education people especially the world poorest communities. By establishing or adopting renewable and energy-efficient technology or consumption, innovation can be stimulated and the local, regional as well as national employment can be affected. Developing energy-related curricular is also capable of enhancing science literacy in population, specifically for the poor, creating opportunity and equipping them to with skills which enable them to have access to a better job (Nilsson, 2017).

Interaction between economic growth and environment

The issue of economic growth takes place in myriad of forms. Some of the growth occurs by causing both environmental as well as social damage. For example, growth by supplying infrastructure for renewable energy not damaging, growth by expanding an area of policies interceding the interdependency between health and well-being is important to ensure a fair balance between the indicators. Additional research is necessary on the interaction among employment, income gains and health by taking into consideration levels of wealth and income for the rich likewise causing of a sense of relative social and economic deprivation among the poor (Nilsson, 2017).

Interaction between health, education and gender inequality

Getting access to high-quality education is connected with better health at the individual as well as community level. The parents who have quality education are bound to have a positive impact on children health. It is also believed that informal education likewise another sources of information is capable of supporting an active role in either good health or ill-health (Groot & Maassen van den Brink, 2007). For instance, wrong information can stimulate a poor health decision especially for developing and developed world settings. Education can also affect health by altered behavior or acceptance of new technologies. The benefit accrued from education to health does not confine itself to early schooling or long-life learning but it provides a vital opportunity in terms of quick transformation. Although these links are common, many benefits are promising especially in the developing world environment. The new technologies (health promotion as well as communication technology) is likely to raise the efficiency of health interventions and broadcast the knowledge to many people. The link between education and health is bidirectional since the poor health impede school attendance likewise educational attainment (Eide & Showalter, 2011).

Besides, ensuring gender equality generally facilitate the attainment of better health. Women health issues are sometimes relegated to the background as well as underfunded and improving gender equality in these context will create easy heath gains. Also, it is common that women make most of the health decisions especially for children, and this empowerment result in improvement of child health consequence. The much involvement of women in a paid work force is bound to generate economic gains and therefore improve health. The reason for acknowledging the interaction between gender inequality and health much prudence where women are confronting high inequalities (Nilsson, 2017).

Interaction between health, air pollution, climate changes and cities

In worldwide, air pollution causes about three million deaths per year. It is also believed that there is a relationship between air pollution and prenatal mortality (Malley et al., 2017). The effect of this to society comprises loss of productivity (sick leave as well as medical cost) about one percent global GDP. Also, the welfare cost also increases from five to ten percent of GDP especially in much polluted places (Mele et al., 2021). Besides, the climate change effects on health are direct and indirect. They include much heat impact on our ability to work outside, severe weather event specifically, rampant increase intense storm, frequent flood as well as droughts. The indirect effect can also be attributed to the spread of vector disease (like dengue and malaria) which creates food insecurity likewise undernutrition. The indirect effect tends to stimulate climate disruption which is apt to spark local or region conflict, influencing breakdown of governance, creating massive migration (Nilsson, 2017). Currently, the rise in heat from the temperature (as a result climate change) has been a growing phenomenon, specifically in cities or urban centers. The lack of vegetation to absorb the heat have contributed to rise in temperature to about 3 degrees warmer likewise rise up to 12 degrees in the night in our countryside. Extreme heat in turn results in respiratory disease and death (D'amato et al., 2016). The issue has a marginal impact in both Europe as most death cases are caused by heat stress.

However, in general, the effect of these indicators are not only skewed towards human physical and mental health but has some implications on our well-being, specifically on our cultural identity and income provision (Assessment, 2005). Establishing peace, justice as well as strong institutions is believed to pave the way to enhance the health and well-being of the people. This is because the absence of these is bound to worsen inequality, violence, and impede the government's capacity to deliver and ensure strong justices delivered in our communities. Also, the link between climate changes on health is very wide. The main emphasis is on air-water pollution and soil degradation. The emissions from the combustion of fossil fuels have an impact on climate and local air quality. Reducing air pollution has been one of the aims of international environmental policy developers or leaders. Their determination to control harmful emissions like sulphur dioxide has been a long tradition (Kanada et al., 2013). An example of short-live pollutants that have an adverse effect on climate includes aerosols like black carbon (from domestic) as well as industrial processes like diesel combustion vehicle and electricity combustion, biomass from cooking likewise brick production and tropospheric ozone (Assembly, 2015). All these pollutants contribute or form smog and hence create health risks by inhaling and climate change. Their interaction seems to be unidirectional because reducing climate change by ensuring air quality and this policy can make an economy less dependent on fossil fuels is likely to create some jobs in the short run. It may also have some influence on health and spending. Impliedly, in the long run, the health gain is bound to greatly outweigh the costs (Nilsson, 2017).

Interactions between infrastructure, climate change and social inclusion

Another step of development that will contribute to the attainment of sustainable development is the structural transformation of infrastructural as well as industrial production coordination which demands an amount of investment from the public and private sectors. For instance, an effort to combat climate or reduce climate change and air pollution has been agreed upon by shift the use of fossil fuel infrastructure which needs a huge amount of investment to redevelop the transports, electricity of our urban regions (Economy, 2017). Also, forecasts revealed that the world needs to spend about sixty trillion USD on infrastructure to meet SDG9 (zu Ermgassen et al., 2019). The development of the urban infrastructure is acknowledged to take the greatest portion of the amount of these undertakings. Impliedly, it will reduce future CO2 emission as a result of a novel electricity transport system (Erikson and Tempest 2015). If another effect of perusing this investment is done, this will redesign how resistant or venerable cities to climate transformation. A study has shown that designing of cities to become compactly connected as well as ensuring low carbon by means of providing affordable public transport and investments will stimulate cycling and walking. Consequently, it will facilitate social inclusion, create more equal access to different areas or suburbs of the city and create opportunities for employment for marginalized people (Economy, 2017).

To develop resilient infrastructure, three strategies have been proposed, namely supporting structural change (thus creating a new type of jobs as well as industries), providing access to basic needs to reduce poverty (water, sanitation electricity, and communication), and providing access to markets (through transport infrastructure likewise information and communication technology) (Magagna et al., 2016). Presently, the insufficient provision of these infrastructures is impeding economic activities and hindering poverty reduction particularly in lower-income countries. A study provides an indication that infrastructure deficit decreases economic growth by two percent annually and also decrease firm productivity about 40 percent in Africa (Ramachandran et al., 2009). A well developed or improved regional transport systems in developing regions will stimulate intra-regional trade likewise regional integration as well as foster strong cooperation. Again, creating easy access to infrastructure services is apt to enhance the chances for the poor to participate in economic activities.

Evidence has portrayed that transport as well as ICT infrastructure tends to decrease poverty in some areas, by enhancing labour mobility and flow of information (Calderón & Servén, 2014). Regarding the social aspect, infrastructure development, has a strong influence on both health and education. Particularly, transport infrastructure assists the development of the hospital, schools and lessens the travel times to them (Brenneman & Kerf, 2002). Energy infrastructure also plays a pivotal role as it supports both the adult and children to use better facilities as well as minimizes the need to spend labor on collecting a traditional form of energy. Besides, industrialization and infrastructure are connected with a trade-off with environmental objectives that been regarded as an impediment to industrialization to date. On the contrary, the issue might be changing as science, technology, as well as innovation have provided solutions to most of the environmental issues (Economy, 2014; Giovannini et al., 2015). Much effort and education are needed from the public to familiarize themselves towards environmentally sustainable product, processes as well as services. There should also be public investment to propel research institutions to go beyond research, development and demonstration. The creation of an institution for risk assessment (like biotechnology) and establishing a conducive environment for innovation is laudable. It was alleged that “mission-oriented innovation” method is capable of steering innovation strategies towards definite societal problems and orient actors in different sectors to synchronize effort to solve them (Cattaneo, 2014).

Interactions among sustainable development indicators in the EU context

The agenda 2030 for SDGs shows a complex contest. Yet, understanding the broad nature of the interconnections among these indicators or SDGs will serve as a tool to reveal the full potential and safeguard the progress in achieving in one area (of indicator or SDG), is not done at expense of another one. Therefore, exploring the trade-off, synergy and unintended outcome emanating from the interconnections between those indicators or SDGs is vital for attaining long-lasting sustainable results. For the aim of demonstrating the nature of SDGs, the EU uses multi-purpose indicators to monitor the report of SDGs (Nilsson, 2017).

Exchanges or back-and-forth negative interactions between different SDGs as well as targets when the enhancement or upgrading progress in one dimension can also impede the progress in another dimension. For example, achieving economic growth demands higher resources likewise energy consumption, can create a negative impact between resources and energy consumption since much of these resources are demanded to supplement growth. On the other side, the positive interconnection between goals and indicators can also improve in another goal to ensure a progress in another dimension. For instance, 20% improvement in renewable resources in the EU is bound to reduce GHG emissions. Impliedly, numerous efforts have been made to deal with both negative and positive impact of interactions among these indicators or SDGs by academician and international organizations to find the balance among these indicators (Griggs et al., 2014).

For example, the interlinkages working group of the Inter-agency and Expert Group (IAEG)-SDGs carried out a study that resulted in a positive interaction between the goals and indicators in order to enable countries to pay much attention to indicators that create positive externalities (Miola et al., 2019). The National Institute of Statistics and Economics Studies in France employed statistical methods to analyze EU indicators and thus identify the links between the SDGs (Cling et al., 2019). The relationship among SDGs using the economic model and some academic studies also employed integrated assessment models to find out the interaction, synergies as well as the trade-off between the SDGs (Moyer & Bohl, 2019). To sum up, these studies concluded that there are numerous interconnections among SDGs and their indicators. Also, what is needed is to find out the interlinkages in order to determine the most effective policy strategy. Now it can be deduced from the above that the interconnection between the indicators or SDGs depends on the method and the data utilized (by an expert judgement or quantitative analyses) as well as the geographical area in which the interactions are reported. These interactions show the way we live, produce, likewise consume and strongly connected with many areas. Again, our cities as well as a human settlement are very vital for Europeans welfare likewise the quality of life as they demonstrate the level of economic, environmental territorial together with social development. The urban vicinities are the main focus especially urban environment change as a result of soil sealing, housing, mobility issues waste generation, and food supply. It is also believed that inappropriate or unsafe waste (including both solid and liquid) collection, treatment and disposal are impeding human activities on the environment. Consumption and production patterns have a great effect on a resource as well as energy efficiency and biodiversity and ecosystems services (van Soest et al., 2019). Similarly, dependable and sustainable energy systems stimulate the transition towards sustainability as well as resilient low carbon society, which will intend have to less amount impact on our climate. Impliedly, the viability of their influence social environmental and economic systems will be reduced. Obviously, climate action is connected with providing affordable and clean energy. This linkage is emphasized by the GHG emission, as the magnitude of energy consumption as one of the causes of climate action. Cities also serve a hub of economic growth. Generally, if the economy increases employment tends also to assist in alleviating poverty as well as gender inequality. Pressure from urbanization does not only have an effect on resources and material consumption and climate change but it also demonstrates some effect on ecosystems as well as biodiversity. The healthy ecosystem regarding forest, wetlands drylands and mountains offer numerous services such as biodiversity conservation, climate change reduction and provide both clean air and water. However, much pressure resulting from urbanization is capable of worsening increase pollution from industry, agriculture and tend to stimulate climate change likewise obstruct water quality. The setbacks are made more transparent and observed by the population during wastewater treatment. The water quality assessment done by evaluating pollutants in the rivers is connected to overall ecosystem status. The sustainable agriculture also influences the protection of biodiversity as well as soil sustainability.

Besides, the way we live determines other driving force or factors (either positive of negative factor). This intends to have an influence in our society which will determine the quality of life of the citizen in the coming future. For example, we usually yearn for good health as well as well-being, but variables such as noise or air pollutions are among the factors which determine the health status and quality of life of the populace. Again decent work and economic growth are also other indicators we desire to have. Therefore, decent employment opportunities help people to afford basic needs and enjoy certain living standards and probably attain desired goals in life. Impliedly, they prevent people from descending into the risk of poverty or social exclusion.

Education and innovation are only sporadically connected to other indicators when assessing them based on multi-purpose criteria in the EU. But both indicators are very important in achieving the SDG 2030 program as a whole. Having a quality education helps people secure jobs which will in turn break the cycle of poverty it also minimized the level of gender inequality. It also steers people to live healthier lives. In other words, people adopt a sustainable life style.

With the promotion of science, technology likewise innovation, tend to boost productivity. Similarly, the developed infrastructure as from the perspective of science and technology influence and aid easy access to educational resources, quality health-related services and enhance economic growth (Nilsson, 2017).

Generally, the above outline cannot cover all the indicators but I attempted to present the most important interactions among these indicators. The following section will shed more light on how the interactions among SDGs and their indicators were investigated in previous studies.

2. State-of-the-art in Modelling Sustainable Development

In this chapter, existing approaches to modelling sustainable development are presented, covering scenario modelling, decision support systems, optimization models, dimensionality reduction methods, and interaction frameworks.

2.1 Scenario Modelling for Sustainable Development

Effective implementation of sustainable development goals is difficult because the SDG framework is complex, dynamic and multi-dimensional. Scenario analysis based on simulation models is considered a suitable method for policy planning and formulating sustainable development strategies. Accurate simulation models enable the users to consider both short-run and long-run effects of changes in individual sustainable development indicators.

A wide range of modelling methods can be considered for scenario modelling in sustainable development (Allen et al., 2017):

- Input-output models (models using aggregated inputs and outputs of products and services of an economy; when regions are connected, the input-output models are able to capture supply chain relationships; environmentally extended models were proposed to consider local emissions of producers (Mattila et al., 2013; Siala et al., 2019; Wiedmann, 2009));
- Macro-econometric models (using time series of sustainable development indicators to model dynamics in the input-output system (Hatfield-Dodds et al., 2015; Stocker et al., 2012); cross-sectional relationships are usually considered to model dependence among regions, such as the model of dynamics among environmental sustainability, trade, and technology innovation (U. Ali et al., 2021));
- Computable general equilibrium models (by imposing economic assumptions, while some economic variables remain fixed and other are flexible, these models enable the user to simulate the effects of changes in external determinants, such as technology and policy interventions, on the economic system (Böhringer & Löschel, 2006; B. K. Pradhan & Ghosh, 2019));
- System dynamics models (to mimic historical behavioral patterns, system dynamics model use differential equations, which can be utilized, among others, to develop

sustainable business models (Cosenz et al., 2020) and sustainable supply chains (Rebs et al., 2019; Saavedra M. et al., 2018));

- Optimization simulation models (partial equilibrium optimization models employ equilibrium theory to simulate a single subsystem, such as energy-environment system (Byravan et al., 2017; Heinrich et al., 2007); the Global change assessment model represents a dynamic-recursive, partial equilibrium model that links socio-economic system with land use, energy and climate subsystems, which makes it possible to simulate the effects of changes in climate mitigation policies (Forouli et al., 2020));
- Multi-agent models (simulates behavior and interactions between various agents in an artificial environment; for example, multi-agent simulations were used to investigate the effects of environment on water pollution (Han et al., 2017), and sustainable lifestyle choices (X. Cheng et al., 2019)).

In addition, hybrid models were introduced to combine the above methods into integrated top-down and bottom-up models.

2.2 Integrated Assessment using Decision Support Systems and Optimization Models

The inherent multi-dimensionality of sustainable development models leads to the definition of multiple sustainable development indicators and criteria. Indeed, multiple often contradictory criteria must be considered in selecting sustainable solutions and other policy decisions. Multi-criteria decision making models enable finding a compromise solution that takes conflicts among indicators and criteria into account. Multiple experts should also be involved in assigning criteria weights to obtain more objective criteria weights. Finally, a suitable ranking method is used to obtain the best alternative (solution). Weighted arithmetic mean and Analytic hierarchy process are the two most popular multi-criteria decision making models in assessment of systems sustainability (Diaz-Balteiro et al., 2017). Examples of using the multi-criteria decision making models include selection of sustainable transport projects (MacHaris et al., 2012), sustainable renewable energy solutions (Campos-Guzmán et al., 2019; Kumar et al., 2017), and sustainable supplier selection (Memari et al., 2019). To enhance the multi-criteria decision making models, data envelopment analysis was used to calculate an efficiency index for each dimension of sustainability (Keshavarz & Toloo, 2020).

To consider multiple conflicting objectives in sustainability-related decision-making problems, optimization methods from the field of operational research. For example, the multi-objective goal programming method considers the trade-off between the underachievement and overachievement decision-makers' objectives, such as economic growth, GHG emissions, electricity consumption and employment rates in economic sectors (I. Ali et al., 2021).

2.3 Dimensionality Reduction of Sustainable Development Indicators

Dimensionality reduction methods, as well as cluster analysis, have been used as representatives of multivariate statistical methods. Dimensionality reduction methods aim to decrease the multidimensional space of sustainable development indicators by choosing most important indicators (variables) or combining them by designing novel variables as a combination of the original ones. Cluster analysis aims to assess similarities in the data, encapsulates or outlines the variables that are similar to each other in terms of distance measures. However, multi-collinearity between the variables in the data leads to unreliable cluster generation. Therefore, cluster analysis and dimensionality reduction methods are usually combined to address this issue. More precisely, dimensional reduction is applied in the first stage to remove the multi-collinearity and cluster analyses is then applied to find similar variables (or data samples) (van de Velden et al., 2019).

A set of operational indicators was identified for sustainability assessment of four pillars, namely environmental, economic, institutional, and social dimensions (Mirshojaeian Hosseini & Kaneko, 2011). Data for these sustainable development indicators were collected for more than one hundred countries to track their dynamic sustainability in the period 2000–2007. First, the data were normalized to rescale the sustainable development indicators and, then, principal component analysis (PCA) was used for weighting the sustainable development indicators. This enabled the authors to rank the countries using their principal components representing the four dimensions. To aggregate sustainability indicators, several other studies adopted the PCA-based methodology, such as that designed to assess energy sustainability of rural communities (Doukas et al., 2012).

More recently, a comprehensive benchmark study was performed for OECD countries by considering the seventeen SDGs of the 2030 agenda (Lamichhane et al., 2021). Specifically, the authors developed a goal-specific PCA model enabling them to assess the sustainable development performance in terms of each SDG. What is worth mentioning, each SDG performance combined several economic, environmental, and social indicators. In other words, strong linear relationship among the indicators was assumed within each SDG. Alternatively, nonlinear PCA was applied to improve the quality of regional sustainable development assessment (Tan & Lu, 2016). As noted above, the results of PCA (values of principal components) can further be combined with cluster analysis to obtain the categories of regions / countries with similar sustainable development performance (Megyesiova & Lieskovska, 2018). To reduce the dimensionality of sustainable development indicators, variable clustering was also used as an alternative to PCA (Tran, 2016). To sum up, these approaches lead to a small number of relevant indicators while retaining most variance in the data, provided that the sustainable development indicators are in strong linear / nonlinear relationships.

However, the authors of the above studies admit that the dimensionality reduction approach has several limitations. Most importantly, testing the causality of interactions among the sustainable development indicators was recommended for future research.

2.4 Modelling Interactions among Sustainable Development Goals

To investigate the interactions among SDGs, a network-based approach was proposed that links the goals and targets (Le Blanc, 2015). The authors found that the SDGs set by the United Nations, represents a more integrated system than that using MDGs. The resulting network represents a political map of the sustainable development.

To investigate the synergies and trade-offs between SDGs, correlation analysis was performed where positive correlations indicated synergies whereas negative correlations implied trade-offs (P. Pradhan et al., 2017). Significant correlations were observed between the pairs of SDGs on both country and global scales. Notably, synergetic interactions with most SDGs was found for SDG1 (No poverty). By contrast, most trade-offs were detected for SDG12 (Responsible consumption and production), indicating obstacles induced by SDG12. Similarly, inconsistencies among SDGs were investigated using dynamic Bayes factor models, finding that the focus on consumption and economic growth is the main source of these inconsistencies and that there exist tools that do not increase these inconsistencies, such as health programs and renewable energy (Spaiser et al., 2017).

An expert survey was conducted to study the interactions among SDGs (van Soest et al., 2019). Additional support for the existence of the interactions was found using Integrated Assessment Model, showing that goals related to earth system and sustainable resource use are well represented by SGSs. However, other important components of the model, namely governance and human development, were underrepresented by SDGs. Another conceptual framework was proposed that enables to evaluate the interactions between SDGs (Nilsson et al., 2016). More precisely, the influence of one SDG on another can range from Cancelling to Indivisible on a simple scale of seven interaction levels. The strengths of interactions were also utilized in integrated simulation models to show the long-term impact of policy interventions on several SDGs (Collste et al., 2017).

By considering sustainable development as a social product, SDGs were categorized into essential needs, objectives, and governance. Maximum effectiveness can be achieved through appropriate governance, and essential needs increase resource-use efficiency via technological innovation (Fu et al., 2019).

2.5 Partial Conclusion

The above literature review suggests that to model sustainable development, modelling interactions among SDGs (and sustainable development indicators) is the crucial and challenging problem. Existing approaches to this problem assume bidirectional relationships among SDGs. However, this assumption is often not realistic and better understanding of interactions among SGSs is needed. In fact, finding the directions of the relationships is difficult and requires sufficient time series data. To better understand interconnections among SDGs, nexus approaches have been recommended (Jianguo Liu et al., 2018). In the nexus approach, the importance of synergies and trade-offs are highlighted by simultaneously examining interactions among SDGs. Such models can be potentially used to reduce negative effects and improve integrated sustainable development management and planning.

3. Aim and Objectives of the Dissertation

The aim of the thesis is to *propose an economy-society-environment nexus model to examine interactions among SDGs and sustainable development indicators at national and regional EU levels*.

To achieve this aim and model the complex interactions among sustainable development components, the thesis defines the following specific objectives:

- *To identify the main SDGs and sustainable development indicators* that constitute the core components of the economy-society-environment nexus at the level of EU countries and regions. to economic growth in the region. This model must deal with complex interactions between economic growth, societal development and environmental condition. To effectively investigate the nexus model using existing econometric techniques, there are several constraints that must be taken into account. First, only a limited number of variables can be incorporated into the nexus model to obtain reliable estimates of econometric models' parameters. Second, long enough time series must be collected for the sustainable development indicators to enable investigation of short- and long-run interactions.
- *To develop an appropriate econometric model* to study the short- and long-run causal relationships between economic development, social development, and environmental quality. Based on the partial findings of the prior literature reported above, it is hypothesized that bidirectional short- and long-run interactions exist among SDGs and sustainable development indicators. A panel vector error correction model (VECM) will be used to test the short- and long-run causalities among SDGs and sustainable development indicators at national and regional EU levels. Multivariate cointegration will be performed to detect the existence of causal relationships among sustainable development indicators. Short- and long-run Granger causality tests will be performed to confirm the main hypothesis on the existence of the economy-society-environment nexus.
- *To separately investigate new and old EU member countries* by considering specific economic environments, different levels of technology development level, and different

sustainable development patterns in new and old EU member countries and their regions.

- *To assess the magnitude of the interaction effects* among sustainable development indicators by performing variance decomposition. Impulse response functions will be used to map out the intensity of the shock from one endogenous variable to the other.

4. Research Methodology

4.1 Model of Interactions among SDGs and Sustainable Development Indicators

The transformative 2030 Agenda for Sustainable Development defined 17 SDGs as depicted in Figure 1. In this integrated framework, the SDGs can be categorized into three sustainable development pillars, this is economic, environmental, and social pillar. Hence, a balanced development in the three areas of sustainable development should be achieved. To measure the advancements in each SDG, sustainable development indicators are associated with SDGs and specific targets.

Figure 1: Categorization of 17 SDGs into economic, environmental, and social pillars

Source: (Kostoska & Kocarev, 2019)

To investigate interactions among SDGs and corresponding sustainable development indicators, three nexus models were developed in this dissertation thesis:

1) Model of energy consumption, CO2, and economic development nexus;
2) Model of inequality, economic growth and risk of poverty nexus;
3) Model of municipal waste generation, R&D intensity, and economic growth nexus.

The first model investigates the importance of synergies and trade-offs between economic and environmental pillars in particular. Figure 2 shows the conceptual framework for the first nexus model by assuming interactions among four SDGs.

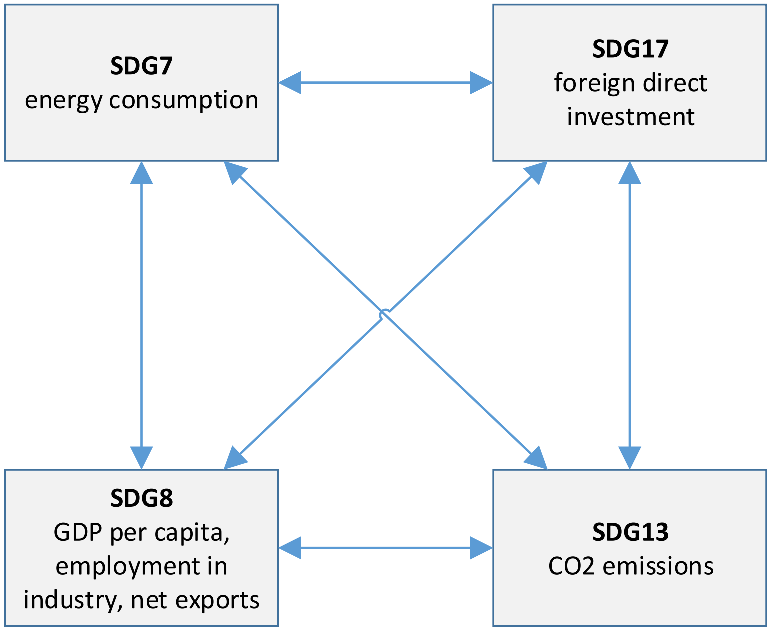


Figure 2: Interactions among SDGs and sustainable development indicators in the model of energy consumption, CO2, and economic development nexus

Similarly, Figure 3 depicts the second nexus model that examines interactions among SDGs from the economic and social pillars. These first two nexus models were designed to model sustainable development interactions at the level of EU countries, while the third model reflects the heterogeneity of the NUTS-2 regions. Specifically, interactions among economic and environmental SDGs are considered, as presented in Figure 4.

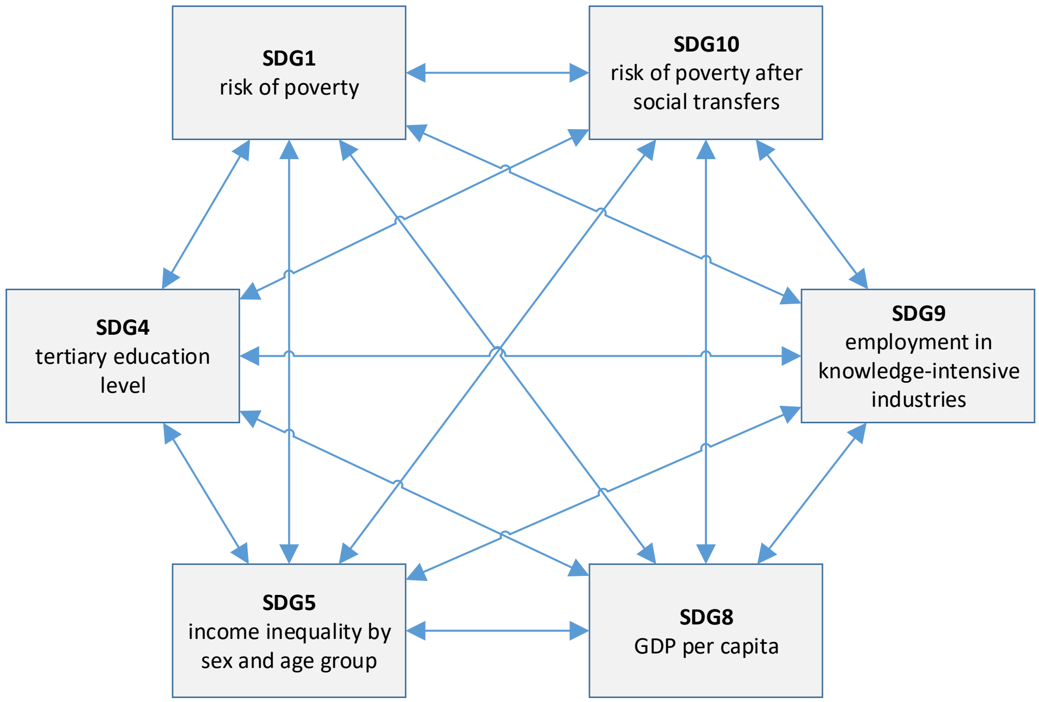


Figure 3: Interactions among SDGs and sustainable development indicators in the model of inequality, economic growth and risk of poverty nexus

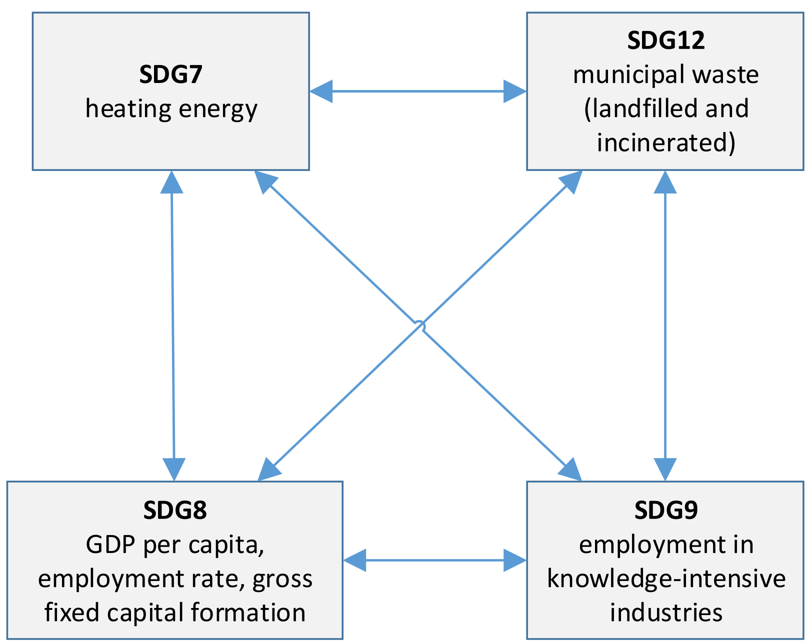


Figure 4: Interactions among SDGs and sustainable development indicators in the model of municipal waste generation, R&D intensity, and economic growth nexus

4.2 Selection of Regions

The concept of "region" has also attracted a lot of philosophical arguments about its connotation. The traditional regional geography perceived it as purely intellectual construct, considering a region to be a total complex unit (Nir, 2012; Semian, 2016). In other words, it is perceived as an interaction between man and his environment. Whereas new regional geographers also regard it as a social construct. For example, like individual marked with identity can form a region, we can also define an administrative region, home as region and political entity as a region (Demeritt, 2002; Kasala & Šifta, 2017). Region is also described as a product of network, communication, juxtaposition and articulate of many interactions through which all social phenomena depend on each other. Moreover, a region is formed from social connections that take place among institutions, group and individual in a range of zone. It is usually stimulated by culture and identity, interaction that exist at different scale levels as well as different hierarchy of society. This relation must be mutual in terms of conditions of rapport which is being the result. Regional formation can also be connected to the vicinity where the region is located. For instance, landscape and specific natural environment obviously sometimes decides and affect both the material as well as the symbol aspect of the regions establishing process (Šifta & Chromý, 2017).

In Europe, new regionalism resurfaced in connection to the development of the regions within EU. This approach of regionalism was based on both political and economic point of view (Hettne, 2005). Also, the EU as a region used it central institutions to promote competitiveness and abridging the gap between the developed and the less developed region to form a region (Bristow, 2010). The EU also supports socio-cultural development of the region, regional development process of globalization together with unification in its formation (Šifta & Chromý, 2017). Comparably and consequently, the impact of the regional integration has placed EU as one of the well-developed regions on the globe.

Here, new and old EU member countries will be assessed on the grounds that some new members are still in a transitional stage of their economic structure and will continue to affect regional societal and environmental development as a result of their rapid economic growth and development. Moreover, old EU member countries (regarded as the West) seemed to have developed their economies earlier than new members. In the same way, the West possesses advanced technology to offset the adverse effect of CO2 and other degradation-related issues. Further, many recent empirical studies have extensively examined both short- and long-run relationships with economic growth-related degradation in the region. However, too little attention has been paid to assessing the causal relationships among those variables concurrently between new and old EU countries. This viewpoint makes the current research an interesting topic that aims to bridge that gap in the literature.

4.3 Econometric Methods

Prior to the analysis of stationary properties of the above sustainable development indicators, it is crucial to investigate the characteristics of the panel time-series data to select the appropriate panel unit root tests. Indeed, the use of traditional panel unit root tests may result in unreliable and inconsistent estimates in the case of cross-sectional dependence and heterogeneity.

To address the problem of inter-dependent observations across sample countries, I investigated the characteristic of error terms using the residual cross-sectional dependence Pesaran test (M. H. Pesaran, 2004). The test uses the scaled average pairwise correlation coefficient statistic, which applies to shorter panel time-series data and smaller numbers of cross-sectional units. Addressing the problem of cross-sectional dependence was essential in this study because the sample countries from which data were gathered were strongly economically interconnected.

Another critical problem to overcome in the case of panel time-series data is the heterogeneity across individual units. To obtain more reliable estimates, econometric approaches to causal modeling assume that the information from the time-series dimension can be selectively pooled with the cross-dimensional information (Blomquist & Westerlund, 2013). In other words, there is an assumption of homogeneity of the parameters (slope coefficients) of interest. To test for this assumption, I used the method for testing slope homogeneity (Blomquist & Westerlund, 2013) that handles the problems of heteroscedasticity and serial correlation in the data (M. H. Pesaran & Yamagata, 2008).

The stationarity properties of the variables were investigated using panel unit root tests robust to the issues of cross-sectional dependence and heterogeneity in the values of autoregressive coefficients. The CIPS (cross-sectionally augmented Im–Pesaran–Shin) panel unit root test (M. H. Pesaran, 2007) was performed, which produces consistent and reliable estimates robust to these issues. This test was also preferred because it allows for heterogeneous autoregressive coefficients. The CIPS test uses separate unit root tests for each cross-section unit and the cross-section average of the CADF (cross-sectionally augmented Dickey-Fuller) across the units, expressed as follows:

$$\Delta X_{i,t} = \alpha_i + \beta_i X_{i,t-1} + \rho_i T + \sum_{j=1}^{N} \theta_{i,j} \Delta X_{i,t-j} + \varepsilon_{i,t}, \tag{1}$$

where Δ denotes the difference operator, T is the time trend, and ρ_i and $\theta_{i,j}$ are coefficients representing time trend and cross-section dependence, respectively.

For variables that are not stationary at levels, reliable long-run parameter estimates must be cointegrated (i.e., the presence of a long-term equilibrium among variables is required). The combined Johansen–Fisher panel cointegration test (Maddala & Wu, 1999) was used to check whether the variables were cointegrated because the test enables detection of more than one cointegrating relationship (R. K. Mishra & Sharma, 2010). This overcomes the main limitation of the traditional residual-based tests.

To investigate the direction of the short- and long-run causality among the six variables, a panel VECM (M. H. Pesaran et al., 1999) was specified in two steps as recommended in earlier studies (Kasman & Duman, 2015). In the first step, panel FMOLS (fully modified ordinary least squares) was used with a weighted panel method to obtain long-term parameter estimates (Pedroni, 2000). FMOLS was used because it is robust to heterogeneity and allows for the correction of simultaneity and residual correlation bias (Dogan & Aslan, 2017; Kasman & Duman, 2015). The panel FMOLS model is given as follows:

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{n} \beta_k X_{i,t}^{k} + \varepsilon_{i,t}, \text{ where} \tag{2}$$

$$\hat{\beta}_{FMOLS}^{*} = \frac{1}{N} \sum_{i=1}^{N} \left[\left(\sum_{t=1}^{T} \left(X_{i,t} - \bar{X}_i \right)^2 \right)^{-1} \left(\sum_{t=1}^{T} \left(X_{i,t} - \bar{X}_i \right) Y_{i,t}^{*} - T \hat{\gamma}_i \right) \right], \tag{3}$$

$$Y_{i,t}^{*} = Y_{i,t} - \bar{Y}_i \quad - (\hat{\Omega}_{2,1,i} / \hat{\Omega}_{2,2,i}) \Delta X_{i,t}, \tag{4}$$

$$\hat{\gamma}_i = \hat{\Gamma}_{2,1,i} + \hat{\Omega}_{2,1,i}^{0} - (\hat{\Omega}_{2,1,i} / \hat{\Omega}_{2,2,i})(\hat{\Gamma}_{2,2,i} + \hat{\Omega}_{2,2,i}), \tag{5}$$

where $i = 1, 2, \ldots, N$ are cross-sectional units, t is time, $t = 1, 2, \ldots, T$, α_i is a constant term, β_k denotes a coefficient of independent variable X^k, $\varepsilon_{i,t}$ is an error term, Ω denotes the covariance matrix, and Γ_i represents the weighted sum of autocovariances.

Lastly, the Granger causality test for panel data was performed to reveal causality among the variables. The Granger causality test only provides evidence of causality among the variables but not the explicit magnitude of the impact from one variable to another. Hence, I used variance decomposition analyses based on the Cholesky decomposition technique (H. H. Pesaran & Shin, 1998) in the VECM to supply the quantitative intensity of the causality among the variables. In other words, I estimated this by employing the impulse response function to map out the intensity of the shock from one endogenous variable to the other. Within the variance decomposition structure, a shock to one variable not only influences that variable but also passes onto all the other endogenous variables in the dynamic structure of the model.

5. Econometric Models

5.1Model of Energy Consumption, CO2, and Economic Development Nexus

5.1.1 Theoretical Background

Over time, the adverse impact of economic growth on environmental quality began to resurface as emissions of CO2 increased coupled with global warming and climate change. This raised concerns among world institutions such as the United Nations Framework Convention on Climate Change, Global Environment Facility, International Union for Conservation of Nature, United Nations Environment Programme and European Environmental Agency as well as many scholars to find the nexus between economic growth, macroeconomic variables and environmental degradation such as CO2 emissions, energy consumption, income, population and foreign direct investment (FDI). Scholars have used different econometric methodologies, time periods and countries/regions to confirm this assertion. Kraft and Kraft (1978) pioneered the topic by determining the causal relationship between energy and gross national product (GNP). The authors found a unidirectional relationship, which implied that the relation runs from GNP to energy consumption, with no relation from energy consumption to GNP. Since then, a number of studies have been conducted to investigate the interactions among energy consumptions, CO2 emissions and economic development (Dogan & Aslan, 2017; M. L. Wang et al., 2020). Recent studies have highlighted the contradictory results obtained in earlier empirical studies owing to the outcomes of some macroeconomic variables and economic growth (Amri, 2017; Mardani et al., 2019). Hence, the topic is creating more curiosity for current and further research. Moreover, many regions globally have not been explored to assess the current trend of these variables and their impact on the environment. Here, I aim to bridge those gaps by assessing the current trend of these indicators as well as their policy implications.

The EU is used as a case study because it has shown much concern about economic growth and environmental quality by minimising the adverse effects of CO2 emissions, GHG and energy consumption on economic growth. Explicit evidence can be drawn from the initiative implemented in 1991 to reduce emissions and improve energy efficiency (European Commission, 2019). Similarly, GHG emissions in Europe, according to Micquel Arias Conte (EU climate head), have also declined to their lowest level from 1990–2014, which is about 23% more than the estimated one-fifth projected for 2020. At the same time, the EU economy grew by 46%. This was declared before the Paris Conference in December 2015. The EU has still set a goal to reduce its emissions and minimise global warming by 2 degrees by the middle of this century while ensuring economic growth. Some researchers challenge the possibility of achieving this goal, believing only that the EU can achieve this if its member countries can reduce their recent emissions by three times the current level. Then, it would be possible to achieve the projected abatement target by 2030 (Neslen, 2015).

Here, I assess new and old EU member countries on the grounds that some new members are still in a transitional stage of their economic structure and will continue to affect regional CO2 as a result of their rapid economic growth and development (Azam, 2016). Moreover, old EU member countries (regarded as the West) seemed to have developed their economies earlier than new members. In the same way, the West possesses advanced technology to offset the adverse effect of CO2 and other degradation-related issues. Further, many recent empirical studies have extensively examined both short- and long-run relationships with economic growth-related degradation in the region (Dogan & Aslan, 2017; Stjepanović, 2018).

The links among economic growth, environmental quality, employment, FDI and net exports are unclear. Earlier works on the economic growth–environmental quality nexus have failed to recognise the effect of employment, FDI and net exports on the economic system. Statistically, a 1% increase in GDP increased employment by 0.21% from 1991 to 2003 (Kapsos, 2006). This signifies that an upsurge in economic growth has a positive effect on employment. An increase in employment also gives rise to consumption and in effect increases pollution in the environment. FDI also assists in the development of human capital, transfer of technology and production of goods and services (McAusland, 2008). By contrast, it tends to contribute 70% of industrial pollution (Melnyk et al., 2014) and other environmental pollution (López-Menéndez et al., 2014). Generally, exports also promote economic growth, especially when specialized in high value-added products such as high-tech manufacturing (Santos et al., 2013). Occasionally, they also induce some countries to specialise in dirty activities (inferior goods or products), which they send abroad without regard for the adverse impact on the environment (McAusland, 2008). Hence, environmental quality is hampered by pollution (air, land and water), compounding the precarious situation of global warming.

Previous empirical studies strongly imply the role of economic development in the nexus between economic growth and environment (Çoban & Topcu, 2013; Tiba & Omri, 2017).

The effects among economic growth, energy consumption, CO2, and FDI as well as the environmental implications have been examined in the related literature (Table 1). Studies have been conducted across countries and regions using different time periods and variables. This section deals with previous works studying those effects.

The world economy depends heavily on energy and the EU is no exception. (Alam et al., 2012) found that energy is the indispensable force driving all economic activities. This implies that the more energy is consumed, the more the economic activities in the nation and thus the increase in economic growth. Researchers have found links between economic growth and energy consumption. For example, (Masih & Masih, 1996) used data from 1955–1990 for six Asian countries, (Asafu-Adjaye, 2000) used data from 1971–1995 for the Philippines and (Dahmardeh et al., 2012) used data from 1980–2008 for 10 Asian developing countries. All these authors used panel cointegration tests to examine the relationship. Overall, their results provide empirical support for the nexus between energy consumption and economic growth. (Farhani & Ben Rejeb, 2012) used data from 1971–2005 to confirm the trend through cointegration, and the results of Granger causality tests showed that GDP contributes to energy consumption in low-income countries. A bidirectional causal relationship between economic growth and energy was also found by (Menegaki & Ozturk, 2013) for 26 European countries over 1975–2009 using a two-way fixed effects model. However, the survey by (Ozturk et al., 2010) on the energy consumption–economic growth nexus highlights that the literature has produced conflicting results, resulting in no consensus on the existence or on the direction of the causality. (Matar & Bekhet, 2015) showed that this causality can be affected by financial development (domestic credit to private sector). A strong relationship between economic growth and energy consumption has recently been found by (Stjepanović, 2018) for 30 European countries using Eurostat data from 1994-2016.

Many studies have empirically examined the nexus between CO2 emissions (environmental pollution) and economic growth using the environmental Kuznets curve hypothesis. Most use CO2 as a dependent variable. For example, (Azomahou et al., 2006) used a non-parametric kernel-based estimator to find the nexus between economic growth and CO2 emissions for a panel of 100 countries from 1960–1996. The results indicated the structural stability of the relationship. Another result from the top 70 countries based on variance decomposition also found a positive relationship between GDP and CO_2 emissions from fossil fuels (Bacon & Bhattacharya, 2007). (Jalil & Mahmud, 2009) used data from 1995–2005 and employed an autoregressive distributed lag approach, providing evidence of a quadratic relationship between income and CO_2 emissions. (Ozturk & Acaravci, 2010) also investigated the long-run causal relationships among economic growth, energy consumption, CO_2 emissions and employment in Turkey using data from 1968–2005 and the autoregressive distribution lag bounds method of cointegration. The results showed that neither energy consumption per capita nor CO_2 emissions causes GDP growth. Yet, the employment ratio was reported to have a causal relation with GDP per capita (Park & Hong, 2013). (Yuan et al., 2010) examined the relation between China's economic growth and energy consumption using grey incidence analyses and data from 1980–2007. The results differed by period, although there was some positive effect on GDP. On the contrary, (Arouri et al., 2012) used panel unit root tests and the cointegration technique to determine the relationship between energy consumption and real GDP for 12 North Africa and Middle Eastern countries from 1981–2005. Their results indicated that there was a significant impact of real GDP on energy consumption and CO_2 emissions. More research on the relationship between GDP and CO_2 emissions can be traced to many other researchers (Saboori et al., 2012). For example, (Zambrano-Monserrate et al., 2016) employed ARDL (Autoregressive distribution lag model) and VECM to explore the links between economic growth and environmental degradation in Brazil using data from 1971-2011. Their results indicate the long-run relationship between CO_2 and economic growth. This finding has recently been confirmed by a systematic meta-analysis (Aye & Edoja, 2017; Mardani et al., 2019) employed a dynamic panel threshold framework to demonstrate that the correlation between CO_2 and economic growth is positive for developed economies (in the high growth regime), whereas negative for developing economies (in the low growth regime).

FDI is made up of a bundle of the technological transfer of capital inflows and knowledge (Balasubramanyam et al., 1996). It can be deduced from this assertion that the contributions of FDI to economic growth are numerous. Other scholars regard its impact as contradictory because it also creates environmental setbacks, as it obstructs the effective allocation of resources and hence economic growth (Boyd & Smith, 1992). Theoretical studies of the positive effect of FDI on economic growth include that of (Marwah & Tavakoli, 2004). They used data from 1979–1998 on Thailand, Malaysia, Indonesia and the Philippines to study the effect of FDI on economic growth, finding a positive correlation in those countries. (Li & Liu, 2005) used single and simultaneous equation techniques and found a growing relationship between FDI and economic growth using panel data from 1970–1999 for 84 countries. The results indicated a positive effect of FDI on economic growth. (Vu et al., 2008) used an augmented production function specification as well as regression methods to study sector-specific FDI inflows for Vietnam and China over 1990–2002. Their conclusion was that FDI has a positive and direct effect on economic growth. Moreover, (Alfaro et al., 2006) employed an extended dataset and found that the same increase in FDI, regardless of the region, generates three times more additional growth in financially well-developed countries than financially poorly developed countries. (Upadhyaya et al., 2007) used panel and generalised least squares methods and found a similar result in his research. In addition, (Matar & Bekhet, 2015) reported a unidirectional causality between FDI and economic growth in Jordan over the period 1976-2011. In contrast, no positive effect of FDI on economic growth was reported by (Bermejo Carbonell & Werner, 2018) for Spain using data from 1984-2010. The negative effect of CO_2 emissions on FDI was observed for Chinese provinces by (M. L. Wang et al., 2020), suggesting that less stringent environmental regulations attract FDI.

Net exports signify the total exports exceeding the total imports of a domestic country. The role of net exports in the economy is significant.(Jiang, 2017) provided evidence of a negative relationship between GDP growth and net exports. In other words, net exports impede economic growth in China. The study by (Subasat, 2002) examined the effect of net exports on economic growth in middle-income countries, finding a positive effect of net exports on economic growth. (Dritsakis, 2004) assessed the relationships among economic growth, net exports and investment in Bulgaria and Romania. He employed a cointegration approach and the results indicated that net exports have a positive effect on GDP. (Akalpler & Shamadeen, 2017) investigated the effect of net exports on economic growth in the US using quarterly data from 1970-2015, suggesting a long-run positive effect. The positive effect of exports on financial development and energy consumption in Jordan was observed by Matar a Bekhet (2015).

Evidence of economic growth promoting employment was found by (Seyfried, 2011). He used some states in the US and data from 1990–2003, finding evidence of the immediate impact of economic growth on employment and showing that its effects continued for several quarters in the states considered. Choi (2007) also used an equilibrium labour market model to assess the employment effect of economic growth and the results indicated that labour supply based on wages is a vital determinant of the employment effect on economic growth. Herman (2011) also investigated the impact of economic growth on employment in EU countries. The results portrayed a problem, particularly in Central and Eastern European countries in that they have a low ability to create employment, whereas their economies keep growing (Herman, 2011). He also suggested that human capital development increases employment and hence contributes to economic growth. Kapsos (2006) assessed how employment intensity varies with economic output or the elasticity of employment using data from 1991 to 2003 for 160 economies (cross-country). His results indicated that every 1% increase in GDP growth raises employment growth by between 0.30% and 0.38%. Overall, the literature suggests a reciprocal effect between economic growth and employment (Burggraeve et al., 2015).

The above literature indicates strong interactions among energy consumption, CO2 and economic development. The strengths and directions of these interactions seem to be related to different economic environments. In order to determine their role in the nexus among energy consumption, CO2 emissions and economic development, it is needed to examine the combined effects of economic development factors in different economic environments.

5.1.2 Econometric Model

Based on the literature and findings in energy economics, it is prudent to form long-run relationships among energy consumption (EC), CO2 emissions, employment (EMP), net exports (NEXP), FDI and economic growth (GDP) in a linear quadratic form to test the validity of the interactions among those variables using a cointegration approach. Considering the recent panel data, the issue of short data span for individual countries was addressed. Hence, the explanatory power of the employed econometric model is improved.

Table 1: List of earlier studies on interactions among studied indicators

Study	Period	Methodology	Country	Causality
(Yu & Jin, 1992)	1974-1990	cointegration, Granger causality	US	EC≠EMP
(B. S. Cheng & Lai, 1997)	1955-1993	cointegration, Granger causality	Taiwan	GDP→EC
(Atici, 2009)	1980-2002	OLS	CEE countries	EC→CO2
(Apergis & Payne, 2010b)	1992-2004	VECM	Commonwealth Independent States' countries	EC↔CO2, GDP→CO2
(Apergis & Payne, 2010a)	1985-2005	panel cointegration, VECM	OECD countries	EMP→GDP, GDP↔EMP
(Jalil & Feridun, 2011)	1953-2006	VECM causality cointegration analyses	China	EC→CO2, FDI→CO2
(Park & Hong, 2013)	1991-2011	Markov switching model	South Korea	GDP↔CO2
(Baek, 2015)	1960-2010	cointegration	Canada, Northern EU countries	EC→CO2, GDP→CO2
(Ajmi et al., 2015)	1960-2010	Granger causality	G-7 countries	Japan: GDP→EC, Italy: GDP→EC, GDP→CO2, Canada: EC→GDP, US: EC→CO2, France: EC→CO2, GDP→CO2
(Kasman & Duman, 2015)	1992-2010	panel cointegration, Granger causality	EU countries	GDP↔CO2, EC↔CO2, EC→GDP
(Matar & Bekhet, 2015)	1996-2011	ARDL, Granger causality	Jordan	GDP→EC, EX→EC, financial development→EC
(Zambrano-Monserrate et al., 2016)	1971-2011	ARDL, cointegration, Granger causality	Brazil	GDP→CO2, EC→CO2
(Işik et al., 2017)	1970-2014	VECM, Granger causality	Greece	GDP→CO2
(Bekhet et al., 2017)	1980-2011	ARDL	Gulf cooperation council countries	EC↔GDP, CO2↔GDP (except UAE)
(Aye & Edoja, 2017)	1970-2013	DPTF	31 developing countries	GDP≠CO2
(Stjepanović, 2018)	1994-2016	PRFE	30 European countries	EC→GDP

Note: ARDL – Autoregressive distribution lag model, BRIC – Brazil, Russia, India and China, CEE – Central and Eastern European countries, CO2 – Carbon dioxide, DOLS – Dynamic ordinary least squares, DPTF – Dynamic panel threshold framework, EC – Energy consumption, EMP – Employment, FMOLS – Fully modified ordinary least squares, GMM – Gaussian mixture model, OLS – Ordinary least squares, PRFE – Panel regression with fixed effects, VECM – Vector error correction model, → unidirectional causality, ↔ bidirectional causality, ≠ no causality.

To investigate the directions of the cointegrating relationships among variables, the short- and long-run Granger causality test is given as follows:

$$\Delta GDP_{i,t} = \alpha_{1,i} + \sum_{j=1}^{q} \beta_{1,1,i,j} \Delta EC_{i,t-j} + \sum_{j=1}^{q} \beta_{1,2,i,j} \Delta CO2_{i,t-j} + \sum_{j=1}^{q} \beta_{1,3,i,j} \Delta FDI_{i,t-j} +$$

$$\sum_{j=1}^{q} \beta_{1,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{1,5,i,j} \Delta NEXP_{i,t-j} + \gamma_{1,i} ECT_{i,t-1} + \varepsilon_{1,i,t}, \quad (6)$$

$$\Delta EC_{i,t} = \alpha_{2,i} + \sum_{j=1}^{q} \beta_{2,1,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{2,2,i,j} \Delta CO2_{i,t-j} + \sum_{j=1}^{q} \beta_{2,3,i,j} \Delta FDI_{i,t-j} + \sum_{j=1}^{q} \beta_{2,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{2,5,i,j} \Delta NEXP_{i,t-j} + \gamma_{2,i} ECT_{i,t-1} + \varepsilon_{2,i,t}, \quad (7)$$

$$\Delta CO2_{i,t} = \alpha_{3,i} + \sum_{j=1}^{q} \beta_{3,1,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{3,2,i,j} \Delta EC_{i,t-j} + \sum_{j=1}^{q} \beta_{3,3,i,j} \Delta FDI_{i,t-j} + \sum_{j=1}^{q} \beta_{3,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{3,5,i,j} \Delta NEXP_{i,t-j} + \gamma_{3,i} ECT_{i,t-1} + \varepsilon_{3,i,t}, \quad (8)$$

$$\Delta FDI_{i,t} = \alpha_{4,i} + \sum_{j=1}^{q} \beta_{4,1,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{4,2,i,j} \Delta EC_{i,t-j} + \sum_{j=1}^{q} \beta_{4,3,i,j} \Delta CO2_{i,t-j} + \sum_{j=1}^{q} \beta_{4,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{4,5,i,j} \Delta NEXP_{i,t-j} + \gamma_{4,i} ECT_{i,t-1} + \varepsilon_{4,i,t}, \quad (9)$$

$$\Delta EMP_{i,t} = \alpha_{5,i} + \sum_{j=1}^{q} \beta_{5,1,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{5,2,i,j} \Delta EC_{i,t-j} + \sum_{j=1}^{q} \beta_{5,3,i,j} \Delta CO2_{i,t-j} + \sum_{j=1}^{q} \beta_{5,4,i,j} \Delta FDI_{i,t-j} + \sum_{j=1}^{q} \beta_{5,5,i,j} \Delta NEXP_{i,t-j} + \gamma_{5,i} ECT_{i,t-1} + \varepsilon_{5,i,t}, \quad (10)$$

$$\Delta NEXP_{i,t} = \alpha_{6,i} + \sum_{j=1}^{q} \beta_{6,1,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{6,2,i,j} \Delta EC_{i,t-j} + \sum_{j=1}^{q} \beta_{6,3,i,j} \Delta CO2_{i,t-j} + \sum_{j=1}^{q} \beta_{6,4,i,j} \Delta FDI_{i,t-j} + \sum_{j=1}^{q} \beta_{6,5,i,j} \Delta EMP_{i,t-j} + \gamma_{6,i} ECT_{i,t-1} + \varepsilon_{6,i,t}, \quad (11)$$

where Δ is the first difference operator, $\beta_{i,j}$ are coefficients representing short-run cointegrating relations, γ_i are coefficients representing long-run cointegrating relations and ECT is the error correction term.

The long-run relationship was also determined by using an error correction test. This operates on the premise that if GDP, energy consumption, CO2 emissions, FDI, employment and net exports are cointegrated, then at least one of the error correction tests contains a negative coefficient and ought to be significantly non-zero. On the contrary, short-run causality is also estimated using the standard Wald test (by testing H_0: $\beta_{i,j}$=0) as well as the lags of each of the explanatory variables in each equation from the VECM.

For instance, when the first null hypothesis of Eq. (6) is accepted, it signifies that energy consumption per capita does not Granger cause GDP per capita in the short run. On the contrary, if the null hypothesis is rejected and the alternative hypothesis in Eq. (6) is accepted, it means that energy consumption per capita can Granger cause GDP per capita. All these are based on the *P*-value. This is also applicable to all the other variables.

5.1.3 Data

For the empirical study, I collected annual time series data from the World Bank database that cover 1990 to 2015. The economic variables used are GDP (measured in millions of current US dollars), energy consumption (measured in millions of kg of oil equivalent per capita), CO2 emissions (measured in millions of metric tons per capita), employment in industry (percentage of total employment), net exports (current US dollars) and FDI (measured as the balance of payments, current US dollars). The sample of EU countries includes Croatia, Czech Republic, Cyprus, Hungary, Poland, Slovakia and Slovenia for the new countries. The old countries comprise Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. Thus, the panel data for the new and old countries consisted of 208 and 390 observations, respectively. The summary statistics of the time series variables are presented in Table 2.

Table 2: Summary statistics of variables (mean ± standard deviation over 1990–2015)

Country	GDP	Energy cons.	CO2	Employm.	Net export	FDI
Austria	35353±10856	3712±294	7.93±0.53	28.42±6.74	716.3±836.1	-602.3±3373.1
Belgium	33330±10086	5359±292	10.39±0.96	24.75±6.53	835.6±452.6	-639.6±3262.6
Bulgaria	3806.3±2629	2528±197	6.39±0.77	33.70±6.11	-223.1±385.3	-283.8±415.2
Croatia	9738±3577	1809±185	4.52±0.53	29.41±5.88	552.8±5343.2	-454.9±1147.9
Cyprus	20548±8132	2122±175	6.83±0.64	22.64±6.54	-345.5±822.7	8.9±2088.8
Czech Rep.	15365±1222	4189±220	11.54±0.94	39.81±5.68	287.9±467.0	-168.3±869.5
Denmark	43285±13330	3546±262	9.76±1.65	22.83±6.59	2472.6±910.3	487.5±891.5
Estonia	10794±5649	4085±667	12.74±1.24	32.31±5.43	4938.8±15945.3	-612.1±6918.7
Finland	34777±11420	6320±473	10.93±1.14	25.03±5.46	1137.7±1117.3	60.4±1287.9
France	31599±8519	4047±171	5.87±0.41	23.95±6.06	-93.2±557.5	455.1±520.9
Germany	33528±8568	4075±159	10.07±0.68	31.60±7.37	1261.1±1179.8	348.4±581.7
Greece	18189±6905	2399±247	7.93±0.71	21.24±5.72	-1526.4±935.8	-44.3±122.9
Hungary	8721±4248	2528±121	5.56±0.55	31.98±5.70	183.8±484.8	-280.3±248.1
Ireland	36553±16711	3194±318	9.56±1.04	24.91±6.34	5309.9±4075.7	614.7±6296.6
Italy	28870±7300	2847±209	7.45±0.61	30.10±6.05	-6330.5±2406.8	162.2±303.1
Latvia	8531±4673	2042±301	3.57±0.56	25.67±6.01	2268.2±11183.6	-12.5±983.3
Lithuania	8572.8±4679	2709±571	4.38±0.51	27.25±6.07	795.6±5218.9	-208.7±1192
Luxembourg	72432±29223	8268±786	22.11±2.93	18.68±8.22	19715±11926	25435±118560
Malta	13416±5073	1986±135	6.16±0.46	27.09±6.15	-16794±21244	-10276±13972
Netherlands	36795±12269	4654±157	10.61±0.29	18.92±5.98	2934.5±1534.6	1157.6±3011.7
Poland	7422±4473	2518±116	8.47±0.57	30.41±6.22	-98.3±221.4	-175.6±116.1
Portugal	15995±5450	2166±254	5.27±0.68	30.74±6.15	-5617.0±5852.7	-116.0±439.0
Romania	4559±3501	1883±228	4.72±0.74	31.12±6.58	-293.0±342.7	-148.3±168.8
Slovakia	9938±6046	3350±207.6	7.17±0.56	37.73±5.45	-136.9±387.0	313.1±1775.9
Slovenia	17707±5497	3286±318	7.51±0.52	36.70±6.95	240.5±651,1	-72.1±3813.2
Spain	22111±7616	2778±307	6.58±0.89	27.53±6.57	-384.5±720.2	180.3±548.2
Sweden	40190±12246	5496±269	5.72±0.48	22.25±6.39	2167.0±961.2	614.0±1406.2
UK	32192±10042	3530±316	8.83±0.79	23.08±7.25	-620.9±462.9	182.1±1221.7

5.2 Model of Inequality, Economic Growth and Risk of Poverty Nexus

5.2.1 Theoretical Background

The issue of ensuring sustainable economic growth and reducing inequality and risk of poverty has become a major goal for development and constitutes the core part of the international sustainable development agenda. This is because inequality and risk of poverty have exacerbated problems such as hunger, illness, and poor sanitation, which not only make people vulnerable to disease but also have harmful effects on social relations and political participation (Mood & Jonsson, 2016). Inequalities in income or an unfair distribution of income affects economic parameters, and the presence of a poverty gap increases social tensions within nations and generates conflicts among nations. In addition, it may lead to poor economic decision making, a lack of educational opportunities, inadequate health care, and it destabilizes entire countries by generating crime, victimization, and social exclusion (Adamkovič & Martončik, 2017; Aue et al., 2016; Dong et al., 2020). The impact of economic growth on the reduction of poverty has been reported to be lessened under such conditions (Škare & Družeta, 2016). Regarding the present-day factors of inequality and risk of poverty, the direction is affected by altered conditions for development cooperation. It is influenced by economic integration, demographic changes, mounting pressures on national resources, global epidemics and changing patterns of disease, a shift of power from the West to emerging economies, and the re-emergence of digital technology (which widens the gap between those who benefit from globalization and those who do not) (Akoum, 2008; Bergh & Nilsson, 2014; Wade, 2004). All these factors are bound to redesign the future for developing and developed countries and regions (Lin et al., 2020).

Much evidence in the literature supports the theory that growth–inequality relationship is real (Voitchovsky, 2005) and that economic growth and the equitable distribution of income are essential for poverty risk reduction (Fosu, 2017; Ho & Iyke, 2018; Ravallion, 2001). The main tenet is that unfavourable income distribution limits the effectiveness of growth policies in reducing poverty risk (Cunguara & Hanlon, 2012; De Magalhães & Santaeulàlia-Llopis, 2018). Inequality in income may cause an absence of basic freedom, as well as opportunity, and this absence is, in turn, considered a major impediment to poverty alleviation (Beker, 2016). Approximately 10 per cent of the wealthiest households in the world possess half of the world’s total wealth, whereas the poorest 40 per cent of the population has less than 3 per cent of the total assets (Keeley, 2015). This demonstrates the magnitude of the gap that exists between the rich and the poor. Several studies have produced causality estimates of the relationships in the model of inequality, growth and poverty risk (Akanbi, 2016; Janvry & Sadoulet, 2000; Khemili & Belloumi, 2018). In addition, for developing countries, empirical evidence suggests that financial development helps in inequality reduction (Sehrawat & Giri, 2018). However, previous work has failed to incorporate the effects of R&D and education into the nexus.

What are the effects of R&D intensity on economic growth, inequality, and risk of poverty? It has been demonstrated that developing countries cannot exploit R&D for economic growth and that middle-income countries have the highest rates of return (Goñi & Maloney, 2017). For low-income countries, this finding indicates the critical role of factors that complement R&D, such as education and the quality of the innovation system. In other words, these countries must have a sufficient absorptive capacity to exploit technological advances. Economies can be stuck in an equilibrium poverty trap if there are nonoptimal dynamics between the R&D intensity and the complementary human capital level (Accinelli & Sanchez Carrera, 2011; Arunachalam & Shenoy, 2017). On the one hand, R&D-intensive industries may have knock-on effects that increase wages and generate jobs in nontradable activities. On the other hand, growth in R&D employment may create tensions by raising the cost of living in the region and thus worsening the precarious situation of nontechnology workers and disadvantaged people (Kemeny & Osman, 2018). Technology was also found to fuel inequality, which in turn could lead to resource depletion and an increase in poverty risk (Mao et al., 2020; Mirza et al., 2019).

There is a consensus among economists that economic growth reduces risk of poverty and inequality increases risk of poverty. Over the last decade, there has been considerable debate on how growth, inequality and risk of poverty interact with each other (Basu & Subramanian, 2020). If it is true that growth reduces poverty risk, then by how much and how fast, for whom, and under what circumstances does this occur? Previous studies have agreed that unfavourable income distribution is associated with a restricted effect of growth on poverty risk reduction (Adams, 2004; Sumner, 2019). As presented in Table 3, empirical evidence suggests that bidirectional causality exists between growth and inequality (Akanbi, 2016; Sehrawat & Giri, 2018). However, the direction of the growth-to-inequality effect depends on the economic development stage; growth increases inequality in low-income countries (Juknys et al., 2017). The bidirectional link between inequality and income / non-income poverty has also been studied, and is usually ascribed to the relationships of the factors to economic growth (Akanbi, 2016).

The results of an empirical study on Malaysia suggested that economic growth was essential for but not sufficient for poverty rate reduction, especially when the goal was rapid poverty rate reduction (Mulok et al., 2012). Similarly, results for Swaziland showed that economic growth did not reduce poverty (measures as consumption per capita); the poverty level was attributed to a high level of income inequality in this country (Nindi & Odhiambo, 2015). Growth was found to have no significant effect on the distribution of income in South Africa, but increased equality was found to promote economic growth (Akanbi, 2016). A bidirectional causality between economic growth and inequality was observed for Tunisia, a finding that suggested that the effect of growth on consumption per capita reduction could be strengthened by reducing inequality (Khemili & Belloumi, 2018).

Note that the concept of monetized and consumption-based poverty traditionally used for developing countries is not suitable for developed countries, such as EU countries. Therefore, the EU definition is based on the proportion of the population living at risk of poverty, this is the share of households whose total equivalized income falls below 60 percent of the median national equivalized household income for the reference year. This measure considers purchasing power standard and relative as there are differences in cost of living and median national equivalised household income across EU countries. Most EU countries experienced risk of poverty being elastic of economic growth (Dudzeviciute & Prakapiene, 2018). More precisely, significant relationships were found between economic growth and risk of poverty in half of the EU countries. Indeed, countries with higher economic level exhibited a relatively low share of population living below the national poverty line. However, the relationship between growth and inequality substantially varied across the EU countries, with economically developed countries showing relatively high income inequality while lower inequality observed for economically weaker EU countries. Furthermore, risk of poverty and inequality tended to move in the same direction in most EU countries (Dudzeviciute & Prakapiene, 2018). Different broad categories of EU countries were detected with different rates of development (Michálek & Výbošťok, 2019). Across the broad categories, economic growth was found to be connected with a decrease in risk of poverty, while risk of poverty increased with higher inequality. Highly developed and emerging EU were studied separately to find opposite effects of GDP on inequality (Soava et al., 2020). This finding is consistent with the Kuznets hypothesis that early economic development tends to increase income inequality, whereas the inequality tends to decrease at a certain level of economic development. For the highly developed EU countries, risk of poverty promoted income inequality, while economic growth decreased income inequality. Inverse effects were obtained for the emerging EU countries (Soava et al., 2020).

Recent evidence revealed that additional factors must be considered in the inequality, growth and risk of poverty model because growth is not a sufficient condition for reducing poverty risk. For EU countries, previous research suggested that government spending (social transfers) reduced risk of poverty, but this effect varied across countries based on their specific sectors of spending (Miežiene & Krutuliene, 2019). This effect also reportedly depended on the ratio between social transfers and the GDP, indicating that an increase in social transfers above a certain threshold did not contribute to poverty risk reduction (da Silva & Andrade, 2016).

Education has also been considered one of the instruments for reducing poverty risk and inequality by increasing the productivity of the poor, allowing vertical mobility, and improving chances to get better-paid jobs (Bourguignon & Morrisson, 1998; Burzynski et al., 2020). In addition, an indirect effect of education on poverty risk was found to be mediated by economic growth (Agasisti & Bertoletti, 2020; Janvry & Sadoulet, 2000). A negative impact of the increase in educational level on the poverty risk level was demonstrated for both EU (Mihai et al., 2015) and OECD countries (Paraschiv, 2017). Education was found to be a possible mediator of the relationship between economic growth and income inequality (Berg et al., 2018). An evolving role of higher education was observed, with increasing returns to education promoting income inequality (A. K. Mishra & Bhardwaj, 2020). Previous studies also suggest that human capital should be developed to ensure an inclusive economic growth (Alia, 2017).

It has been theorized that R&D intensity not only stimulates economic growth but can also contribute to poverty risk reduction by increasing the employment rate (Moretti, 2010) and consumption expenditure (Biru et al., 2020). The findings for cities in the United States indicated that high-technology industries increased wages for workers who did not have college degree, but no real impact was found on poverty rate reduction (N. Lee & Rodríguez-Pose, 2016). Similarly, a positive job multiplication effect was observed for local labour markets in the United Kingdom, but the presence of high-technology industries resulted in lower wages for low-skilled workers and an increase in inequality (N. Lee & Clarke, 2019). The positive role of technology in enhancing the overall quality of life (human development index decomposed into GDP, education and life expectancy) was also demonstrated (R. L. Ibrahim et al., 2021).

Table 3: Summary of previous studies on the model of inequality, growth and risk of poverty

Study	Period	Methodology	Country	Causality
(Mulok et al., 2012)	1970-2009	ARDL bound test, Granger causality test	Malaysia	GDP→Poverty rate
(Akanbi, 2016)	1995-2012	Granger causality test	South Africa	Inequality↔GDP, GDP↔Poverty (income: private household consumption per capita, non-income: human poverty index), Inequality↔Poverty
(Khemili & Belloumi, 2018)	1970-2013	ARDL bound test, Granger causality test	Tunisia	GDP→Consumption per capita, Inequality→ Consumption per capita, Inequality↔GDP
(Nakabashi, 2018)	1980-2015	OLS, DPD model	Brazil	Poverty (proportion of individuals and households living in poverty)→GDP
(Sehrawat & Giri, 2018)	1970-2015	ARDL bound test, Granger causality test	India	GDP→Poverty headcount rate, Financial development→Poverty headcount rate, Inequality↔Poverty headcount rate
(Dudzeviciute & Prakapiene, 2018)	2005-2016	OLS	28 EU countries	GDP→Risk of poverty, GDP↔Inequality, Inequality→Risk of poverty
(Michálek & Výbošťok, 2019)	2005-2015	Growth incidence curve	28 EU countries	GDP→Risk of poverty, Inequality→Risk of poverty
(Soava et al., 2020)	2005-2016	Granger causality test	Highly developed and emerging EU countries	GDP→Inequality, Risk of poverty →Inequality, GDP→Inequality
This study	2000-2018	FMOLS, VECM Granger causality test	old and new EU countries	old EU countries: GDP→Inequality, Inequality→Risk of poverty, R&D↔GDP, R&D→Inequality, R&D→Education, GDP→ Risk of poverty after social transfer new EU countries: Risk of poverty→GDP, Risk of poverty→Inequality, R&D→Risk of poverty, GDP→R&D, Education↔Inequality, Education↔Risk of poverty after social transfer, R&D→Risk of poverty after social transfer, GDP→Risk of poverty after social transfer, R&D→Inequality, R&D→Education

Notes: ≠ no causality, → unidirectional causality, ↔ bidirectional causality, ARDL – autoregressive distribution lag model, DPD – dynamic panel data, FMOLS – fully modified ordinary least squares, OLS – ordinary least squares, and VECM – vector error correction model.

Collectively, earlier research found strong relationships among inequality, economic growth, and risk of poverty. Different strengths of these links can be attributed to varying levels of economic development and social transfers and differing capacities of economies to exploit

R&D and human capital for economic growth. To evaluate these effects on the model of inequality, growth and risk of poverty, I here examined the causal relationships in old and new EU countries. In modeling these effects, the data would likely be subject to cross-sectional dependence and heterogeneity. Therefore, I used appropriate modifications of traditional econometric methods to overcome these problems in the data and produce more consistent results and accurate policy implications for the countries.

5.2.2 Econometric Model

The intense debate hovering around the effects of R&D intensity and human capital on inequality, economic growth and risk of poverty, presented above makes it plausible to assume that there are long-run relationships between these variables. To test the validity of this interaction framework, I developed an econometric model combining the FMOLS and the panel VECM. I wished to detect causalities among the following variables: risk of poverty (POVR), risk of poverty after social transfers (POVRST), inequality (INEQ), economic growth (EG), R&D intensity (R&D), and education (EDU).

The VECM can be defined as follows:

$$\Delta POVR_{i,t} = \alpha_{1,i} + \sum_{j=1}^{q} \beta_{1,0,i,j} \Delta POVR_{i,t-j} + \sum_{j=1}^{q} \beta_{1,1,i,j} \Delta POVRST_{i,t-j} + \sum_{j=1}^{q} \beta_{1,2,i,j} \Delta INEQ_{i,t-j} + \sum_{j=1}^{q} \beta_{1,3,i,j} \Delta EG_{i,t-j} + \sum_{j=1}^{q} \beta_{1,4,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{1,5,i,j} \Delta EDU_{i,t-j} + \gamma_{1,i} ECT_{i,t-1} + \varepsilon_{1,i,t}, \quad (12)$$

$$\Delta POVRST_{i,t} = \alpha_{2,i} + \sum_{j=1}^{q} \beta_{2,0,i,j} \Delta POVRST_{i,t-j} + \sum_{j=1}^{q} \beta_{2,1,i,j} \Delta POVR_{i,t-j} + \sum_{j=1}^{q} \beta_{2,2,i,j} \Delta INEQ_{i,t-j} + \sum_{j=1}^{q} \beta_{2,3,i,j} \Delta EG_{i,t-j} + \sum_{j=1}^{q} \beta_{2,4,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{2,5,i,j} \Delta EDU_{i,t-j} + \gamma_{2,i} ECT_{i,t-1} + \varepsilon_{2,i,t}, \quad (13)$$

$$\Delta INEQ_{i,t} = \alpha_{3,i} + \sum_{j=1}^{q} \beta_{3,0,i,j} \Delta INEQ_{i,t-j} + \sum_{j=1}^{q} \beta_{3,1,i,j} \Delta POVR_{i,t-j} + \sum_{j=1}^{q} \beta_{3,2,i,j} \Delta POVRST_{i,t-j} + \sum_{j=1}^{q} \beta_{3,3,i,j} \Delta EG_{i,t-j} + \sum_{j=1}^{q} \beta_{3,4,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{3,5,i,j} \Delta EDU_{i,t-j} + \gamma_{3,i} ECT_{i,t-1} + \varepsilon_{3,i,t}, \quad (14)$$

$$\Delta EG_{i,t} = \alpha_{4,i} + \sum_{j=1}^{q} \beta_{4,0,i,j} \Delta EG_{i,t-j} + \sum_{j=1}^{q} \beta_{4,1,i,j} \Delta POVR_{i,t-j} + \sum_{j=1}^{q} \beta_{4,2,i,j} \Delta POVRST_{i,t-j} + \sum_{j=1}^{q} \beta_{4,3,i,j} \Delta INEQ_{i,t-j} + \sum_{j=1}^{q} \beta_{4,4,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{4,5,i,j} \Delta EDU_{i,t-j} + \gamma_{4,i} ECT_{i,t-1} + \varepsilon_{4,i,t}, \quad (15)$$

$$\Delta R\&D_{i,t} = \alpha_{5,i} + \sum_{j=1}^{q} \beta_{5,0,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{5,1,i,j} \Delta POVR_{i,t-j} + \sum_{j=1}^{q} \beta_{5,2,i,j} \Delta POVRST_{i,t-j} + \sum_{j=1}^{q} \beta_{5,3,i,j} \Delta INEQ_{i,t-j} + \sum_{j=1}^{q} \beta_{5,4,i,j} \Delta EG_{i,t-j} + \sum_{j=1}^{q} \beta_{5,5,i,j} \Delta EDU_{i,t-j} + \gamma_{5,i} ECT_{i,t-1} + \varepsilon_{5,i,t}, \quad (16)$$

$$\Delta EDU_{i,t} = \alpha_{7,i} + \sum_{j=1}^{q} \beta_{6,0,i,j} \Delta EDU_{i,t-j} + \sum_{j=1}^{q} \beta_{6,1,i,j} \Delta POVR_{i,t-j} + \sum_{j=1}^{q} \beta_{6,2,i,j} \Delta POVRST_{i,t-j} + \sum_{j=1}^{q} \beta_{6,3,i,j} \Delta INEQ_{i,t-j} + \sum_{j=1}^{q} \beta_{6,4,i,j} \Delta EG_{i,t-j} + \sum_{j=1}^{q} \beta_{6,5,i,j} \Delta R\&D_{i,t-j} + \gamma_{6,i} ECT_{i,t-1} + \varepsilon_{6,i,t}, \quad (17)$$

where $\beta_{i,j}$ and γ_i denote short-run and long-run coefficients, respectively; ECT is the error correction term; and j represents the hysteresis length. To further explore the magnitudes of the effects in the VECMs, I applied the variance decomposition method (H. H. Pesaran & Shin, 1998).

5.2.3 Data

This study encompasses the following set of variables: (1) risk of poverty (measured as the at-risk-of-poverty rate, where the at-risk-of-poverty threshold is set at 60 per cent of the national median equivalised disposable income); (2) risk of poverty after social transfers (people at risk of poverty after social transfers); (3) inequality (income quintile share ratio S80/S20 for disposable income by sex and age group; based on the data in the EU Statistics on Income and Living Conditions survey); (4) GDP (real GDP in Euro per capita); (5) R&D intensity (employment in high-technology and medium-high-technology manufacturing and knowledge-intensive services, in percentage of total employment); and (6) education (percentage of the population aged 30 to 34 years who have completed tertiary studies).

For the empirical experiments, I used panel time-series data for old and new EU countries from 2000 to 2018 obtained from the Eurostat database. To replace missing data and reach more valid conclusions, a multiple imputation method was employed in the IBM SPSS Statistics 25 program environment. More precisely, linear regression was used to produce five parameter estimates and then these estimates were pooled to obtain the final parameter estimates. This study considered 15 old EU countries, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom, and 13 new EU countries, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia. In total, the data for the new and old EU countries were comprised of 247 and 285 observations, respectively.

Following previous studies (Akanbi, 2016; Sehrawat & Giri, 2018), I converted all of the variables (except for those measured in percentages) using logarithmic transformation to reduce heteroscedasticity. Another advantage of this transformation is that the coefficients of the models can be interpreted as the elasticities of dependent variables with respect to independent variables. Figure 5 depicts the yearly averages from 2000 to 2018 in both country samples.

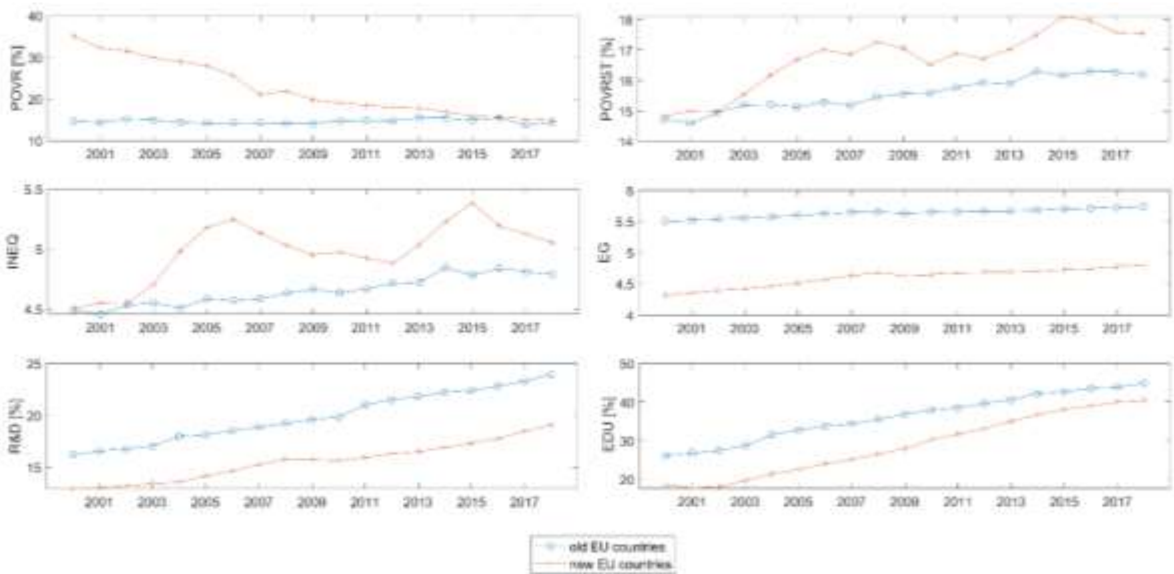


Figure 5: Yearly averages of variables in the model

5.3 Model of Municipal Waste Generation, R&D Intensity, and Economic Growth Nexus

5.3.1 Theoretical Background

It is becoming increasingly difficult to ignore the impact of economic growth on waste generation and environmental degradation. This is due to the adverse effects that waste generation has on health, environmental, and socio-economic conditions, as well as its contribution to climate change (Mor et al., 2006; Uddin et al., 2017). Recent population growth and development of cities and regions are coupled with an increase in consumption, which, owing to the large quantity of generated waste, placed increased pressure on resources and the environment. One consequence of this concern was the 1999 World Bank report (Hoornweg, Daniel, Laura Thomas, 1999). Previous studies revealed that annual global waste generation has reached approximately 17 billion tonnes, which is estimated to increase to 27 billion by 2050 (Karak et al., 2012). Moreover, world urban centres generate approximately 2 billion tonnes per year, which is expected to hit 3.4 billion by 2050 (Kaza et al., 2018). Notably, only 33% of waste is managed in an environmentally favourable way. Currently, waste generation and its improper management leads to production of 1.6 billion tonnes of CO_2 emissions, which implies adverse effect on air pollution worldwide. The cost of solid waste management is likely to increase from the current level of 205 billion USD to 376 billion by 2025 (Hoornweg & Bhada, 2012).

As the economies of EU countries continue to grow, the EU has to deal with waste generation problems. Currently, the EU ranks second among the world's regions, with 392 million tonnes of municipal solid waste (Kaza et al., 2018). In the EU, the production of municipal solid waste has steadily increased over the last 20 years (Traven et al., 2018). To reduce the adverse effects of municipal waste on the environment via promotion of a circular economy, the EU introduced the 7th Environmental Action Plan (EAP) in 2014. The EAP insists that by managing solid waste to at least 65% at present will help attain the objective of "zero waste emission" by 2030 (Cecere & Corrocher, 2016). To achieve the identified key objectives, the appropriate measures must be implemented, such as stimulating development of new technologies and sustainable business models and promoting sustainable patterns of resource usage. Moreover, the responsibility of meeting new requirements, including the establishment of adequate sustainable waste management infrastructure and collection / sorting systems for different waste streams, has increasingly been delegated to regions and municipalities (Hansen et al., 2002). The strong dependence of waste management tools on local conditions, such as energy systems and waste composition, has also been reported in the literature (Laurent et al., 2014). Indeed, waste performance reportedly reflects the differences in decisions made by regional waste management (Rogge et al., 2017). Local and regional specific conditions should therefore be considered when modelling the economic and environmental impact of waste generation (J. Cheng et al., 2020).

Previous studies identified a long-run cointegrating relationship between waste generation and GDP per capita (Richard Gardiner & Hajek, 2020; Gui et al., 2019; M. L. Song et al., 2013; T. Song et al., 2008), which provides additional support to the environmental Kuznets curve hypothesis. A significant effect of GDP on municipal waste generation was also demonstrated for nine of thirteen solid waste streams in ten EU countries (Namlis & Komilis, 2019). Recent findings also suggest that different regional economic environments significantly affect the link between economic growth and environmental quality (R. Gardiner & Hajek, 2020). For example, an increase in production factors (employment and capital) contribute not only to production and consumption but also to industrial pollution (Alam et al., 2011). Unemployment rate was another factor significantly correlated with solid waste generation (Namlis & Komilis, 2019). The effects of these socio-economic determinants have also been confirmed for Turkey (Ceylan, 2020). Recent findings also suggest that the implementation of waste management policies, such as waste charging, may reduce municipal waste generation (J. Cheng et al., 2020). The implementation of the "zero emissions" concept not only radically reduced waste levels but also contributed to job creation, especially in less developed regions (Pauli, 2017). In 28 EU member countries, both employment and gross fixed capital formation were shown to be significant inputs of waste generation and economic growth efficiency (Halkos & Petrou, 2019). The unidirectional effect of gross fixed capital formation on waste generation in EU regions has also been confirmed (R. Gardiner & Hajek, 2017). Moreover, the impact of R&D intensity on waste generation is believed to be crucial because science and technology help address many environmental issues (Voulvoulis & Burgman, 2019). Although technology helps to reduce environmental pollution, more resources (including production factors) and energy are required. Technology solutions may also produce waste through filters or dilution (Kuehr, 2007). Consequently, although most of the waste generated in the EU is treated by various technologies, the recovery rate exhibits a slow pace (Reuter et al., 2013). On the one hand, waste generation is reported to be an important determinant in the renewable energy-GDP nexus (Ohler & Fetters, 2014). On the other hand, existing waste-to-energy facilities operate at relatively low heat recovery efficiency, and efficient incineration capacities are regionally concentrated in the EU (Persson & Münster, 2016). Moreover, recent evidence shows that the number of technological innovations in the waste management sector has stagnated (Hollins et al., 2017).

The last decade has witnessed an increasing attention to the investigation of economic growth–waste generation nexus. Over the last decade, more attention has been paid to the investigation of the nexus between economic growth and waste generation. Table 4 shows that different variables over different time periods have been investigated across several countries. This section provides a review of previous literature regarding this relationship and provides theoretical support for the investigation of other waste generation effects, such as the relationship between waste generation, energy consumption, technology, and factors of production.

Initial studies of these postulated relationships assumed that the direction of causality ran from GDP to solid waste generation (Inglezakis et al., 2012; Mazzanti & Zoboli, 2009; Sjöström & Östblom, 2010). Notably, for all four EU countries investigated, a disassociation trend between waste generation and their economic growth was observed (Inglezakis et al., 2012). No significant relationship between urbanization of the Vuad region in Switzerland and municipal solid waste consumption was found (Jaligot & Chenal, 2018). By contrast, increased urbanization reportedly promotes municipal solid waste generation (J. Cheng et al., 2020). An inverted U-shaped link between economic development and waste production for the Lombardy region was confirmed (Ercolano et al., 2018). Additionally, the direction of causality between GDP and CRW (combustible renewables and waste) consumption was examined for countries of North Africa using Granger causality tests (Ben Jebli & Ben Youssef, 2015). The results indicated that the consumption of CRW promotes economic output of the countries, while reducing their CO2 emissions. These positive effects of CRW consumption were confirmed for Tunisia using the ARDL model (Ben Jebli, 2016; Ben Jebli et al., 2015; Ben Jebli & Belloumi, 2017). A long-run bidirectional causality was identified between GDP and CRW consumption in Brazil (Ben Jebli & Ben Youssef, 2019).

In addition to economic growth, other effects of economic development have been investigated in previous research. The impact of consumption patterns on municipal waste generation in Chinese provinces was explored, which showed that developing regions generate more waste than developed regions (Jinhui Liu et al., 2019). Socio-economic variables and waste management policy were also found to be significant determinants of solid waste generation (Grazhdani, 2016). Other significant factors that impact generation of solid waste include the education level of the population (a demographic factor) and the age of buildings (an economic factor). Economic growth and policy incentives have also been shown to be effective means of reducing waste production. Furthermore, larger and more densely populated cities have higher waste generation rates (Prades et al., 2015). In Taiwan, differences in the composition of municipal solid waste at the regional level have been confirmed, which shows that these differences can be attributed to the level of urbanization and industrialization (Y. C. Chen, 2018).

On the one hand, the rapid acceleration of technological innovation reduces the life span of products, thus increasing the generation of waste. For example, toxicity from mobile phones waste has increased due to technological innovations (Y. Chen et al., 2018). On the other hand, over the last two decades, environmentally-friendly technological innovation has been promoted (Gu et al., 2019; Norberg-Bohm, 1999). This has resulted in several positive outcomes, including reusable products and increased energy efficiency. However, new recycling policies must be implemented in order to deal with diverse waste streams and landfills (Dzombak et al., 2019). Previous studies demonstrated the role of R&D intensity in stimulating economic growth (M. W. Zafar et al., 2019). Notably, increased R&D intensity had a positive effect on decoupling economic growth from CO_2 emission in BRICS countries (Q. Wang & Zhang, 2020).

Table 4: Summary of previous studies on the relationship between waste generation / consumption and economic development

Study	Period	Methodology	Country	Causality
(Mazzanti & Zoboli, 2009)	1995-2005	dynamic based panel analysis	EU	GDP→MW
(Sjöström & Östblom, 2010)	2006	CGE	Sweden	GDP→MW
(Inglezakis et al., 2012)	2000-2013	decoupling analysis	Romania, Slovenia, Greece and Bulgaria	GDP≠MW
(Ben Jebli & Ben Youssef, 2015)	1971-2008	Granger causality, DOLS, FMOLS	North Africa	CRW→GDP
(Ben Jebli et al., 2015)	1990-2010	ARDL	Tunisia	CRW→ CO2 GDP↔CRW
(Ghazi Alajmi, 2016)	1980-2012	OLS	Saudi Arabia	GDP→MW
(Ben Jebli, 2016)	1990-2011	ARDL	Tunisia	health→CRW CRW→ CO2
(Ben Jebli & Belloumi, 2017)	1980-2001	ARDL	Tunisia	GDP→CO2 CRW→CO2
(Jaligot & Chenal, 2018)	1996-2015	GLS	Switzerland	Urbanization≠MW
(Ben Jebli & Ben Youssef, 2019)	1980-2013	ARDL	Brazil	GDP↔CRW
(Namlis & Komilis, 2019)	2008-2015	PCA, OLS	10 EU countries	GDP→MW, HDI→MW, UR→MW
(J. Cheng et al., 2020)	2003-2016	STIRPAT	China	WCP→MW, GDP→MW, Urbanization→MW, STI→MW
This study	2000-2018	panel VECM, Granger causality	NUTS-2 EU regions	regions in old EU countries: GDP↔MW, EMP↔MW, GFC↔MW, HE↔MW, R&D→MW (short run) GDP↔MW, HE↔MW, EMP↔MW, R&D↔MW, GFC→MW (long run) regions in new EU countries: GDP↔MW, EMP↔MW, HE↔MW, MW→R&D, MW→GFC (short run) GDP↔MW, HE↔MW, R&D↔MW, EMP↔MW, GFC→MW (long run)

Notes: ARDL – autoregressive distribution lag model, CGE – computable general equilibrium model, CO2 – carbon dioxide, CRW – combustible renewables and waste, DOLS – dynamic ordinary least squares, EMP – employment in industry, FMOLS – fully modified ordinary least squares, GFC – gross fixed capital formation, GLS – generalized least square, HDI – human development index, HE – heating energy, MW – municipal waste, PCA – principal component analysis, STI – share of tertiary industry, STIRPAT – stochastic impact by regression, UR – unemployment rate, VECM – vector error correction model, WCP – waste charging policy, and ≠, → and ↔ denote no causality, unidirectional and bidirectional causality, respectively.

Energy production from waste has received considerable attention as a result of the energy crises in the 1980s. Total energy cost can be significantly reduced if energy from waste is used ("waste to heat") (Chae et al., 2010; Jouhara et al., 2018). By substituting energy that is otherwise generated from natural resources, waste to power generation also reduces CO2 emissions (Manente & Fortuna, 2019; Takaoka et al., 2011). Regarding the economic factors of production, improved recycling and composting policies promote sustainable job creation. At the same time, the employment level and other socio-economic determinants contribute to waste generation (Sankoh et al., 2014).

Collectively, previous studies found strong relationships between waste generation, technology innovation, energy consumption, and economic development. Different strengths and directions of these relationships can be attributed to specific local conditions and regional heterogeneity.

5.3.2 Econometric Model

The literature review presented above and theoretical background indicate that there are relationships between MW (including MW landfilled - LFMW and MW incinerated - INMW), GDP, R&D, HE, EMP, and GFC. To test the validity of these relationships, I proposed a framework integrating panel cointegration approach and panel VECM in order to identify Granger causality. Note that the large number of observations in the two data sets ensures the robustness of the model and good explanatory power; thus, the problem of a relatively short data span was adequately addressed.

Prior to the analysis of the panel data, cross-sectional dependence in the panel data was investigated to overcome the problem of inter-dependent observations. This is important because the underlying data encompasses neighbouring and economically connected regions. Therefore, the residual cross-sectional dependence test (M. H. Pesaran, 2004) was performed. The Pesaran cross-sectional dependence test is based on a scaled mean value of pairwise correlation coefficients of the residuals. Compared to the Lagrange Multiplier (LM) statistic, the Pesaran cross-sectional dependence test overcomes the problem of a short data span and small number of cross-section units. The cross-sectional dependence test is shown as follows:

$$Y_{i,t} = \alpha_i + \beta_i' X_{i,t} + \varepsilon_{i,t}, \tag{18}$$

where $Y_{i,t}$=[MW (LFMW, INMW), GDP, R&D, HE, EMP, GFC], i is the i-th cross-section unit, $i = 1, 2, \dots, N$, t denotes time, $t = 1, 2, \dots, T$, α_i is a constant term, β_i' is a slope term, and $\varepsilon_{i,t}$ is an identically and independently distributed error term.

The panel-based short- and long-run Granger causality test was used to explore the bidirectional causality among the variables. The first step of this procedure uses OLS to estimate the residual of the vector autoregressive model, which calculates the long-run coefficients of the model. The respective error correction model can be defined as follows:

$$Y_{i,t} = \alpha_i + \sum_{j=1}^{q} \pi_j X_{i,t-j} + \varepsilon_{i,t}, \tag{19}$$

where $Y_{i,t}$=[MW (LFMW, INMW), GDP, R&D, HE, EMP, GFC], i denotes the index for region, $i = 1, 2, \dots, N$, and π_j are coefficients representing cointegrating relationships. The rank of two statistics, maximum eigenvalue statistics and the Fisher trace, was used to determine the number of cointegration vectors among the underlying variables. It should be noted that if the combined Fisher-Johansen panel cointegration test indicates that the variables are cointegrated, there may exist short- or long-run causal relationships among the variables.

Then, the residual is used to estimate the short-run error correction model. The Granger causality models are defined as follows:

$$\Delta MW_{i,t} = \alpha_{1,i} + \sum_{j=1}^{q} \beta_{1,1,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{1,2,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{1,3,i,j} \Delta HE_{i,t-j} + \sum_{j=1}^{q} \beta_{1,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{1,5,i,j} \Delta GFC_{i,t-j} + \gamma_{1,i} ECT_{i,t-1} + \varepsilon_{1,i,t}, \tag{20}$$

$$\Delta LFMW_{i,t} = \alpha_{2,i} + \sum_{j=1}^{q} \beta_{2,1,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{2,2,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{2,3,i,j} \Delta HE_{i,t-j} + \sum_{j=1}^{q} \beta_{2,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{2,5,i,j} \Delta GFC_{i,t-j} + \gamma_{2,i} ECT_{i,t-1} + \varepsilon_{2,i,t}, \tag{21}$$

$$\Delta INMW_{i,t} = \alpha_{3,i} + \sum_{j=1}^{q} \beta_{3,1,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{3,2,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{3,3,i,j} \Delta HE_{i,t-j} + \sum_{j=1}^{q} \beta_{3,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{3,5,i,j} \Delta GFC_{i,t-j} + \gamma_{3,i} ECT_{i,t-1} + \varepsilon_{3,i,t}, \tag{22}$$

$$\Delta GDP_{i,t} = \alpha_{4,i} + \sum_{j=1}^{q} \beta_{4,1,i,j} \Delta MW_{i,t-j} + \sum_{j=1}^{q} \beta_{4,2,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{4,3,i,j} \Delta HE_{i,t-j} + \sum_{j=1}^{q} \beta_{4,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{4,5,i,j} \Delta GFC_{i,t-j} + \gamma_{4,i} ECT_{i,t-1} + \varepsilon_{4,i,t}, \tag{23}$$

$$\Delta R\&D_{i,t} = \alpha_{5,i} + \sum_{j=1}^{q} \beta_{5,1,i,j} \Delta MW_{i,t-j} + \sum_{j=1}^{q} \beta_{5,2,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{5,3,i,j} \Delta HE_{i,t-j} + \sum_{j=1}^{q} \beta_{5,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{5,5,i,j} \Delta GFC_{i,t-j} + \gamma_{5,i} ECT_{i,t-1} + \varepsilon_{5,i,t}, \tag{24}$$

$$\Delta HE_{i,t} = \alpha_{6,i} + \sum_{j=1}^{q} \beta_{6,1,i,j} \Delta MW_{i,t-j} + \sum_{j=1}^{q} \beta_{6,2,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{6,3,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{6,4,i,j} \Delta EMP_{i,t-j} + \sum_{j=1}^{q} \beta_{6,5,i,j} \Delta GFC_{i,t-j} + \gamma_{6,i} ECT_{i,t-1} + \varepsilon_{6,i,t}, \tag{25}$$

$$\Delta EMP_{i,t} = \alpha_{7,i} + \sum_{j=1}^{q} \beta_{7,1,i,j} \Delta MW_{i,t-j} + \sum_{j=1}^{q} \beta_{7,2,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{7,3,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{7,4,i,j} \Delta HE_{i,t-j} + \sum_{j=1}^{q} \beta_{7,5,i,j} \Delta GFC_{i,t-j} + \gamma_{7,i} ECT_{i,t-1} + \varepsilon_{7,i,t}, \tag{26}$$

$$\Delta GFC_{i,t} = \alpha_{8,i} + \sum_{j=1}^{q} \beta_{8,1,i,j} \Delta MW_{i,t-j} + \sum_{j=1}^{q} \beta_{8,2,i,j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q} \beta_{8,3,i,j} \Delta R\&D_{i,t-j} + \sum_{j=1}^{q} \beta_{8,4,i,j} \Delta HE_{i,t-j} + \sum_{j=1}^{q} \beta_{8,5,i,j} \Delta EMP_{i,t-j} + \gamma_{8,i} ECT_{i,t-1} + \varepsilon_{8,i,t}, \tag{27}$$

where $\beta_{i,j}$ and γ_i are coefficients that represent short- and long-run cointegrating relationships, respectively, j is the hysteresis length, and ECT represents the error correction term. The optimal lag length was determined based on two criteria; the Schwarz criterion (SC) and the modified Akaike information criterion (AIC). The error correction test is based on the assumption that if the underlying variables are cointegrated, the coefficient is negative and significantly non-zero.

5.3.3 Data

This empirical study is based on the following indicators: (1) municipal waste (MW) generation (measured in tonnes per capita), (2) GDP (in EUR per capita), (3) R&D intensity (measured by employment levels in technology and knowledge-intensive sectors), (4) heating energy (HE) (measured using the heating degree day index), (5) employment (EMP) rate (in %), and (6) gross fixed capital (GFC) formation (thousands of EUR per capita). The MW variable encompasses waste generated by households and small enterprises. To demonstrate the effects of two predominant MW disposal methods – namely, landfilling and incineration – I also considered MW landfilled (LFMW in tonnes per capita) and MW incinerated (INMW in tonnes per capita), respectively. The selection of technology and knowledge-intensive sectors is based on R&D intensity (R&D expenditure/value added). The heating degree day index is a proxy for the heating energy requirements of buildings. As was done in related studies (Gui et al., 2019), logarithmic transformation was performed on all variables to reduce heteroscedasticity, except for EMP, since it is measured as a percentage.

The data corresponding to the aforementioned variables were collected from the Eurostat database for regions, from 2000 to 2018. First, a multiple imputation technique was performed in IBM SPSS Statistics 25 to replace missing values in the data. The sample was comprised of 284 NUTS-2 (Nomenclature of Territorial Units for Statistics) regions (226 from old EU member countries and 58 from new EU members). Old EU member countries included Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherland, Portugal, Spain, Sweden, and the United Kingdom, while the set of new EU member countries included Bulgaria, the Czech Republic, Croatia, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovenia, and Slovakia. In total, the panel data covered 4,294 and 1,102 observations from the old and new EU countries. The yearly mean values for both sets of samples are presented in Figure 6.

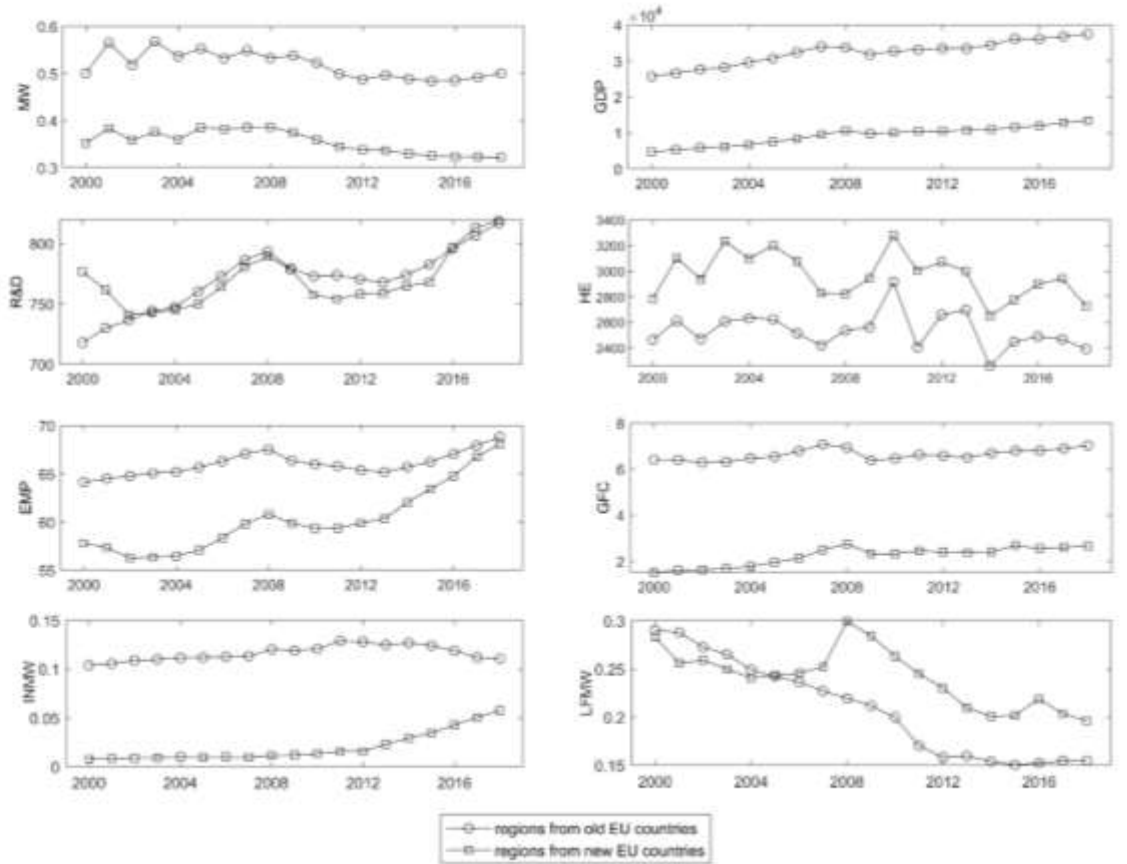


Figure 6: Yearly mean values of all variables

Significant differences can be observed for municipal waste generation, waste disposal methods, heating energy requirements, and the level of economic development between the two categories of regions. This was also confirmed by the statistical description of the data shown below (Table 5).

Table 5: Basic descriptive statistics of the data

Variable	Obs.	Mean	Max.	Min.	Std. Dev.
regions of old EU countries					
MW	4,294	0.518	10.142	0.084	0.227
LFMW	4,294	0.209	0.840	0.000	0.174
INMW	4,294	0.117	0.630	0.000	0.124
GDP	4,294	32,310	231,185	3,177	22,674
R&D	4,294	769.8	5,426.8	13.3	677.2
HE	4,294	2,535	6,985	20	920
EMP	4,294	66.0	83.0	38.9	8.0
GFC	4,294	6.63	90.19	0.33	5.63
regions of new EU countries					
MW	1,102	0.355	0.922	0.107	0.115
LFMW	1,102	0.241	0.684	0.000	0.121
INMW	1,102	0.020	0.337	0.000	0.034
GDP	1,102	9,300	39,037	1,300	5,827
R&D	1,102	769.3	1,911.3	143.0	384.3
HE	1,102	2,967	4,633	322	648
EMP	1,102	60.2	76.6	45.0	6.4
GFC	1,102	2.23	11.60	0.14	1.60

6. Empirical Results

6.1 Model of Energy Consumption, CO2, and, Economic Development Nexus

6.1.1 Cross-sectional Dependence and Unit Root Tests

Table 6 reports the results of the residual cross-sectional dependence test using three statistics, namely Breusch-Pagan LM, Pesaran scaled LM and Pesaran cross-sectional dependence (CD). The results indicate the presence of cross-sectional dependence (the cross-sectional independence is strongly rejected at *P*=0.01). To handle the cross-sectional dependence, I tested for the unit root of the variables using the CIPS test.

Table 6: Results of residual cross-sectional dependence tests

Test statistic	15 old EU countries	8 new EU countries
Breusch–Pagan LM	1069.77***	152.69***
Pesaran scaled LM	65.54***	19.24***
Pesaran CD	31.53***	8.78***

Note: *** indicates significance at *P*=0.01.

The outcomes of the test are presented in Table 7 and Table 8. The results show that all the variables are non-stationary (with or without trend) at the level of *P*=0.05 critical value. Except FDI, which was stationary, the rest of the variables became stationary after the first difference. In other words, they were cointegrated. To estimate if there is cointegration among the variables, I employed the combined Fisher-Johansen panel multivariate cointegration test. Before performing the test, I chose the optimum lag length necessary for the cointegration test. Based on the minimum AIC and SC through the estimation of the unconstrained VAR (vector autoregression) model for the first difference of the six variables under study, a lag length equal to three was obtained. At this point, it was assumed that the data contained deterministic trends but the cointegration equations included intercepts. I selected this design because the unit root test of the six variables exhibited no common deterministic trend. Therefore, the cointegration rank of the variables was estimated by means of the maximum eigenvalue and trace test statistics.

Table 7: Results of cross-sectional panel unit root test for old EU countries

	CIPS (without trend)			CIPS (with trend)		
Variable	lags=0	lags=1	lags=2	lags=0	lags=1	lags=2
GDP	1.75	-1.98**	-1.13	2.83	-0.80	-0.24
EC	-2.35***	-0.86	0.85	-1.93**	-0.98	1.55
CO2	-0.84	-0.06	0.21	-1.41*	0.99	1.27
FDI	-9.74***	-4.71***	-1.19	-9.12***	-4.29***	-0.65
EMP	0.20	-0.97	0.46	2.38	2.26	4.25
NEXP	1.87	3.49	2.57	4.07	5.29	4.99
Δ GDP	-5.93***	-4.78***	-3.72***	-3.96***	-2.81***	-2.73***
Δ EC	-11.80***	-8.80***	-2.38***	-9.54***	-6.62***	-0.79
Δ CO2	-13.85***	-6.26***	-1.70**	-12.55***	-5.03***	-0.30
Δ FDI	-16.64***	-13.44***	-7.62***	-15.63***	-11.57***	-5.66***
Δ EMP	-9.74***	-4.50***	-1.00	-9.13***	-3.73***	-0.79
Δ NEXP	-8.60***	-1.59*	1.04	-7.68***	-0.20	2.78

Note: * indicates significance at P=0.10, ** at P=0.05 and *** at P=0.01.

Table 8: Results of cross-sectional panel unit root test for new EU countries

	CIPS (without trend)			CIPS (with trend)		
Variable	lags=0	lags=1	lags=2	lags=0	lags=1	lags=2
GDP	-3.80***	-3.81***	-1.85**	-0.24	0.24	0.64
EC	-2.08**	-2.08**	-2.07**	-1.16	0.37	0.37
CO2	-1.61*	-0.50	0.53	-2.86***	-4.66***	0.08
FDI	-7.50***	-5.28***	-3.00***	-7.68***	-6.30***	-2.04**
EMP	-2.26**	-0.31	-0.75	-2.21**	0.35	-0.90
NEXP	1.85	3.17	2.83	0.17	1.41	1.93
Δ GDP	-6.27***	-3.23***	-0.62	-6.16***	-2.63***	-0.04
Δ EC	-10.30***	-3.77***	-2.20**	-10.26***	-3.46***	-1.51*
Δ CO2	-8.59***	-7.70***	-3.88***	-7.94***	-6.01***	-2.95***
Δ FDI	-11.31***	-10.11***	-5.18***	-10.83***	-9.74***	-3.66***
Δ EMP	-10.09***	-3.33***	-4.80***	-9.29***	-2.42***	-3.80***
Δ NEXP	-9.26***	-3.96***	-3.03***	-9.13***	-3.66***	-1.71**

Note: * indicates significance at P=0.10, ** at P=0.05 and *** at P=0.01.

The outcome of the combined Fisher-Johansen panel cointegration test is shown in Table 9. The null hypothesis here is no cointegration. For the old EU countries and no cointegrating equations (no. of CEs = 0), the value of the trace test was equal to 716.1 and that of the maximum eigenvalue test was 645.1. Therefore, the null hypothesis $r_0 \leq 0$ was rejected at both P=0.05 and

P=0.01. The null hypothesis $r_0 \leq 1$ was also rejected at P=0.05 and P=0.01, with a trace test value of 338.0 and a maximum eigenvalue test of 184. Similarly, the null hypotheses $r_0 \leq 2$, $r_0 \leq 3$ and $r_0 \leq 4$ were rejected at P=0.05.

Table 9: Results of combined Fisher-Johansen panel cointegration test

	15 old EU countries		8 new EU countries	
no. of CEs	Fisher stat. (trace)	Fisher stat. (max. eigenvalue)	Fisher stat. (trace)	Fisher stat. (max. eigenvalue)
none	716.1***	645.1***	298.1***	177.4***
at most 1	338.0***	184.5***	151.8***	90.27***
at most 2	178.8***	97.5***	78.31***	41.82***
at most 3	106.0***	72.0***	46.26***	33.28***
at most 4	66.6***	52.6	25.81*	17.58
at most 5	72.2***	72.2***	31.40***	31.40***

Note: * indicates significance at P=0.10, *** at P=0.01.

The same analyses were applied to the outcomes of the eight new EU countries. The combined Fisher-Johansen panel cointegration test provided five cointegrating equations at P=0.01. Hence, this shows the existence of a cointegration relationship between GDP (economic growth) and energy consumption, CO2 emissions, employment, FDI and net exports. Summing up the results of this test, support was provided for the long-term relationships among the six variables for both old and new EU countries.

6.1.2 Causality Tests

The results of the FMOLS method for the models represented by Eq. (2) are reported in Table 10 and Table 11. For the 15 old EU countries, the main results indicate positive and significant long-run bidirectional relationships between (1) GDP and energy consumption, (2) energy consumption and CO2 emissions, (3) employment and CO2 emissions, (4) net exports and CO2 emissions, and (5) GDP and net exports. The results further indicate that there is a negative relationship between GDP and CO2 emissions. However, given the poor explanatory power of the FMOLS model for FDI, strong inferences could not be drawn for FDI determinants. A similar problem arises in the FDI and net export models for the eight new EU countries (Table 11). The results in Table 11 indicate that there is a positive and significant relationship between energy consumption and CO2 emissions.

Table 10: Panel FMOLS results for old EU countries

	dependent variable					
indep. variable	GDP	EC	CO2	FDI	EMP	NEXP
GDP		0.0077***	-2.32E-05***	-0.3233	-0.0003***	0.2019***
EC	15.42***		0.0024***	14.55*	-0.0011	-3.69***
CO2	-3988.3***	249.4***		-4724.3*	1.17***	1023.5***
FDI	-0.0171	0.0004	-2.33E-07		-1.99E-05**	-0.0064
EMP	-801.90***	-3.01	0.0212**	-805.4**		13.00
NEXP	1.46***	-0.01***	3.63E-05**	0.42	0.0003***	
R^2	0.750	0.983	0.974	0.037	0.473	0.803
Adj. R^2	0.736	0.982	0.972	-0018	0.443	0.793

Note: * indicates significance at P=0.10, ** at P=0.05 and *** at P=0.01.

Table 11: Panel FMOLS results for new EU countries

	dependent variable					
indep. variable	GDP	EC	CO2	FDI	EMP	NEXP
GDP		0.0046*	-4.20E-06	-0.03*	-0.0003***	-0.0087
EC	6.29		0.0021***	1.40**	-0.0047	-1.56
CO2	-532.4	180.1***		50.8	2.72***	-277.9
FDI	-0.26	-0.0001	2.44E-05		-0.0007**	5.12E-05
EMP	-279.7**	-5.57**	0.02**	-43.3**		-7.99
NEXP	-0.09	-0.01	-2.84E-05	0.08	-0.0002	
R^2	0.987	0.965	0.951	0.077	0.523	0.062
Adj. R^2	0.985	0.963	0.947	0.014	0.490	-0.001

Note: * indicates significance at P=0.10, ** at P=0.05 and *** at P=0.01.

While the result of the combined Fisher-Johansen panel cointegration test refers to Granger causality, it does not show the intensity of the direction of the relation. I found short- and long-run causality among the variables for both the 15 old and the eight new EU countries using the VECM, as reported in Table 12 and Table 13. The VECM's estimated equations are from Eqs. (6) – (11). This was estimated for a period of lag selection based on the AIC and SC.

For the old EU countries, the results in Table 12 indicate that there is a short-run bidirectional causality (also termed weak Granger causality) between (1) GDP and energy consumption, (2) GDP and CO2 emissions, (3) energy consumption and CO2 emissions, (4) net export and CO2 emissions, (5) net export and FDI, and (6) employment and FDI. The results for the new EU countries in Table 13 indicate that there are short-run bidirectional panel causalities between (1) energy consumption and CO2 emissions, (2) employment and energy consumption, and (3) employment and FDI. In addition, there is a unidirectional panel causality running from GDP to energy consumption and CO_2 emissions, respectively. Note that the short-run causality was estimated based on the joint significance of the coefficients of the lagged terms or individual independent variables in Eqs. (6) – (11).

As for the long-run causal relationships, the statistical significance of the ECT coefficients in Eqs. (6) – (11) were investigated. Table 9 and Table 10 show that the estimated coefficients were equal to -0.16 and -0.23 at P=0.01 for GDP for both the old and the new EU countries, respectively. Similarly, energy consumption had coefficients of -0.36 and -0.49 at P=0.01 for both the old and the new EU countries, respectively. The same analyses were applied to the other variables. The results indicate statistically significant coefficients for GDP, energy consumption, CO_2 emissions, FDI and net export, suggesting that these five variables are important for the long-run correction mechanism. In other words, these results indicate long-run bidirectional causal relationships between these variables for both the old and new EU countries. To put it another way, no long-run effect runs from the other variables to employment in the EU countries.

Table 12: Results of panel Granger causality test for old EU countries

	independent variables						
dependent variable	Δ GDP	Δ EC	Δ CO2	Δ FDI	Δ EMP	Δ NEXP	ECT
Δ GDP		25.35***	17.06***	21.99***	1.52	5.82***	-0.16***
Δ EC	2.49*		148.08***	7.66***	1.25	0.78	-0.36***
Δ CO2	5.55***	5.11***		19.98***	0.17	4.78***	-0.38***
Δ FDI	0.49	0.48	2.32		3.30**	8.52***	-1.28***
Δ EMP	0.45	125.90***	224.79***	17.87***		1.35	-0.35
Δ NEXP	1.63	1.70	4.18**	4.66**	1.25		-0.23***

Note: * indicates significance at P=0.10, ** at P=0.05 and *** at P=0.01.

Table 13: Results of panel Granger causality test for new EU countries

	independent variables						
dependent variable	Δ GDP	Δ EC	Δ CO2	Δ FDI	Δ EMP	Δ NEXP	ECT
Δ GDP		12.79***	14.31***	0.69	2.45*	0.07	-0.23***
Δ EC	0.06		3.83**	3.24**	16.52***	1.87	-0.49***
Δ CO2	0.40	15.66***		1.36	51.72***	1.02	-0.27***
Δ FDI	1.92	0.57	0.08		2.87	2.30	-0.10*
Δ EMP	0.68	4.04**	0.82	0.34		8.78***	0.87
Δ NEXP	0.12	1.18	0.23	0.12	2.36*		-0.12**

Note: * indicates significance at P=0.10, ** at P=0.05 and *** at P=0.01.

Figure 7 summarizes the short-run interactions among SDGs as detected by using the Granger causality test. Significant interactions between economic development and environment quality for both country samples, indicating trade-offs between these groups of SDGs. However, energy seems to be more effectively used in old EU countries, leading to synergies between SDG7 and SDG8. The pressure to reduce CO2 emissions is also stronger in old EU countries due to the bidirectional relationship between SDG8 and SDG13.

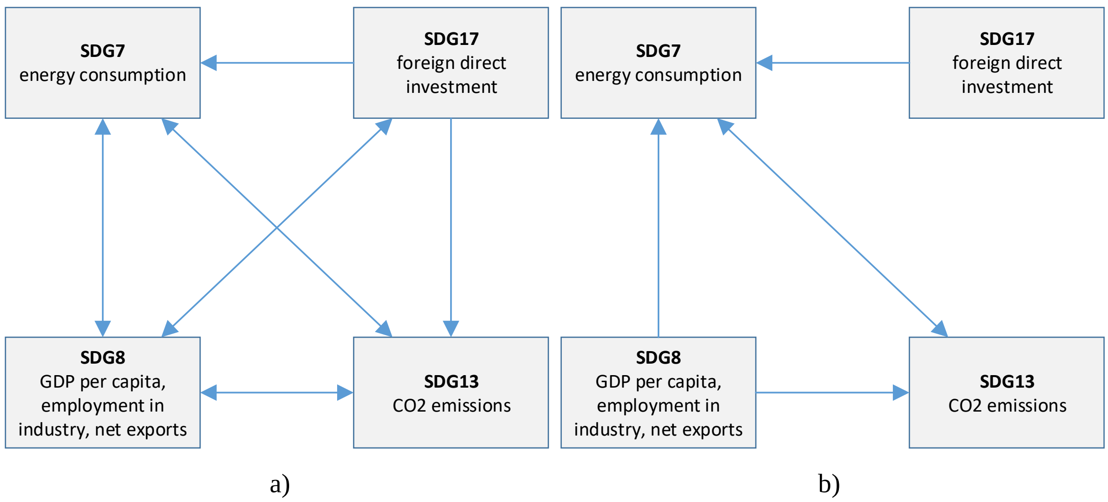


Figure 7: Interactions among SDG7, SDG8, SDG13 and SDG17 for old EU countries (a) and new EU countries (b)

6.1.3 Variance Decomposition

The outcomes of the variance decomposition in the 15 old EU countries are presented in Figure 8. They indicate that 77.80% of GDP is explained by its own shocks. The contribution to economic growth by the other variables is as follows: CO2 emissions, employment, energy consumption, net exports and FDI contribute 9.28%, 5.98%, 5.11%, 1.04% and 0.7%, respectively. The results for energy consumption point out that 66.51% is accounted for by its own shock, whereas CO2 emissions, GDP, FDI, net exports and employment contribute 13.12%, 7.5%, 5.74%, 4.5% and 2.94%, respectively. In addition, the result for CO2 emissions reveals that 44.50% is caused by its own shock, whereas energy consumption, FDI, net exports, employment and GDP contribute 34.85%, 9.14%, 5.56%, 3.39% and 2.54%, respectively. For FDI, 35.91% is caused by its own shock, whereas the contributions of CO2 emissions, employment, energy consumption, net exports and GDP are equal to 33.36%, 19.13%, 6.19%, 4.49% and 0.89%, respectively. The same analyses are applied to the other variables.

The outcomes of the variance decomposition approach in the eight new EU countries are shown in Figure 9. They reveal that 45.52% of GDP was caused by its own shocks. Employment contributed to economic growth by 44.18%. The contribution of the remaining variables was less than 5%. The result for energy consumption indicates that 33.45% of its change was produced by its own shock, while employment contributed to it even more at 55.57%. For CO2 emissions, 40.90% was accounted for by its own shock, whereas energy consumption and employment were the most important contributors with 35.03% and 18.41%, respectively. Finally, 65.26% of FDI was triggered by its own shock, and the contribution of employment was 27.99%.

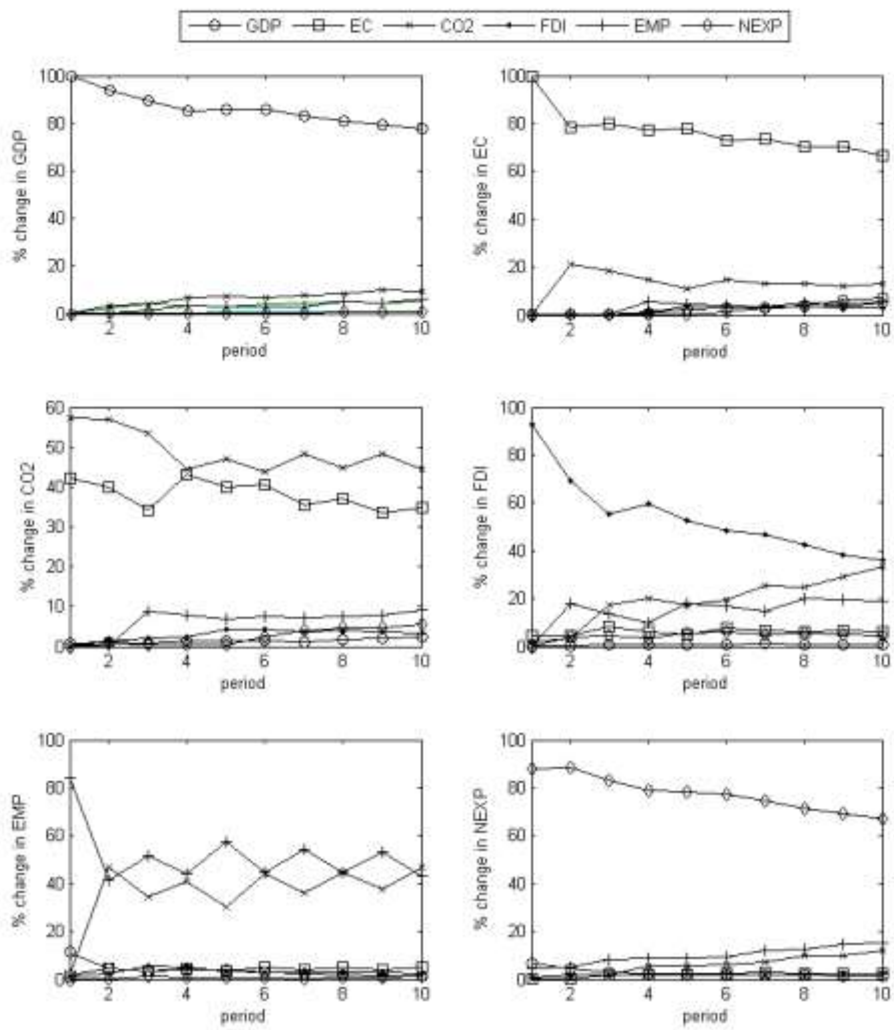


Figure 8: Variance decomposition of outputs - old European Union countries

Regarding the impulse response function in Figure 10 and Figure 11, the effect of one variable influences the other variables. The assessment of GDP indicates that it initially rises, then falls, stabilises at a point in time and then decreases again. Most of these fluctuations stem from energy consumption, CO2 emissions and employment for the 15 old EU countries (Figure 10). An assessment of GDP in the eight new EU countries indicates that it initially rises and then decreases (Figure 11). In a similar fashion to the old EU countries, all those fluctuations stem from energy consumption, CO2 emissions, FDI and employment.

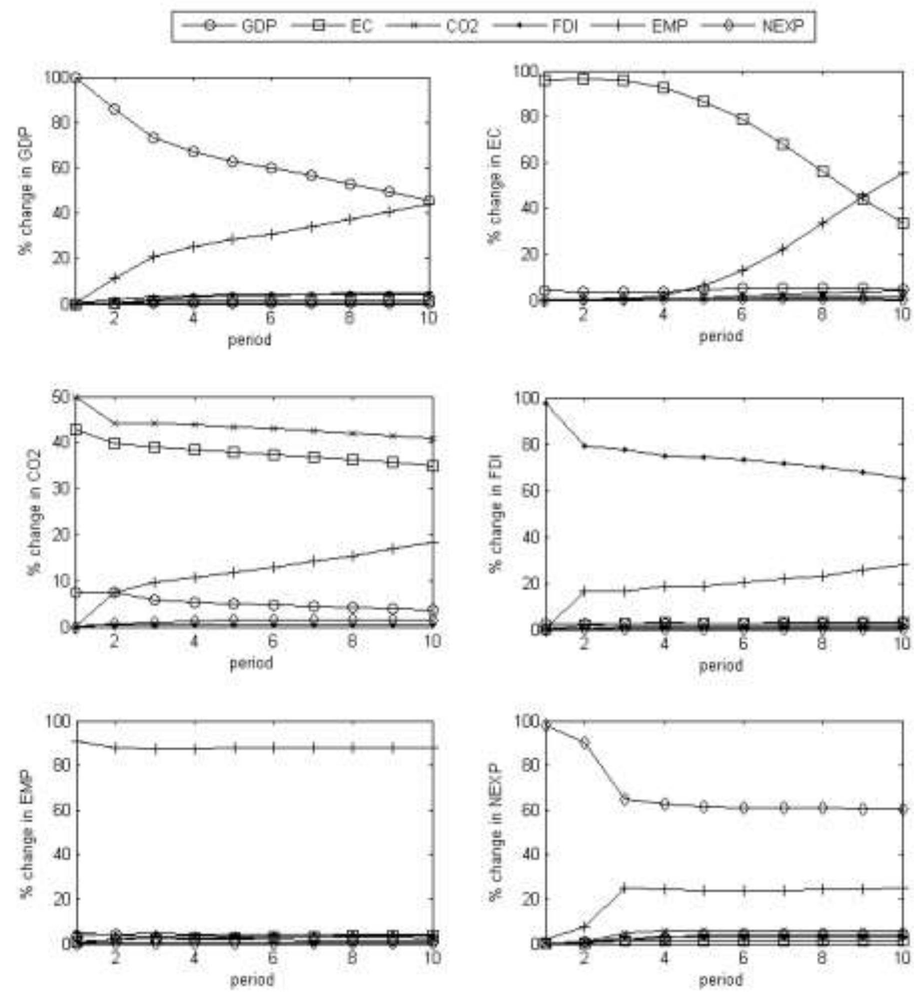


Figure 9: Variance decomposition of outputs - new European Union countries

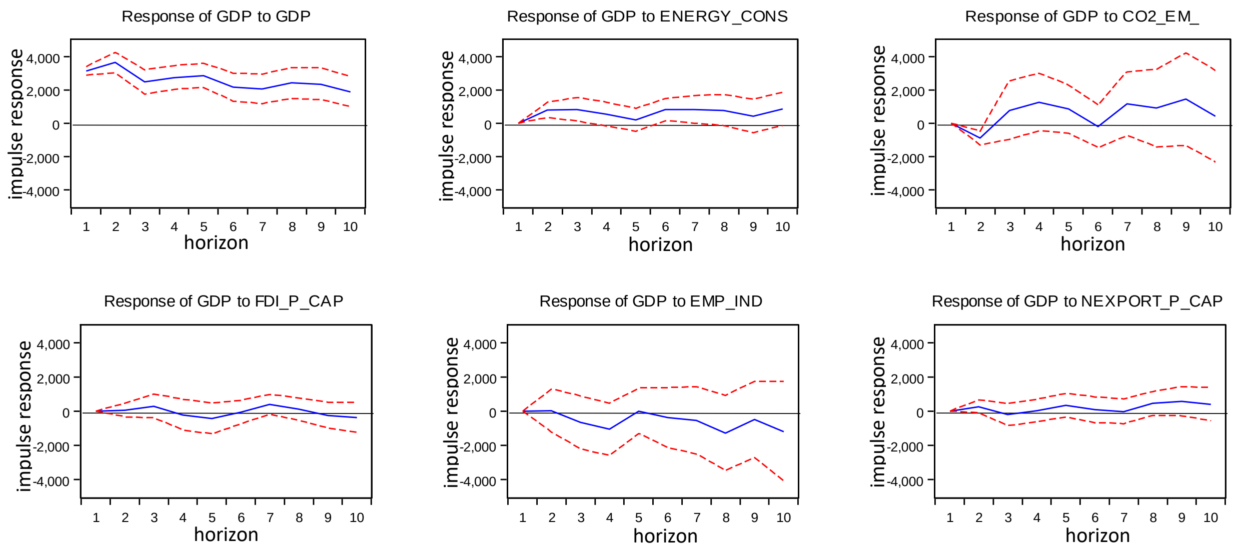


Figure 10: Impulse response functions of GDP for old European Union countries

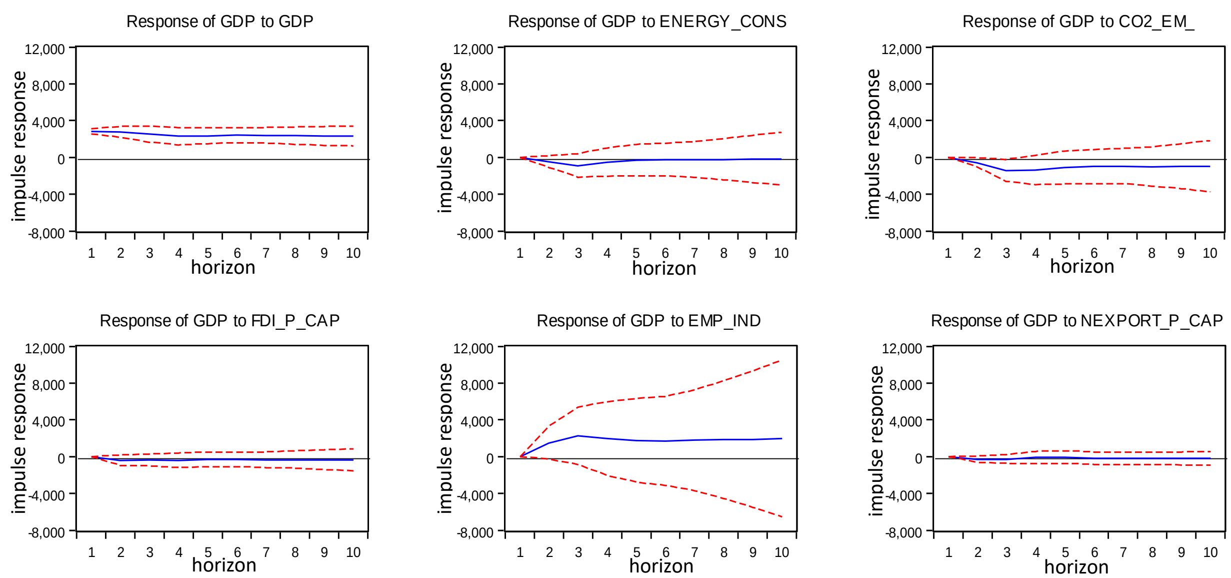


Figure 11: Impulse response functions of GDP for new European Union countries

Further, the response to energy consumption in the old EU countries first increases, then falls, stagnates and decreases by a small margin. This is also due to a shock from the other variables, especially energy consumption and CO2 emissions, whereas in the new EU countries, energy consumption initially rises and then falls. All these fluctuations stem from employment and GDP. Moreover, the response to CO2 emissions also increases, then changes and continuously decreases in the old EU countries due to the shocks from energy consumption and employment. The response to CO2 emissions also increases, then falls marginally, stabilizes and decreases for the new EU countries. This fluctuation also emanates from energy consumption and employment. The rate of CO_2 emissions between the two regions is different since the variance decomposition between the two regions has a different pattern of fluctuations. The fluctuation in terms of the impulse response of employment was mostly caused by CO_2 emissions, GDP and net exports.

6.1.4 Discussion and Policy Implications

On the whole, the responses of GDP, energy consumption, FDI and net exports kept decreasing over time, whereas the responses of CO_2 and employment had an unstable pattern of fluctuations, as they declined from the initial period, became stable and decreased at a certain point in time. This result is not startling, especially since CO_2 emissions, employment and energy consumption have a greater influence on GDP because it is assumed that economic growth usually results in CO_2 emissions, creating employment coupled with high energy consumption. The same results were confirmed by (Ozturk & Acaravci, 2010) for CO_2 emissions and economic growth. Economic growth tends to increase employment and the same results were confirmed by (Herman, 2011; Kapsos, 2006; Seyfried, 2011). Moreover, the EU region continues to experience a rise in the number of services and manufacturing industries with the ability to employ many workers compared with other sectors such as agriculture. Comparably, manufacturing and services industries have contributed to shrinking the high unemployment rate, particularly since the economic crises, by absorbing large segments of the labour force in the region. In effect, the activities and training of those industries have improved labour productivity as well as increased aggregate economic growth. However, it should be noted that the positive effect between employment on economic growth was observed only in the short run, implying a low ability to promote employment in the long run in the region (Herman, 2011). To overcome this problem, policymakers should revise their policies to promote the skills of employees. They should help academic institutions such as universities and vocational institutions persistently redesign their curricula to meet the current needs of the job market for the manufacturing and services industries. They should also assist start-up enterprises or institutions through access to credit. The governments of individual EU countries should help minimise job-related illness and ensure that the psychological health of workers is strengthened through occupational safety and health.

The positive effect of FDI on economic growth was found, which corroborates previous literature (M. S. Ibrahim & Muthusamy, 2014; Jude & Levieuge, 2015; Pelinescu & Radulescu, 2009; Trojette, 2016) This finding can be explained by the favourable business environment in the EU, including the availability of efficient human capital, technology, a conducive business climate and the training of the labour force on how to use these technologies in the region (Armeanu et al., 2018). To raise economic growth, EU countries should continue to restructure their FDI policies to attract the right type of FDI, especially from both the services and the manufacturing sectors of their economies. They should also adopt a policy to keep modernising state enterprises with the current trend of technological advancement and train employees on technological advancement and skills. This will undoubtedly lead to long-term economic growth.

On the contrary, net exports stimulating economic growth is not a shocking result. The hypothesis confirmed this result in the long run, and it is simple and reasonable to understand due to its strong theoretical foundation, including the Heckscher-Ohlin's theory of international trade and more efficient allocation of resources favouring export-oriented industries (Akalpler & Shamadeen, 2017). An increase in net exports usually signifies more output from factories; hence, industrial facilities as well as more labour force are employed to ensure the continuous running of factories. Indeed, EU has strong ties with trading partners globally as one of the most open economies in the world and, at the same time, keeps boosting the manufacturing and services sectors of its economies. In essence, this induces economic growth. To sustain this, policymakers should also control domestic consumption so that more output can be exported. Individual countries and the EU should also implement new trade agreements and keep strengthening their trade ties with other countries.

The more energy consumed, the more CO2 is emitted into the environment (Halicioglu, 2009). This was also observed from our variance decomposition analyses, suggesting a long-run bidirectional relationship between energy consumption and CO2 emissions in both new and old EU countries. These results are consistent with the feedback hypothesis (Dogan & Aslan, 2017; Kasman & Duman, 2015). Hence, this study suggests that the policy makers should encourage energy-efficiency policies, such as financial incentives, market-oriented instruments, regulations or energy audits. Increasing public awareness of energy efficiency though information campaigns is another recommended policy measure.

Another question of energy economists is whether energy consumption affects the economy. The results for energy consumption contradict those of neoclassical growth models (Harod–Domor or Solow–Swan), which stipulate that energy is neutral to the economic growth process. Their model places much priority on capital, labour and land as the factors of production, which increase the output of the economy (Skeer & Wang, 2007). However, our results concur with the findings of (Alam et al., 2012; Kasman & Duman, 2015) and the ideas of ecologist economists such as (Pokrovski, 2003). They posited that energy has a significant role in the production process as the substitute of labour resource, thus representing endogenous technological change in economic growth models (Pokrovski, 2003). In a similar manner, (Ghali & El-Sakka, 2004) claimed that inputs such as capital and labour cannot perform without the use of energy in combination. Consequently, energy serves as a basic input for the value creation process and is pivotal for economic growth. On the one hand, our results support the conservation hypothesis (unidirectional causality running from economic growth to energy consumption) for the new EU countries, implying that energy reduction policies have no adverse effect on economic growth in those countries. On the other hand, the feedback hypothesis (bidirectional causality) was confirmed for the old EU countries, suggesting a complementary relationship between energy consumption and economic growth. In contrast to the previous literature supporting the conservation hypothesis in the EU countries (Dogan & Aslan, 2017), our findings suggest differences between the old and new EU countries, thus providing additional insight into the relationship between energy consumption and economic growth in the region.

I also witnessed that, in the short run, CO2 emissions affect GDP in both the old and new EU member countries. However, the negative bidirectional relationship was only confirmed for the 15 old EU countries. This finding corroborates the feedback hypothesis (Dogan & Aslan, 2017). This implies that there are differences in CO2 emissions between the two regions. The same result is also declared by the result of the variance decomposition. Therefore, these differences are ascribed to energy use intensity, differences in fuel prices in the individual countries, the fuel mix from 2001–2017 (Patiño-Cambeiro et al., 2019), interregional differences in economic growth and attitudes in dealing with carbonisation. In addition, structural differences that comprise the increase in population (resulting from immigration) and the fast rates of economic growth and technology spillover lend credence to the disparity in CO2 emissions (González et al., 2014). Indeed, the economic disparities have been considered in the EU effort to reduce GHG emissions, allowing EU countries with a lower GDP to increase emissions compared to 2005 (Delbeke & Vis, 2015). On the contrary, relatively rich EU countries have to reduce emissions to meet the EU commitments. Our results provide empirical support to this strategy. Specifically, a policy to reduce CO2 emissions is laudable because when CO2 emissions rise (fall), economic growth increases (slows). This holds despite the recent speculation that the trend of CO2 emissions in the region has reduced. In addition, policymakers and economic planners should keep on modifying their environmental tax and emission trading schemes to continue to control emissions. The EU as well as individual countries should keep revising their policies to meet their emission reduction targets to match the current trend of economic growth. They should also institute transparency, accountability and compliance schemes that should not be used as a punitive measure but rather to understand which member countries are off-track and put them back on track. The EU and its member countries should also continue to monitor baseline CO2 emissions, especially the use of technological growth development including automobiles, fluorinated GHG and carbon capture and storage devices to ensure continuous abatement. Finally, the EU must go beyond the proposed current policy as well as promote energy security and lessen air pollution by negotiating with the Technology Executive Committee (Suzuki, 2015).

Further, it was observed that FDI does not contribute to the environmental problem (CO2 emissions), which is in contrast to the findings of (Zheng & Sheng, 2017) for China and (Koçak & Şarkgüneşi, 2018) for Turkey. This can be attributed to higher environmental standards and strict environmental regulations in the EU countries (Seker et al., 2015). On the contrary, our results suggest that there is no causality between FDI and economic growth. This is consistent with the finding of (Bermejo Carbonell & Werner, 2018) for Spain, suggesting that this finding can be generalized for the EU region. This can be explained by the crowding-out effect of FDI on domestic investment, implying that policies for attracting FDI cannot be advised.

6.2 Model of Inequality, Economic Growth and Risk of Poverty Nexus

6.2.1 Cross-sectional Dependence and Unit Root Tests

To choose the appropriate panel unit root and causality tests, the residual cross-sectional dependence Pesaran test and Blomquist and Westerlund slope homogeneity test were performed. The results in Table 14 indicate cross-sectional dependence in both country samples. No cross-sectional dependence was observed for risk of poverty and inequality in the sample of old EU countries. Table 15 shows the empirical results of the Blomquist and Westerlund slope homogeneity test, indicating that the data were heterogeneous. Overall, both the cross-sectional independence and slope homogeneity hypotheses were rejected at P = 0.01.

Table 14: Results of residual cross-sectional dependence Pesaran test

variable	old EU countries	new EU countries
POV	-1.29	18.33***
EG	37.48***	36.78***
INEQ	1.33	3.09***
R&D	21.33***	31.90***
EDU	38.22***	36.07***
ST	4.23***	5.60**

Note: *** statistically significant at P=0.01.

Table 15: Results of Blomquist and Westerlund slope homogeneity test

test	old EU countries	new EU countries
Δ_{adj}	7.66***	10.51***
Δ	10.06***	13.81***

Note: *** statistically significant at P=0.01.

Table 16: Results of CIPS panel unit root test

	CIPS (without trend)		CIPS (with trend)	
old EU coutries	level	Δ	level	Δ
POV	0.22	-12.19***	-1.41	-10.78***
EG	-1.41*	-7.72***	-2.90	-5.69***
INEQ	-0.98	-9.01***	0.65	-7.18***
R&D	-1.38*	-7.08***	0.54	-6.23***
EDU	-0.19	-7.95***	0.23	-7.17***
ST	-1.57*	-9.01***	-0.18	-7.22***
new EU countries	level	Δ	level	Δ
POV	-4.25***	-8.85***	-2.42**	-6.82***
EG	-1.02	-3.94***	-0.66	-2.51**
INEQ	-3.25***	-10.98***	-3.49***	-9.03***
R&D	-2.49**	-7.74***	-2.68***	-5.78***
EDU	-2.37**	-7.28***	-0.48	-5.93***
ST	-1.63*	-9.19***	-1.12	-7.39***

Note: * statistically significant at P=0.10, ** at P=0.05 and *** at P=0.01.

To overcome the problems of cross-sectional dependence and heterogeneity, the CIPS panel unit root test was performed, as presented in Table 16. The results show that most variables include unit root at levels. However, all the variables became stationary at first differences, indicating that the variables were integrated at I(1).

To test whether the levels of the underlying variables were cointegrated, the combined Johansen–Fisher panel cointegration test was used. The results in Table 17 indicate that for both country samples, there were at least four (one) cointegrated relationships between the variables based on the trace (maximum eigenvalue) test. It can concluded that the variables cointegrated and, therefore, that there may exist long-run relationships among the variables for both country samples.

Table 17: Results of combined Johansen–Fisher panel cointegration test

	old EU countries		new EU countries	
no. of CEs	trace stat.	max. eigenvalue stat.	trace stat.	max. eigenvalue stat.
none	20.79	20.79	18.02	18.02
at most 1	19.41	282.8***	13.86	69.12***
at most 2	13.86	106.0***	5.545	171.3***
at most 3	5.545	2903.***	1.386	222.4***
at most 4	92.10***	276.3***	239.5***	239.5***
at most 5	395.1***	276.3***	244.9***	208.3***

Note: *** statistically significant at *P*=0.01, CE denotes cointegrated vector.

6.2.2 Causality Tests

The results of the FMOLS models are presented in Table 18, indicating that there was a negative long-run relationship between risk of poverty and economic growth for both country samples. The negative elasticity of poverty risk with respect to economic growth also implies that an increase in GDP led to a lower at-risk-of-poverty rate in EU countries. A significant effect of inequality on risk of poverty was found for old EU countries, but no significant relationship between risk of poverty and inequality was detected for new EU countries.

Concerning the effects of R&D intensity and human capital (tertiary education level) on poverty, the results indicated that no significant effect was observed for both country samples. For old EU countries, a 1 per cent increase in educational level resulted in a 0.097 per cent decrease in risk of poverty; no significant change was observed for the other sample. The effect was the opposite for social transfers, significantly increasing (decreasing) risk of poverty in old (new) EU countries. A consistently positive (negative) impact of R&D intensity (educational level) on economic growth was found for both country samples. R&D intensity and educational level also decreased inequality for EU countries. Concerning the effect of poverty risk on these two indicators, risk of poverty had a significantly negative impact on educational level in old EU countries, but it had no significant impact in new EU countries. In contrast, inequality had more serious consequences, significantly reducing the educational level in both samples. Notably, a 1 per cent increase in the risk of poverty level led to a more than 1 per cent decrease in educational level. Similarly, a 1.338 per cent reduction in R&D intensity was observed as a result of a 1 per cent increase in the equality level for old EU countries. Another interesting result was the significantly negative effect of risk of poverty after social transfers on inequality, as well as its opposite effect on risk of poverty; it increased (decreased) risk of poverty in old (new) EU countries. Note that I also performed the panel DOLS to ensure the robustness of the long-run coefficient estimates (see Table 19).

Table 18: Results of panel FMOLS model

	dependent var.					
	old EU countries					
indep. var.	POVR	EG	INEQ	R&D	EDU	POVRST
POVR		-0.003**	-0.004	0.022	-0.207*	0.054**
EG	-8.169***		-1.333**	3.627	-10.605	4.528***
INEQ	-0.368***	0.035***		-1.338***	-1.729*	2.090***
R&D	-0.035	0.005*	-0.067***		-0.074	0.032
EDU	-0.097*	-0.002*	-0.010	0.011		-0.024
POVRST	0.308***	0.009**	0.158***	0.064	-0.228	
R^2	0.903	0.997	0.949	0.980	0.899	0.965
Adj. R^2	0.889	0.997	0.944	0.977	0.891	0.960
	new EU countries					
indep. var.	POVR	EG	INEQ	R&D	EDU	POVRST
POVR		-0.004***	0.003	0.005	-0.006	-0.018
EG	-30.55***		0.321	4.114***	-8.506***	2.780**
INEQ	0.650	0.010		-0.004	-1.080**	2.078***
R&D	0.253	0.023***	-0.005		-0.301	-0.051
EDU	-0.063	-0.010***	-0.029***	-0.038		0.073**
POVRST	-0.479**	0.007**	0.224***	-0.020	0.332**	
R^2	0.889	0.992	0.927	0.906	0.980	0.962
Adj. R^2	0.872	0.991	0.921	0.898	0.977	0.956

Note: * statistically significant at P=0.10, ** at P=0.05, and *** at P=0.01.

Table 19: Results of panel DOLS model

	old EU countries					
	dependent var.					
indep. var.	POVR	EG	INEQ	R&D	EDU	POVRST
POVR		-0.003*	-0.001	0.052	-0.271*	0.076*
EG	-9.280***		-1.223*	3.888	-13.063	2.625
INEQ	-1.063*	0.032**		-1.147**	-2.376*	1.924***
R&D	0.139	0.006*	-0.081***		0.102	0.038
EDU	-0.068	-0.002*	-0.015*	0.029		0.014
POVRST	0.501**	0.012***	0.167***	0.025	0.246	
R^2	0.945	0.998	0.973	0.986	0.973	0.979
Adj. R^2	0.907	0.997	0.955	0.976	0.954	0.965
	new EU countries					
indep. var.	POVR	EG	INEQ	R&D	EDU	POVRST
POVR		-0.003**	-0.007	-0.008	-0.055	-0.008
EG	-26.71***		0.126	3.946***	-9.909**	3.258*
INEQ	-0.279	0.024		-0.042	-0.065	2.113***
R&D	0.139	0.023***	-0.047		-0.217	0.063
EDU	-0.103	-0.007**	-0.022	-0.045		0.063
POVRST	-0.320	0.003	0.233***	-0.020	0.157	
R^2	0.952	0.995	0.965	0.978	0.986	0.976
Adj. R^2	0.912	0.992	0.941	0.964	0.976	0.959

Note: * statistically significant at P=0.10, ** at P=0.05, and *** at P=0.01.

The long-run estimates presented in Table 18 indicate the existence of relationships among the underlying variables. Therefore, I further investigated the directions of the causalities using the panel short-run and long-run Granger causality tests. The results in Table 20 indicate the presence of a long-term equilibrium among all variables for new EU countries. At the same time, this relationship was found among the variables risk of poverty, inequality, R&D intensity, education, and risk of poverty after social transfers for old EU countries.

Table 20 also reports short-run relationships among the variables using the Wald test. For old EU countries, evidence was found for a short-run bidirectional relationship between R&D intensity and economic growth; a unidirectional relationship ran from economic growth to inequality, from inequality to risk of poverty, from R&D to inequality and education, and from economic growth to risk of poverty after social transfers. In new EU countries, it can be concluded that there was a short-run bidirectional relationship between educational level and inequality, and between educational level and risk of poverty after social transfers; a unidirectional relationship ran from risk of poverty to economic growth, from risk of poverty to inequality, from R&D to risk of poverty, inequality, education, and risk of poverty after social transfers, and from economic growth to R&D and risk of poverty after social transfers.

Table 20: Results of panel VECM Granger causality test (χ^2 statistics)

	independent variables						
	old EU countries						
dep. var.	Δ POVR	Δ EG	Δ INEQ	Δ R&D	Δ EDU	Δ POVRST	ECT
Δ POVR		6.694	16.845*	10.032	14.448	8.403	-0.004**
Δ EG	14.463		9.742	15.766*	9.117	5.436	-0.000
Δ INEQ	15.081	26.820***		28.475***	8.398	11.986	-0.016**
Δ R&D	9.427	23.176**	7.150		10.387	4.814	-0.015**
Δ EDU	4.649	7.181	6.306	24.212***		15.106	-0.037**
Δ POVRST	8.664	20.365**	5.248	11.155	6.828		-0.018**
	new EU countries						
dep. var.	Δ POVR	Δ EG	Δ INEQ	Δ R&D	Δ EDU	Δ POVRST	ECT
Δ POVR		9.315	7.317	18.996*	7.191	5.804	-0.014**
Δ EG	20.911**		7.886	5.716	7.443	6.192	-0.0001***
Δ INEQ	18.583*	14.629		24.054**	18.512*	15.658	-0.015***
Δ R&D	8.697	23.755**	14.645		13.082	11.407	-0.021**
Δ EDU	11.968	15.913	21.349**	24.103**		22.039**	-0.147**
Δ POVRST	15.423	27.743***	12.974	17.993*	24.452**		-0.004**

Note: * statistically significant at P=0.10, ** at P=0.05 and *** at P=0.01 using the Wald test.

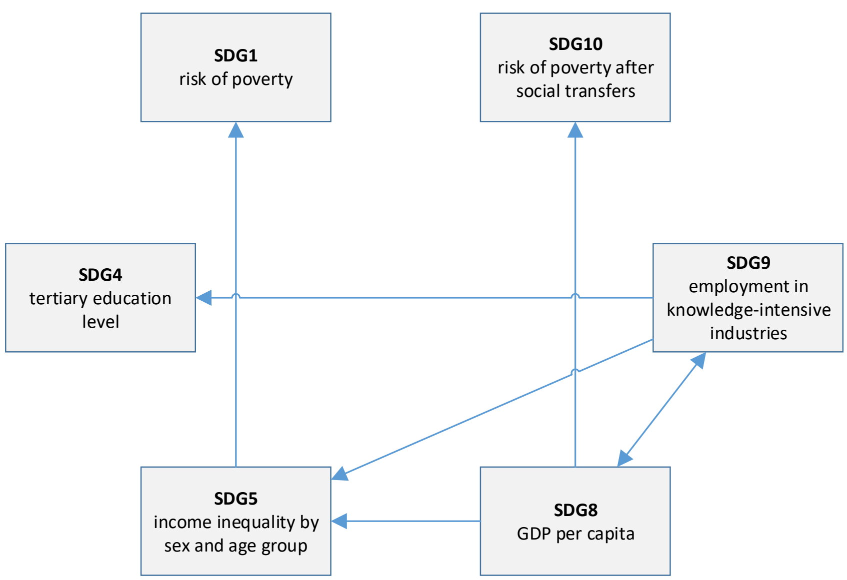


Figure 12: Interactions among SDG1, SDG4, SDG5, SDG8, SDG9 and SDG10 for old EU countries

Figures 12 and 13 depict the short-run interactions among SDGs observed based on the results of the Granger causality test in Table 20. For old EU countries, economic growth reduces inequalities while the effect of SDG8 on SDG1 is only indirect via SDG5. Synergies were found for SDG8 and SDG9 only. The interactions between economic and social-related SDGs were stronger for new EU countries (Figure 13). Unlike the old EU countries, the effect of GDP on poverty risk was mediated through employment in knowledge-intensive industries (SDG9) and synergies can be achieved by reducing poverty risk concerning decrease in inequality and increase in GDP per capita. Other synergistic effects were found between inequalities and education level.

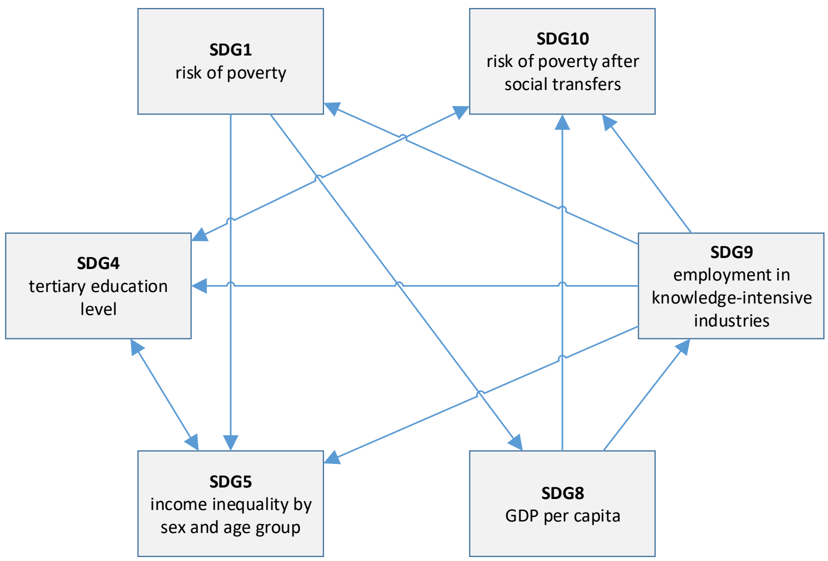


Figure 13: Interactions among SDG1, SDG4, SDG5, SDG8, SDG9 and SDG10 for new EU countries

6.2.3 Variance Decomposition

Results of variance decomposition for old EU countries, as depicted in Figure 14, indicate that the shocks of poverty risk itself explained almost 70 per cent of poverty risk. The results also show that of the remaining variables, economic growth, inequality, and risk of poverty after social transfers contributed most to risk of poverty. Still, it can also be seen that a shock in these three variables was reflected in future changes in risk of poverty only after six periods. A similar pattern can be observed for economic growth, with almost 80 per cent of variance accounted for by the shocks of economic growth itself. A shock in education and poverty was only slowly reflected in a change in economic growth. In contrast, fluctuations in economic growth, R&D,

and risk of poverty after social transfers were quickly reflected in the structural changes in inequality. Figure 14 also shows impulse responses of poverty risk, economic growth, and inequality aftershocks to the independent variables. Risk of poverty responded mainly to economic growth shocks. Consistent with the results of variance decomposition, shocks to risk of poverty and education caused a response of economic growth after six periods. The response of inequality to economic growth shocks substantially increased after six periods. Positive fluctuations in inequality emanated from the risk of poverty after social transfers (after two periods) and R&D intensity (but only after eight periods) for old EU countries.

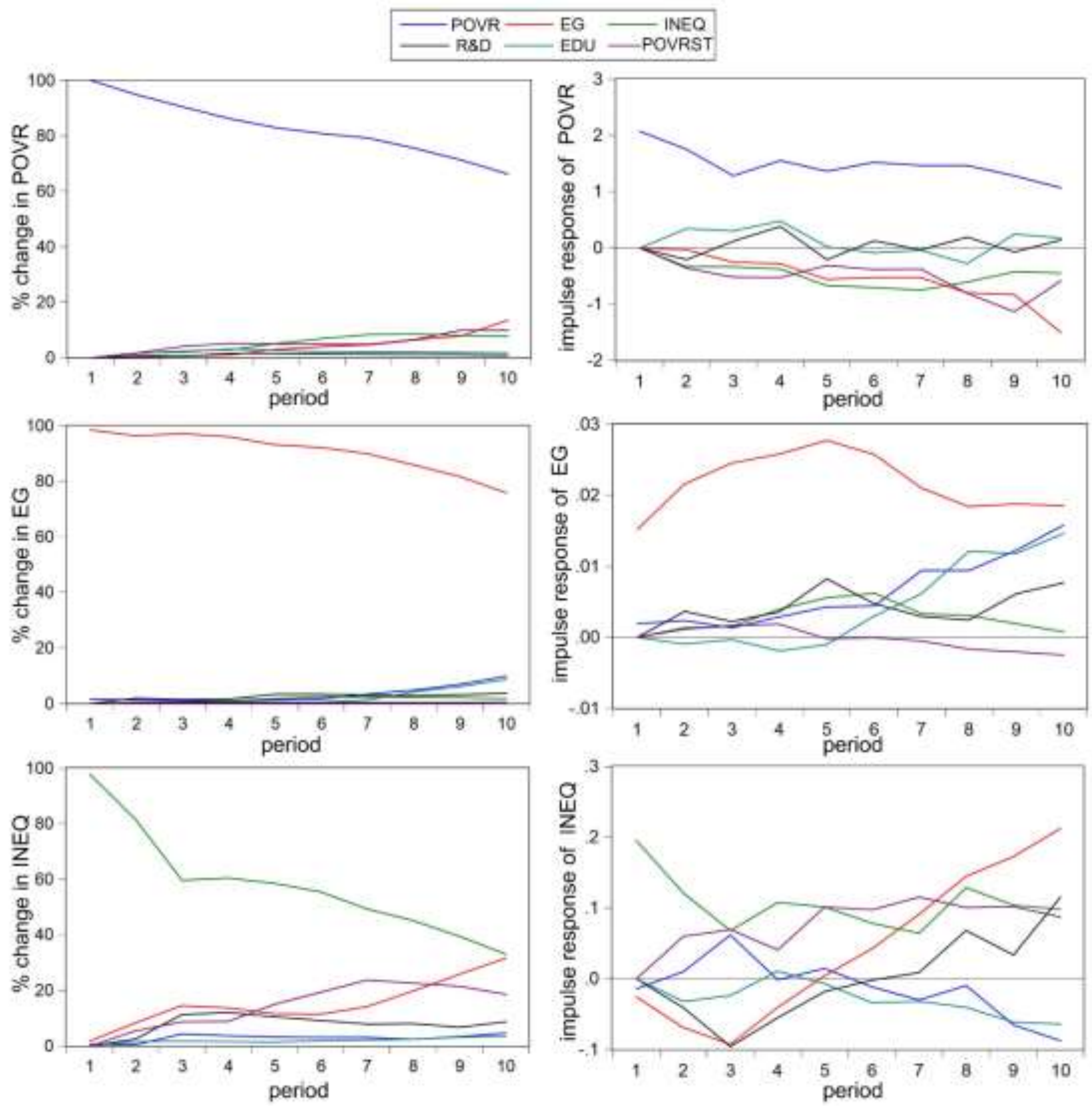


Figure 14: Results of variance decomposition for old EU countries

For new EU countries, risk of poverty responses to economic growth took place after three periods while a shock in R&D intensity was reflected in the change in risk of poverty only after eight periods (Figure 15). In contrast to old EU countries, a large proportion of variance in the economic growth of new EU countries could be explained by changes in risk of poverty and R&D intensity, respectively. After five periods, shocks in economic growth and R&D intensity were reflected in a change in inequality. In terms of impulse responses, poverty responded quickly to R&D intensity and slowly to economic growth and risk of poverty after social transfers. After five periods, poverty increased mainly in response to shocks in inequality. Future changes in economic growth were primarily caused by shocks in R&D intensity (positive response) and risk of poverty (negative response). A different pattern can be observed for inequality, which increased in response to shocks in R&D intensity and risk of poverty. In contrast, a change in economic growth caused a decrease in inequality.

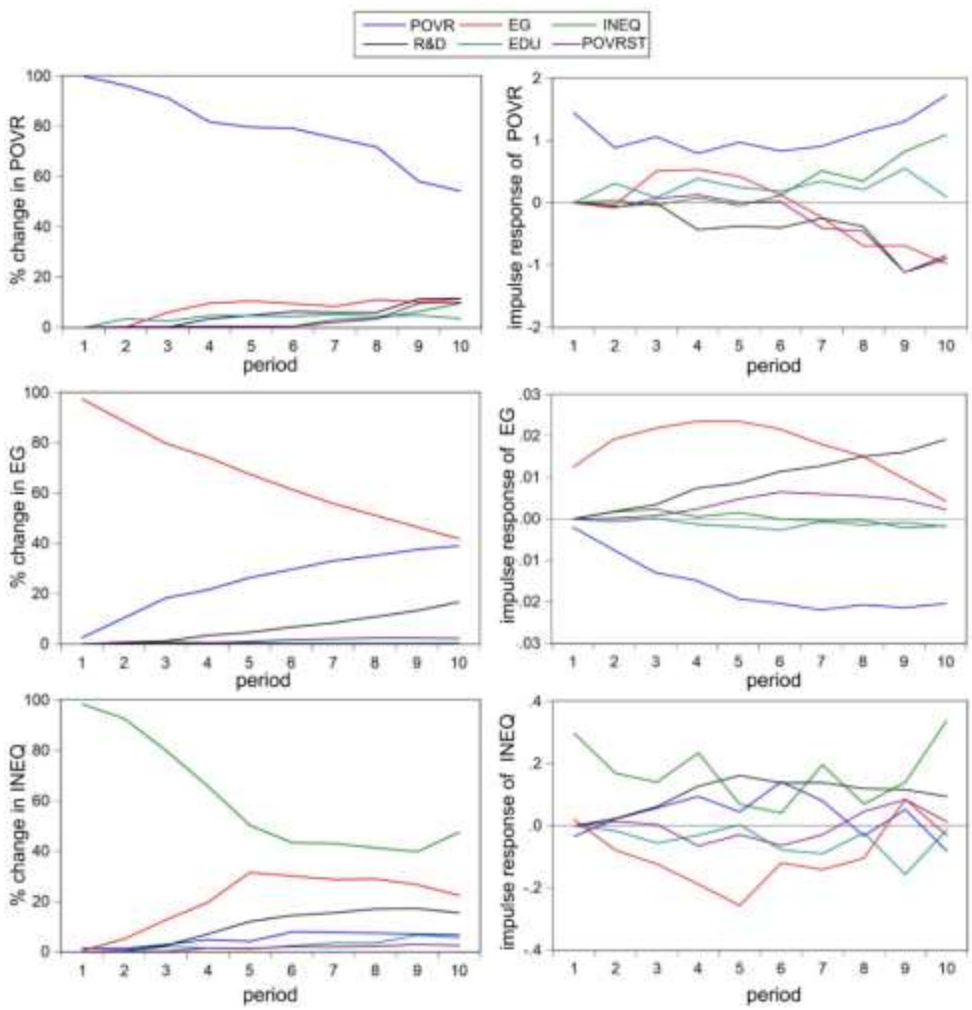


Figure 15: Results of variance decomposition for new EU countries

6.2.4 Discussion and Policy Implications

The inequality-led poverty hypothesis was substantiated for old EU countries, supporting earlier research (Khemili & Belloumi, 2018). In contrast, the opposite relationship was revealed for new EU countries, what could be called the risk of poverty-led inequality hypothesis. In other words, the feedback hypothesis between risk of poverty and inequality, suggested in most prior literature (Akanbi, 2016; Sehrawat & Giri, 2018), was not detected in either of the country samples. These findings may be explained by the Kuznets hypothesis, which states that income inequality tends to increase for low-income countries and tends to decrease for highly developed countries. The findings are also in line with the results for emerging and highly developed EU countries showing that income inequality has a tendency to grow in emerging EU countries (Soava et al., 2020). It was also shown that an increase in R&D intensity has a favorable effect on poverty risk reduction in new EU countries, which can be ascribed to a positive job multiplication effect (N. Lee & Clarke, 2019; Moretti, 2010). This finding indicates that new EU economies have a sufficient capacity to exploit R&D. For old EU countries, the absence of a relationship between R&D intensity and risk of poverty is consistent with the results observed for high-income economies (N. Lee & Rodríguez-Pose, 2016).

The feedback hypothesis was confirmed between economic growth and R&D intensity. In other words, we found Granger bidirectional causality running from R&D intensity to economic growth, and vice versa. This finding is in agreement with earlier research (Hong, 2017; Maradana et al., 2017). However, significant differences were found in the dynamics of this relationship between sample countries. For old EU countries, short-run bidirectional causality was observed, but economic growth caused R&D intensity in the short run for new EU countries and the feedback hypothesis was only confirmed in the long run. In addition, poverty was found to be the main obstacle to economic growth for new EU countries, corroborating findings in another study (Nakabashi, 2018). In contrast, the absence of causality between risk of poverty and economic growth suggests the neutrality hypothesis for old EU countries. Moreover, in contrast with the empirical studies on low- or medium-income countries (Akanbi, 2016; Khemili & Belloumi, 2018), an absence of an adverse impact of economic growth on inequality was found. For high-income old EU countries, the opposite effect was even observed, that inequality is reduced by economic growth. Hence, I confirmed that this relationship depends on the economic development stage.

The unidirectional adverse effect of R&D on inequality was found for both country samples, and it is a relationship supported by previous studies in the literature (N. Lee & Clarke, 2019; Mirza et al., 2019). This effect may be attributed to a wage increase in high-technology industries while there is no significant effect on wages in low-technology industries. Another explanation may be that the increase in living costs affects low-income workers in particular (Kemeny & Osman, 2018). Like poverty and growth, the educational level had no causal relationship with inequality for old EU countries. The feedback hypothesis between educational level and inequality was substantiated for new EU countries. On the one hand, the results indicate a beneficial effect of education on inequality, but on the other hand, an increase in educational level promotes inequality. This relationship can be attributed to a relatively low level of tertiary education in new EU countries. Hence, our results confirm the crucial role of the knowledge absorptive capacity complementary to R&D intensity for new EU countries. Moreover, the neutrality hypothesis between education and risk of poverty suggests that EU economies do not suffer from non-optimal dynamics between R&D intensity and educational level (Accinelli & Sanchez Carrera, 2011).

The implications for policy making are that the governments of new EU countries can reduce risk of poverty and boost economic growth by supporting research and innovation. Our results imply that the absorptive capacity of new EU countries should be strengthened in order to accelerate the effect of R&D on economic growth. Therefore, capacities for learning and research infrastructure facilities should be enhanced. The absence of causality for old EU countries suggests that economic and R&D policies are not effective in reducing risk of poverty. Hence, I argue for a new research and innovation policy linked to social challenges, as represented by the United Nations Sustainable Development Goals. In other words, to address societal challenges, both individual governmental and EU policymakers should shift from emphasizing the traditional role of research and innovation policy for boosting economic growth. Moreover, the absence of the impact of educational and social transfer policies on poverty reduction implies the need for effective education and welfare systems in EU countries without increasing inequality. Therefore, empirical support was provided for recent EU policy responses, including equal opportunities, access to quality education and the labour market, and social inclusion and protection. This is in line with Keynesian/neoliberal schools emphasizing that equal access to public goods, especially to education, tends to reduce poverty (Davis &

Sanchez-Martinez, 2015). Overall, I argue for policies aimed at facilitating market access for the poor, rather than redistributive policies.

6.3 Model of Municipal Waste Generation, R&D Intensity, and Economic Growth Nexus

6.3.1 Cross-sectional Dependence and Unit Root Tests

The residual cross-sectional test was performed to examine the cross-sectional dependence in the panel data. Table 2 shows the empirical results of this test using three test statistics, which indicate the presence of cross-sectional dependence. In other words, the cross-sectional independence was rejected at $P = 0.01$.

Table 21: Cross-sectional dependence tests

Test statistic	regions of old EU countries	regions of new EU countries
Breusch–Pagan LM	68,837.06***	2,733.75***
Pesaran scaled LM	204.79***	24.82***
Pesaran CD	103.15***	14.67***

Note: *** statistically significant at P=0.01.

Therefore, second generation unit root tests were used to address the cross-sectional dependence problem in the panel data. The CIPS test was employed to test for the unit root of the underlying variables. The empirical results of the test (Table 22) indicate that – except HE – all the remaining variables were non-stationary at level (with or without trend) at $P = 0.05$. The variables became stationary for the first difference. In other words, the variables were integrated at I(1).

After confirming the integration relationship between the variables, the combined Fisher-Johansen panel multivariate cointegration test was used to examine the long-term equilibrium. First, the optimum lag length was determined to be equal to three for the test using the minimum values of AIC and SC from the unconstrained vector autoregressive model for the first differences of the variables. Table 23 shows the results of the cointegration test, which indicates that the null hypothesis of no cointegration was rejected for the number of cointegrated vectors (equations) CEs = 0 and CEs = 1 for the regions of old and new EU countries, respectively. For the larger numbers of cointegration vectors among the variables, the null hypothesis was also rejected at the $P = 0.01$ level of significance, which indicates the presence of cointegration among the variables. In other words, long-term relationships may exist among the variables for regions in both old and new EU member states.

Table 22: Second generation panel unit root test

regions of old EU countries						
	CIPS (without trend)			CIPS (with trend)		
Variable	lags=0	lags=1	lags=2	lags=0	lags=1	lags=2
MW	4,497.5***	242.5	382.3	6,590.0***	407.1	904.2***
LFMW	384.7	510.5	613.1***	217.0	313.7	359.1
INMW	573.2***	435.9	535.1**	304.9	253.8	343.3
GDP	518.2**	467.0	464.3	322.4	563.7***	459.8
R&D	164.6	153.9***	208.6	927.1***	871.1***	531.5**
HE	3,461.7***	1,528.1***	610.1***	2,901.5***	1,244.5***	715.4***
EMP	293.5	336.0	338.3	344.2	522.6**	501.3*
GFC	337.1	433.7	320.5	453.7	685.4***	443.6
Δ MW	11,000.0***	1,518.8***	2,439.7***	6,146.3***	1,279.0***	2,440.9***
Δ LFMW	2,199.6***	1,045.9***	711.33***	1,889.9***	1,028.7***	650.3***
Δ INMW	1,675.5***	875.9***	418.7	1,351.4***	846.7***	276.1
Δ GDP	205.0×E+09***	1,559.2***	791.1***	1,448.4***	1,146.4***	499.93*
Δ R&D	4,576.8***	2,708.1***	1,458.6***	3,604.9***	2,047.1***	1,017.4***
Δ HE	8,927.3***	4,956.1***	1,811.2***	7,192.3***	3,797.7***	1,117.51***
Δ EMP	2,790.3***	1,337.1***	932.4***	2,055.7***	866.7***	619.7**
Δ GFC	2,2811.9***	2,061.9***	958.5***	2,054.0***	1,448.6***	544.2***
regions of new EU countries						
Variable	lags=0	lags=1	lags=2	lags=0	lags=1	lags=2
MW	375.1***	87.8	101.8	407.7***	79.1	86.8
LFMW	57.2	52.7	49.3	63.7	69.5	40.3
INMW	97.1	47.2	25.2	148.1**	90.0	49.8
GDP	34.0	33.5	33.1	46.8	110.1	53.2
R&D	35.5	185.9***	33.8	140.9*	187.9***	110.0
HE	500.1***	28.4	155.0**	552.5***	211.7***	444.0***
EMP	40.9	103.2	43.7	83.4	249.6***	167.6
GFC	130.6	154.3**	137.0*	81.1	118.2	71.5
Δ MW	1,929.7***	418.4***	285.2***	1,573.5***	381.2***	264.4***
Δ LFMW	791.6***	376.0***	142.7*	720.6***	347.8***	107.8
Δ INMW	854.6***	439.1***	208.5***	640.6***	322.0***	142.5*
Δ GDP	524.4***	388.7***	150.4**	340.2***	239.4***	76.0
Δ R&D	861.55***	682.6***	321.0***	646.6***	540.1***	241.4***
Δ HE	1,777.8***	626.6***	514.1***	1,390.3***	419.0***	292.1***
Δ EMP	737.3***	350.5***	218.6***	380.7***	302.4***	151.7**
Δ GFC	410.0***	500.0***	216.2***	560.5***	376.9***	181.8***

Note: * statistically significant at P=0.10, ** at P=0.05 and *** at P=0.01.

Table 23: Combined Fisher-Johansen panel cointegration test

	regions of old EU countries		regions of new EU countries	
no. of CEs	Fisher stat. (trace)	Fisher stat. (max. eigenvalue)	Fisher stat. (trace)	Fisher stat. (max. eigenvalue)
none	263***	798***	66	159***
at most 1	3,455***	3,455***	771.9***	772***
at most 2	6,064***	4,431***	1,473***.	1,046***
at most 3	2,630***	1,966***	641***	461***
at most 4	1,191***	1,026***	310***	247***
at most 5	788***	788***	231***	231***

Note: *** statistically significant at P=0.01

6.3.2 Causality Tests

Table 24 shows the results of the FMOLS models, which indicate that there are positive and significant long-run bidirectional relationships between (1) MW and R&D and (2) MW and HE for both data sets. Notably, a 1% increase in R&D intensity resulted in a 0.53% and 0.64% increase in MW in the regions from old and new EU countries, respectively. In addition, a positive bidirectional relationship between MW and GDP was observed for the regions of old EU countries. More precisely, a 1% increase in GDP led to a 0.16% and 0.27% increase in MW for old and new EU regions, respectively. By contrast, only a positive unidirectional effect running from GDP to MW (and negative effect of MW on GDP) was detected for the regions of new EU countries. Furthermore, MW had no significant influence on GFC, while GFC had a positive and significant long-run impact on MW in the regions from old EU countries. EMP has a positive bidirectional relationship with MW for the regions of old EU countries while the opposite effect was observed for the other category of regions. Other notable differences can be observed for the GDP – HE nexus; for example, which has a negative bidirectional relationship with regions of old EU countries, but has a positive and significant bidirectional relationship with regions of new EU countries.

When considering the effects of waste disposal methods, significant differences can be observed compared with MW generation. Economic growth promotes INMW, whereas LFMW is reduced in both categories of regions, indicating the positive environmental impact of GDP growth. Heating energy requirements also has a positive impact on waste disposal strategies. By contrast, the positive effect of R&D intensity was found only for regions of old EU countries. When it comes to the remaining socio-economic variables, only EMP for regions of new EU countries had a positive effect on INMW.

The strength of the relationships among the variables was evaluated by testing for short- and long-run causality using the VECM from Eqs. (20) – (27), as shown in Table 25. The results for regions of old EU countries shown in Table 25 indicate short-run bidirectional causality between (1) MW and GDP, (2) MW and EMP, (3) MW and HE, (4) MW and GFC, (5) GDP and R&D, (6) GDP and HE, (7) GDP and EMP, (8) R&D and HE, (9) R&D and EMP, (10) R&D and GFC, and (11) EMP and GFC. In addition, short-run unidirectional relationships running from R&D to MW, from HE to EMP, from GFC to HE, and from GDP to GFC can be observed. Table 25 shows that there are short-run bidirectional panel causalities among all the variables, except for unidirectional relationships from MW, GDP and EMP to R&D, from HE to EMP and GFC, and from GFC to EMP. Finally, no relationship was found between R&D and HE for regions of new EU countries. In contrast to MW, the only short-run relationships relevant for LFMW and INMW are those associated with EMP.

Table 24: Panel FMOLS

				regions of old EU countries				
				dependent var.				
indep. var.	MW	LFMW	INMW	GDP	R&D	HE	EMP	GFC
MW				0.057***	0.009***	0.214***	1.185**	0.016
GDP	0.155***	-1.722***	2.235***		-0.023***	-0.008	16.563***	0.688***
R&D	0.528***	-1.203***	0.274	-0.770***		0.315***	16.197***	0.326***
HE	0.221***	-0.591***	0.771	-0.010	0.017***		-0.084	-0.106***
EMP	0.001**	0.019***	-0.052***	0.004***	0.001***	0.001*		0.015***
GFC	0.085***	0.184**	-0.819**	0.249***	0.014***	-0.018***	14.622***	
R^2	0.868	0.993	0.872	0.993	0.982	0.964	0.979	0.973
Adj. R^2	0.828	0.992	0.860	0.990	0.979	0.959	0.976	0.968
				regions of new EU countries				
indep. var.	MW	LFMW	INMW	GDP	R&D	HE	EMP	GFC
MW				-0.048**	0.009***	0.024**	-2.115**	0.011
GDP	0.273***	-1.141***	1.539***		-0.005	0.055***	10.317***	0.948***
R&D	0.639***	0.295	-11.47***	2.308***		-0.080	78.037***	0.696**
HE	0.124**	-3.769***	0.332	0.278***	-0.004		-22.589***	-0.311***
EMP	-0.002***	-0.040***	0.078***	0.005***	0.0001**	-0.002***		0.001
GFC	-0.037**	0.377***	-0.477*	0.599***	0.006**	-0.020***	-5.314***	
R^2	0.872	0.871	0.799	0.929	0.986	0.944	0.814	0.929
Adj. R^2	0.853	0.847	0.781	0.924	0.984	0.937	0.802	0.919

Note: * statistically significant at P=0.10, ** at P=0.05, and *** at P=0.01.

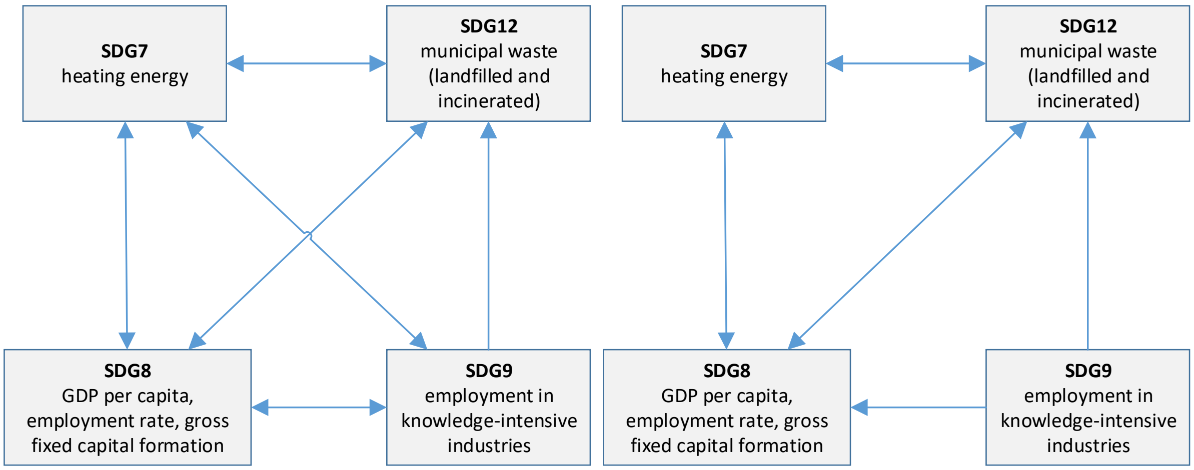
The statistical significance of the ECT coefficients from Eqs. (20) – (27) was tested to examine the long-run causal links. Table 25 shows that MW, GDP, EMP, and GFC are crucial for the long-run correction mechanism in the regions of old EU countries, indicating the presence of long-run bidirectional causal effects between these variables. Note that GDP, EMP, and GFC were also in bidirectional causality with LFMW and INMW. These results were also confirmed by the stacked pairwise Granger causality tests. By contrast, no long-run relationships running from the variables to R&D and HE in these regions were detected. Different results were obtained for the regions of new EU countries, as shown in Table 25. Long-run bidirectional causal effects between MW, GDP, and HE can be seen. Unlike in the regions of old EU countries, no bidirectional effects were present for LFMW and INMW.

Table 25: Panel Granger causality test

regions of old EU countries							
independent variables							
dep. var.	Δ MW	Δ GDP	Δ R&D	Δ HE	Δ EMP	Δ GFC	ECT
Δ MW		0.007***	-0.0007	0.022***	0.00003*	-0.001**	-0.002*
Δ LFMW		-0.048	-0.022	-0.071*	-0.001***	-0.038*	-0.001***
Δ INMW		0.098	0.552	-0.149	-0.014**	0.341	-0.025***
Δ GDP	0.034***		-0.025***	0.004**	0.0007***	0.010**	-0.002***
Δ R&D	0.009***	0.026***		0.006**	-0.0003**	0.010*	0.001
Δ HE	-0.033***	-0.259***	0.093***		0.0002*	-0.007	0.002***
Δ EMP	2.097***	13.125***	-6.505***	-0.658		2.823***	-0.706***
Δ GFC	0.107***	0.270***	-0.060**	0.035***	0.004***		-0.020***
regions of new EU countries							
dep. var.	Δ MW	Δ GDP	Δ R&D	Δ HE	Δ EMP	Δ GFC	ECT
Δ MW		0.057***	0.198***	-0.026***	-0.0003***	-0.009**	-0.016***
Δ LFMW		1.564	0.879	-5.015	-0.048**	0.227	0.001***
Δ INMW		-1.834	3.324	-2.756	-0.032**	-1.731	0.000**
Δ GDP	0.027**		0.115**	0.078***	0.0005***	-0.029***	-0.019***
Δ R&D	0.001	0.005		-0.005	-0.003	0.010***	0.003***
Δ HE	0.003*	-0.176***	-0.017		-0.001***	-0.014***	-0.004***
Δ EMP	-1.118**	6.316***	-9.573**	0.596		-0.039	-0.038
Δ GFC	-0.014	0.333***	-0.074	0.017	0.004**		0.013***

Note: * statistically significant at *P*=0.10, ** at *P*=0.05 and *** at *P*=0.01 using the Wald test.

Figure 16 shows short-run interactions among economic and environment-related SDGs at the regional level. Similarly to the national level in Chapter 6.1, tradeoffs between these two SDG categories can be observed while more intensive synergies exist in the regions of old EU countries.



a) b)

Figure 16: Interactions among SDG7, SDG8, SDG and SDG 12 for regions of old EU countries (a) and new EU countries (b)

6.3.3 Variance Decomposition

Results of the variance decomposition, shown in Figure 17 and Figure 18, indicate that 97.72% of MW can be explained by its own shocks (values for LFMW and INMW are 96.82% and 99.07%, respectively). Concerning the effect of remaining variables on MW, HE contributes to MW by 1.22%. The results of the other outcomes show that 2.53%, 0.82%, 1.75%, 1.95%, and 4.69% of variance in GDP, R&D, HE, EMP, and GFC, respectively, can be accounted for by MW. It is also noteworthy that a shock in GDP is quickly reflected in future changes in EMP and GFC. On the one hand, structural changes in EMP take more than five periods to be reflected in the long-run growth of INMW, and these changes can only account for 1.63%. On the other hand, 6.82% of variance in LFMW can be explained by the change in HE, whereas 3.21% and 2.76% can be attributed to the changes in GDP and GFC, respectively. These effects increase rapidly after two periods.

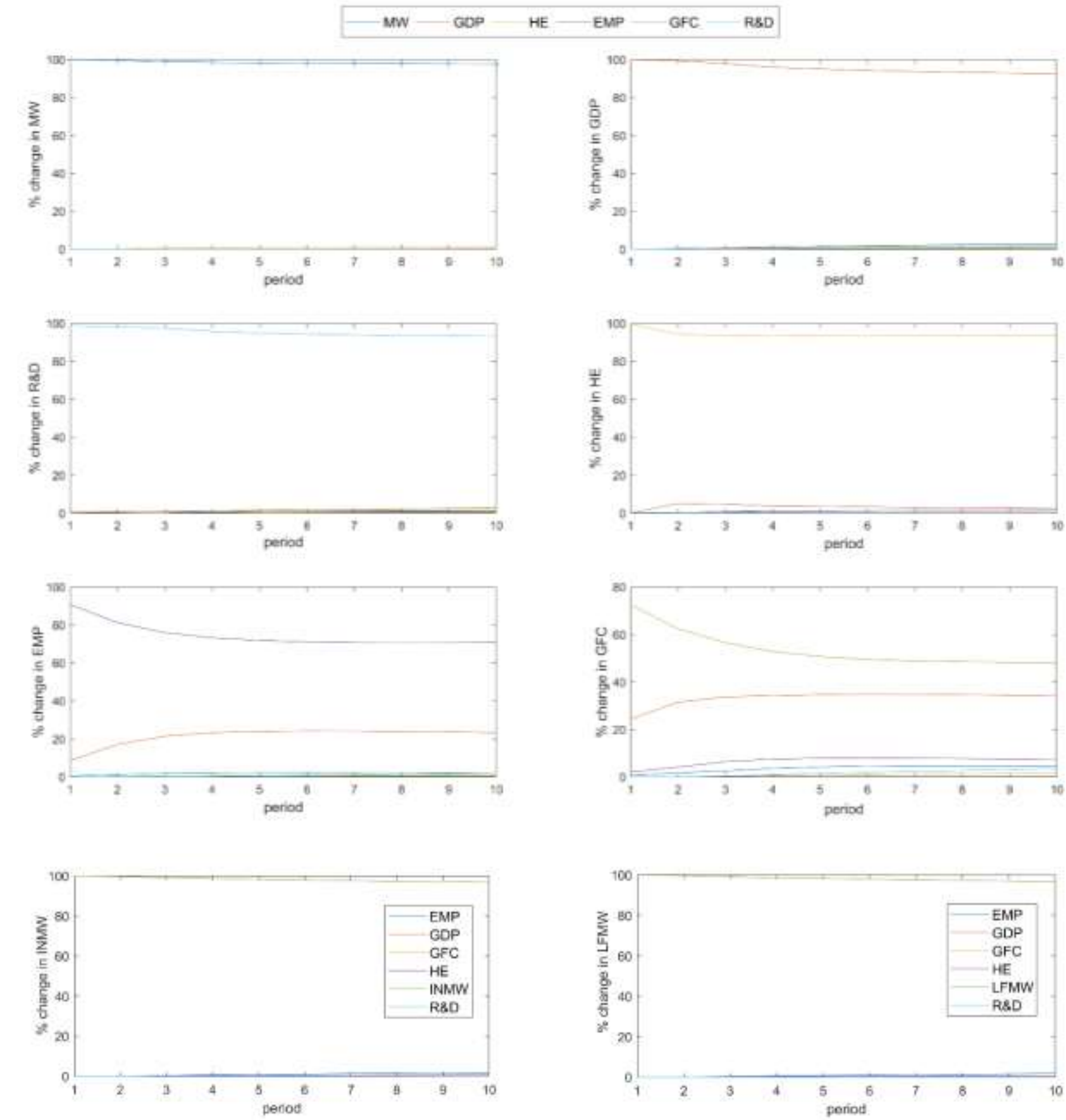


Figure 17: Variance decomposition for the regions of old EU countries

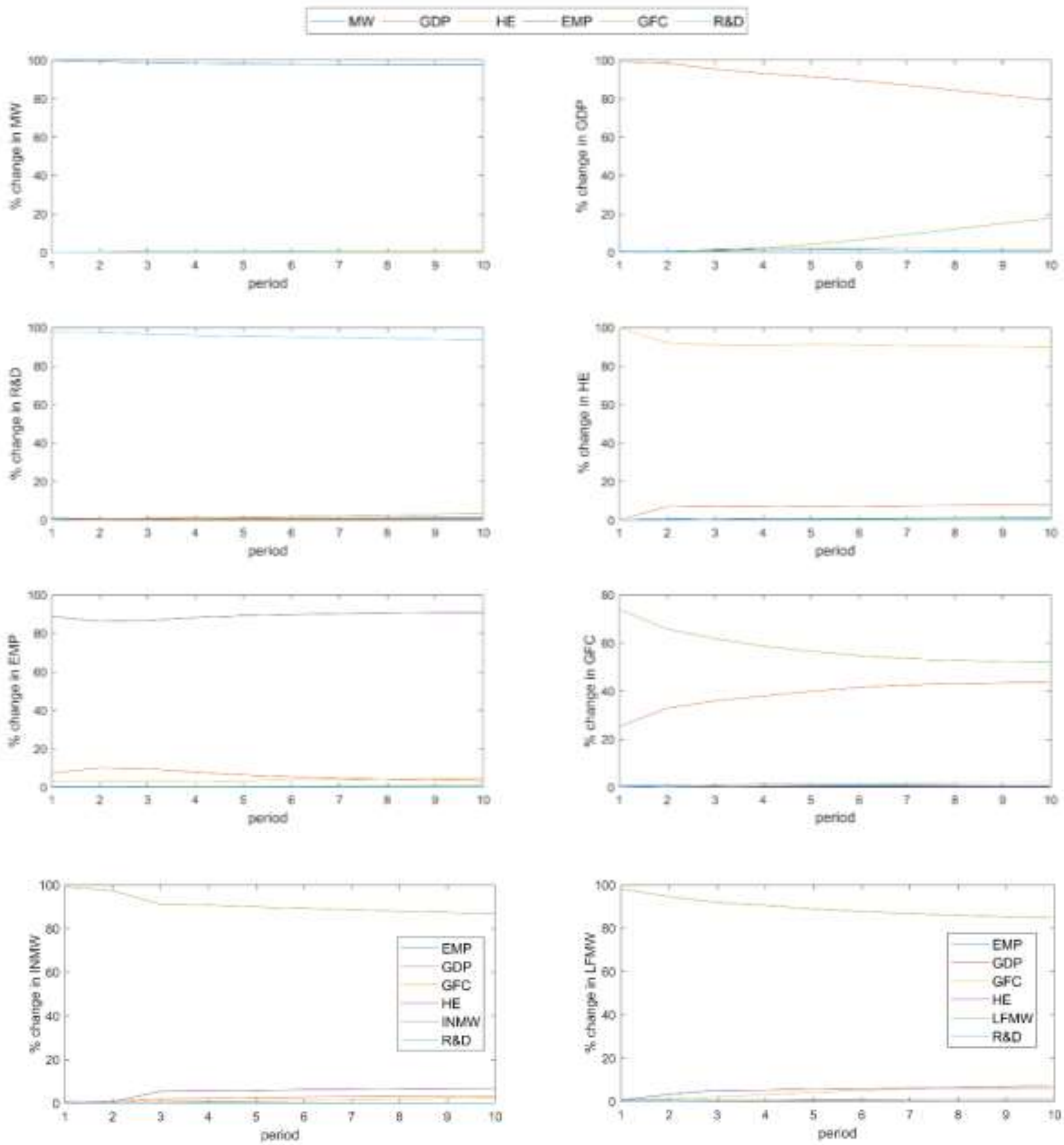
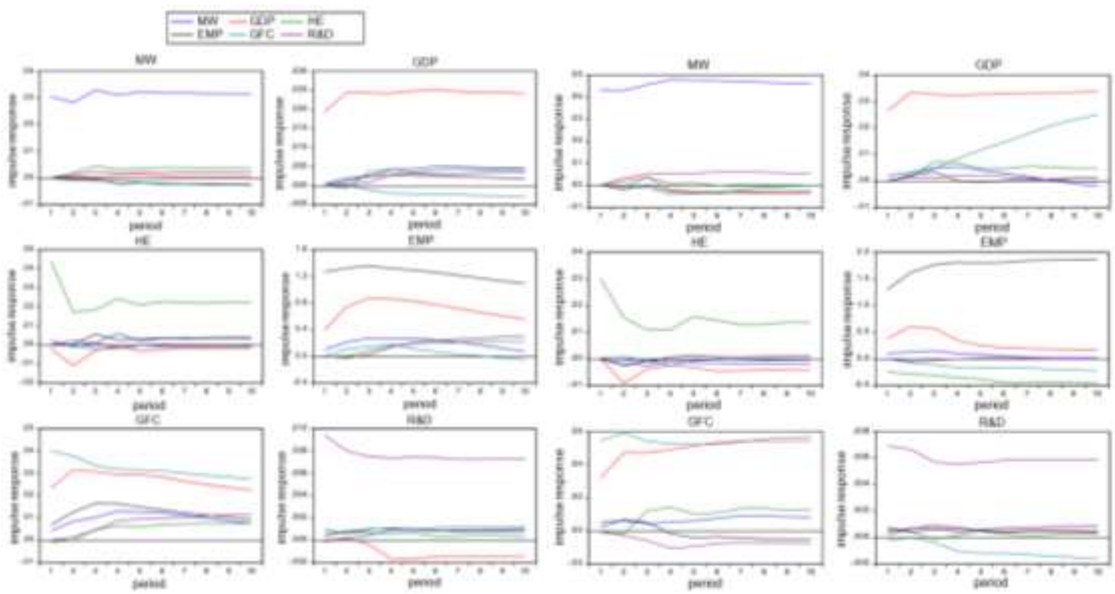


Figure 18: Variance decomposition for the regions of new EU countries

The results for the regions in new EU member states reveal that 97.77% of MW can be caused by its own shocks and 1.22% can be attributed to the change in R&D. MW contributed to R&D and HE by 1.24% and 1.22%, respectively. The contribution of MW to the other variables was less than 1%. Interestingly, the effect of GFC variation on GDP increased substantially after five periods. In contrast to the regions of old EU countries, the effect of GDP variation on EMP decreased after three periods.

To model the dynamic behaviour of the model, impulse response of the variables aftershocks to the other variables was examined, as shown in Figure 19. MW responds mainly to HE and R&D shocks for both categories of regions. In agreement with the results of the variance decomposition approach, shocks to GFC caused a significant GDP response in the regions of new EU countries. The response of GDP, EMP, and GFC to R&D shocks in the regions of old EU countries increased after three periods, while no significant response was measured for the regions of new EU countries. A different pattern of fluctuations emanating from MW were observed for the two categories of regions. The response of the remaining variables to MW shocks after three periods in the regions of old EU countries was particularly high, while this pattern was only seen for the GDP response of the other regions.



a) b)

Figure 19: Impulse response functions for regions of a) old EU countries and b) new EU countries

6.3.4 Discussion and Policy Implications

As previously reported in the literature, a strong relationship between MW and economic growth suggests an inverse U-shaped environmental Kuznets curve (EKC) (Ghazi Alajmi, 2016; T. Song et al., 2008). However, our study was unable to demonstrate this relationship. The results of our study suggest that the effect of GDP growth is significantly positive even in more developed regions of old EU countries, indicating that the problems of MW become worse with economic growth. However, the strength of the effect was decreased in economically developed regions, suggesting a more effective environmental policy implication of EU leaders (Melidis & Russel, 2020). On the one hand, our results imply that economic growth policies are not effective at reducing MW, which corroborates recent findings (Savini, 2019). On the other hand, the positive effect of economic growth on the use of waste disposal methods (in favour of incineration) suggests that incineration capacities are increasing in less developed regions. Therefore, whether other economic determinants have an analogous effect on MW is an interesting question to pursue. Moreover, our findings support the negative role of employment level in developed regions, which indicates that stronger consumer power leads to an increase in waste generation (Khajevand & Tehrani, 2019). What is worse, our evidence suggests that this leads to a reduction in incineration capacities and an increase in landfilled MW, indicating negative environmental impacts. Finally, GFC contributed to waste generation in the regions of old EU countries, which implies that economic development policies cannot be recommended for these regions. By contrast, for the regions of new EU countries, the positive effect of economic restructuring on the service sector prevails over the effect of consumer power. In summary, traditional economic development policy seems to be ineffective for regions that are completing the transitional stage of their economic structure, and new tools should be implemented to facilitate this transition toward the concept of the circular economy, such as innovative business models, product / organizational environmental footprint, and green public procurement to encourage demand for green goods and services. In addition, covering resource-efficient and financially sustainable waste management through user charges is usually not socially acceptable. To cover the costs of full-service, a wide range of economic instruments should be implemented, such as property and landfill taxes, tourist taxes and fees and product taxes. Note that the regional level is crucial for establishing these instruments. I also suggest this policy because these economic instruments have been reported to be effective at changing consumer preferences (Yamaguchi & Takeuchi, 2016) and promoting household waste separation (Xu et al., 2018).

Given that R&D intensity increased MW in both categories of EU regions, it is tempting to speculate that technology innovation promotes waste generation as the life span of products decreases. Thus, technology development has an adverse effect on waste generation, which implies that innovation policy that supports environmentally-friendly technological innovation must be designed. Our evidence suggests that R&D intensity promotes incinerated waste only in regions of old EU countries, corroborating the findings of (Mazzanti & Zoboli, 2009). Indeed, eco-innovation is crucial for delivering key aspects of the circular economy. Regions of Luxembourg, Germany, and other eco-innovation leaders should be used as benchmarks. Our research also suggests that policy makers should encourage introduction of the eco-innovation index / scoreboard at the level of EU regions to show their strengths and weaknesses. A set of circular economy indicators that measure eco-innovations at the regional level, as proposed in (Smol et al., 2017), is recommended. To stimulate innovation, market-based solutions such as taxes, charges, and deposit-refund systems must be strengthened. Information technology can also be used to support or widen the scope and usefulness of the incentive-based approach. For example, a remote sensor technology can be used to monitor emissions that will either enforce compliance or levy a tax on pollution. In the same manner, spaced-based satellites can help monitor environmental compliance across the regions (Singh, 2019). These technologies may also improve site selection, waste collection and route optimisation (Akhtar et al., 2017). For efficient monitoring of waste collection systems, radio-frequency identification (RFID) has been developed. An incentive-based RFID waste charging system was adopted in Korea. In the adoption process of this innovative system, the role of community-led governance was emphasized (S. Lee & Jung, 2018). In EU countries, RFID is used for solid waste collection and disposal, particularly in developed regions due to relatively high installation costs (Das et al., 2019). Smart recycling technologies utilising artificial intelligence to identify specific garbage components are another example of innovative technologies in waste management (Das et al., 2019). Overall, regional policy makers should encourage the production of eco-innovation outputs and outcomes by stimulating eco-innovation inputs through public R&D expenditures and green investments. This is also important for the planned EU transition to the concept of the circular economy.

Considering the effect that waste generation has on economic development, our work showed that there are significant differences between the old and new EU regions. Specifically, waste generation promotes (impedes) economic development in the regions of old (new) EU countries, indicating that waste management policies should be targeted at less developed EU regions in order to mitigate the adverse effect of waste generation on European regional economic development. For the regions of old EU countries, the results of the present study are in agreement with those of previous studies (Gutberlet, 2018), which suggests that sustainable jobs in the waste management sector can be created. As stated in previous reports (Hollins et al., 2017; International Labour Organisation, 2018; Pauli, 2017), turning waste to heat and renewable energy in the green or circular economy should create almost twenty million jobs around the globe by the year 2030. If 70% of the waste generated in the EU is recycled, this would create 322,000 direct jobs, 160,000 indirect jobs, and 80,000 induced jobs (Pauli, 2017). Similarly, approaches used in waste management (collecting, sorting, and separation) tend to create more jobs, especially for the socially excluded or unskilled labour force. As a side effect, people who are directly employed by waste management companies increase their consumption of goods and services as a result of their increase in salary. Hence, poverty can be reduced by growth of the waste management sector (Gutberlet, 2010). In effect, this growth would contribute to the achievement of both an "EU Zero economy" objective and Sustainable Development Goals (poverty reduction) by the year 2030 (Griggs et al., 2013). Hence, policy makers must be vigilant to evaluate the net macroeconomic impact of waste management policy and take into account the economic costs of such a policy. To sustain the positive effect that waste management has on economic development, policies should be revised in order to develop employee skills in the waste management sector. Job-related illness should also be minimized, and occupational safety must be strengthened (protection equipment) due to unhealthy working conditions in the waste management sector.

Another interesting difference between the regions of old and new EU countries was that R&D intensity contributes positively to GDP in the regions of new EU countries but negatively in the old regions. This negative effect can be ascribed to the effect of the economic recession, which resulted in decreased demand and supply of technological products (Fernald, 2014). Another factor could be the slowdown of labour productivity and total productivity in R&D intensive sectors in developed economies (Byrne et al., 2016). By contrast, the positive effect of technology development and GFC confirms the validity of the endogenous growth theory for the regions of new EU countries.

That waste generation contributes positively to R&D intensity is possibly due to state-of-the-art technologies that were developed in the EU regions. Strong knowledge spillovers have also been reported in the domain of waste recycling and environmental innovations in Europe (Aldieri et al., 2019). Another possible explanation is that high rates of recycling in EU regions promote competitiveness between European firms (Agovino et al., 2020). In addition, waste can be transformed into power (energy), which contributes to the competitiveness of other economic sectors. In fact, production of renewable energy has a strong influence on both R&D intensity and reduction of CO_2 emissions (Sim, 2018). By empirically confirming the positive effect that waste generation has on heating energy (waste to heat), our results provide strong support for the above findings. Consequently, the more that waste is converted into energy, the greater is the decline of GHG emissions (Uche-Soria & Rodríguez-Monroy, 2019). In order to sustain this, feed-in tariffs for waste to energy conversion should be implemented at the regional level. EU citizens should regard waste as a resource, and agencies responsible for converting waste to energy should be supported in their efforts to develop more innovative ways that enhance their current operational techniques. The regions should be encouraged to convert more waste to anaerobic digestion that would produce biogas for future use. The general public should help provide financing for such innovative waste management technologies at both the regional and national level through cohesion policy funding. The MW incineration capacity should be evenly distributed among the regions, which would reduce dependency on landfills. Indeed, our results suggest that economic growth policies are effective at reducing this dependency rather than at reducing MW generation. This will contribute to achieving the objectives related to resource efficiency of the EU 7th Environmental Action Programme. Efficient use of energy is a pre-requisite for attaining the circular economy by the year 2030.

7. Limitations and Further Research Suggestions

The current dissertation thesis found spatial dependencies within country samples, thus confirming the importance of spatial distribution in modelling sustainable development. Therefore, further experimental investigations are needed to estimate the spatio-temporal effects by using advanced exploratory and dynamic models. Future studies should also be conducted as a longer time series becomes available in the Eurostat database to address the issue of the relatively short time span of data in the current dissertation thesis.

Furthermore, I recommend the investigation of other national innovation performance indicators promoting economic growth, such as patent-based indicators, indicators of technological and nontechnological innovation activities (Antonelli & Gehringer, 2017), total factor productivity (You et al., 2020), and indicators of the capability of accessing innovative work and other types of knowledge (Perez-Trujillo & Lacalle-Calderon, 2020). Environmental variables should also be studied to investigate the trade-off between poverty reduction and environmental quality (Jin et al., 2020; Malerba, 2020).

Some variables that might have significant effect on environmental quality were not considered, such as R&D level or population density (J. Zhang et al., 2020). In a similar fashion, the effect of economic development on financial markets can be considered (Bekhet & Matar, 2012). Therefore, the proposed model can be further extended by incorporating those variables. An investigation of the interactions among energy consumption, CO2 emissions and economic development in different economy sectors could be another promising direction for future work. Another limitation might be the focus on two categories of EU countries, rather than investigating the interactions at the country level. This was mainly due to the short data span for individual countries. Hence, it would be beneficial to investigate the country-level interactions when a longer time series will be available.

Spatial dependence among regions was also observed. The location of waste disposal facilities (incinerators and landfills) is an important factor for municipal waste production and recycling (Ercolano et al., 2018). The model proposed here for modelling municipal waste can be extended by considering additional important variables from previous studies, such as combustible renewables and waste and CO_2 emissions. Additionally, R&D intensity was approximated based on innovation inputs only, but not eco-innovation outputs and resource efficiency outcomes.

Moreover, regional waste management methods were limited to landfilling and incineration, with no consideration given to municipal waste recycling (Lavee & Khatib, 2010). However, regional data on these variables must be provided by the EU to make such an analysis possible. Finally, it is fair to admit that the results of unit root and cointegration tests may be uncertain and contradictory. To obtain robust estimates, I performed multiple tests robust to cross-sectional dependence and heterogeneity. In a similar manner, the panel VECM was developed using two approaches to ensure robustness of the results. Unlike OLS, the FMOLS model was used to correct for endogeneity and serial correlation problems, which allows estimated coefficients to be asymptotically unbiased. However, note that the estimation of the vector autoregressive model coefficients may be uncertain due to relatively short time series. To reduce this uncertainty, a large number of observations was used in this study. Nevertheless, this limitation prevents the identification of nonlinear models. Therefore, to validate my findings in future studies, the use of a longer data span and nonlinear model estimations is strongly recommended.

8. Contributions of the Dissertation Thesis

The aim of the dissertation thesis was to propose and empirically verify the economy-society-environment nexus models of interactions among SDGs and sustainable development indicators at national and regional EU levels. The scientific contributions of this dissertation thesis are as follows:

- First, despite the considerable impact that R&D and complementary factors may have on the interactions among inequality, growth and risk of poverty, no one, to the best of my knowledge, has studied the dynamics of causal relationships among these variables while controlling for social transfers. The rationale for including this factor is that the income-based measures of inequality and risk of poverty are not sufficient to reflect diverse living conditions in different countries. For instance, significant differences in material deprivation between new and old European Union (EU) countries were demonstrated in one study (Fusco et al., 2011). Besides, the link between social transfers and inequality reduction has generated a debate as to whether social transfers actually reduce inequality and risk of poverty (Gnangnon, 2020; Riggirozzi, 2020; Wagle, 2017). A saturation point was found for EU countries, indicating that social transfers are efficient only for values below 27 per cent of GDP. The importance of specific economic conditions was confirmed in one report (Anderson et al., 2018), showing that government spending had a limited effect on redistributing income among poverty-stricken persons.
- My second contribution is to empirically evaluate the effects of R&D intensity on the model of inequality, growth, and risk of poverty in old and new EU countries while considering cross-sectional dependence and heterogeneity in the data. The EU, as one of the most developed regions on planet Earth, has not been entirely spared the scourge of inequality and risk of poverty. Its at-risk-of-poverty rate was almost 17 per cent in 2018, with more than 8 per cent of the population lifted above the poverty threshold by social transfers (Eurostat, 2020). What is most striking is that these rates have remained relatively stable in the last 10 years despite significant economic growth. Considerable variations exist across the EU countries, and inequality in the distribution of income was steadily increasing in the last 10 years (Eurostat, 2020). Therefore, at-risk-of-poverty

rate reduction was considered one of the top priorities for Europe 2020 in the initiatives set in 2010 (i.e., getting at least 20 million people out of poverty risk by the year 2020); it remains difficult to achieve this initiative because at-risk-of-poverty rate has continued to grow in the last 10 years (Madama & Jessoula, 2018). Indeed, previous studies indicated that the gaps have widened in the EU countries, with the new countries being the most disadvantaged (Weziak-Bialowolska, 2016). Here, I study new and old EU member countries separately to model diverse living conditions. Some new EU countries are still considered transitional economies and will continue to experience reductions in poverty risk as a result of rapid growth in their GDPs. In addition to substantial variations in poverty risk and the effectiveness of governmental policies between new and old EU countries, the economic and welfare state strategies also differ (Bosco & Poggi, 2020). Compared with the old countries, new EU countries also lag behind in terms of wages, social protection expenditures, and levels of life satisfaction (Aidukaite, 2011). Unlike most of the previous work, it is here shown that the panel data on the model of inequality, growth, and risk of poverty for EU countries over the period 2000 to 2018 are cross-sectionally dependent and heterogeneous. Therefore, to obtain consistent and reliable empirical results, I used appropriate modifications of traditional panel estimation methods that are robust for these problems.

- Previous empirical studies strongly imply the role of economic development in the nexus between economic growth and environment (Çoban & Topcu, 2013; Tiba & Omri, 2017). However, to the best of my knowledge, this is the first study to investigate the causal relationships among energy consumption, CO2 and economic development concurrently between new and old EU countries. This framework makes the current research an interesting topic that aims to bridge that gap in the literature. The short- and the long-run effects between economic development and environmental quality have not been tested for new and fifteen old EU countries. Hence, investigating a panel of eight new and fifteen old EU countries might reveal important insights into the effect of different economic environments on the nexus between economic growth and environment.
- Different aspects of economic development, incorporating GDP, FDI, net exports and employment in industry, are considered for the first time in this study. This can shed

new light on the complex interactions among economic development, energy consumption and CO2 in the investigated regions.

- To date, little agreement has been reached on what impact R&D has on the relationship between economic growth and municipal waste generation. Additionally, most studies to date that evaluated this relationship focused on individual countries, such as Saudi Arabia (Ghazi Alajmi, 2016) and Switzerland (Jaligot & Chenal, 2018). In other words, far too little attention has been given to local conditions and different regional economic environments. Moreover, EU regions have not been investigated, even though these regions have expressed high levels of concern about the adverse effects of waste generation. This study aims to bridge these gaps by examining the nexus between complex waste generation, R&D intensity, and economic growth at the level of EU regions. To examine these interactions, an appropriate econometric model was develop. The results of this study may have important implications for EU waste management policies and may provide support to existing and future EU action programmes. In this work, these two categories of regions were separately investigated by considering specific economic environments, different levels of technology development level, and different waste generation patterns in the regions of new and old EU member countries (Traven et al., 2018). To the best of our knowledge, this work represents the first time that the short- and long-run causal relationships between economic development, R&D intensity, and waste generation have been studied at the level of EU regions. In addition, for the first time, this study incorporates different regional aspects of production sources into the causal model. Considering recent panel data on NUTS-2 regions, VECM was used to test the Granger causality. More precisely, both the FMOLS model and the panel Granger causality test were performed to test the short- and long-run causalities. The problem of short data span (2000-2018) was addressed and unbiased estimates for the coefficients of the causal model were obtained using 226 and 58 regions for old and new EU countries, respectively. To estimate the magnitude of the identified effects, variance decomposition was performed in the last step.

Conclusion

This dissertation has investigated interactions among SDGs and sustainable development indicators in the EU. I have argued that the nexus approach is the best instrument to explore the interactions because it not only enabled me to detect the existence of relationships but also to estimate their directions and intensities. Therefore, the dissertation used panel cointegration, FMOLS and Granger causality tests to highlight the unidirectional and bidirectional relationships at both the national and regional EU level. Specifically, and for the first and foremost, it addressed the interactions in the economy-society-environment nexus model. The results indicate long-run equilibrium relationships in the proposed nexus models. In addition, several important short-run relationships were found, which has important implications for European sustainable development policies. It is worth noting that different economic, social, and environmental policies should be implemented in old and new EU countries due to the different interactions among SDGs and their indicators. These unique results are bound to avoid unanticipated consequences and it is apt to promote integrated planning and judicious decision making.

Generally, the results confirmed the vital roles of promoting energy use efficiency, providing protection for global climate change, and ensure technology development as priority SDGs. Consequently, the solution to my findings demands more integrated policies, harmony and teamwork among scientists, government, industry as well as citizens when negotiating priorities in SDGs. Moreover, it will be prudent for policymakers to continue monitoring these indicators to ensure their easy integration as well as long-run sustainability. This can be done by providing accurate and complete annual data about the indicators. Also, policymakers need to channel much effort to ensure capacity building in this regard. Again, it is obvious that government-led measures and policies will stimulate the attainment of positive results and curtail the negative consequences from these SDGs and their indicators. This may involve coordination among government bodies to achieve these aims. In addition, continuous strengthening the already cross-country and cross-regional coordination will help ensure policy integration as well as coherence. But this must be in harmony with decision making likewise implementation process procedures, particularly, regarding data collection and resource sharing and allocation, and assistance for research and innovation.

There is also a need to create a structured integrated strategy in supervising the process of attainment of SDGs and its indicators. For instance, and in the early stage, there is need to set a baseline or a scoreboard to monitor the progress of these indicators (especially carbon emission, waste generation, energy consumption, etc.). The data as well as information systems must be integrated to facilitate the assessment of the interactions among the sustainable development indicators. This can be applied at various stages from planning to the implementation of the policies and the evaluation of the policy results.

Besides, pursuing interdisciplinary research in the future will help unfold knowledge gaps in the nexus models. Additional SDGs and their indicators should be investigated to support and extend findings of this dissertation. This can also be accompanied by investigating different sustainable development scenarios, such as simulations of sustainable development policies. The verification of the nexus models was undertaken at the EU level. However, similar research or investigation can be carried out in other regions or globally, though different regions or institutions possess different sustainable development priorities.

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LIST OF PUBLICATIONS AND GRAND OF THE PROJECT

[1] GARDINER, R., HAJEK, P. Interactions among energy consumption, CO2, and economic development in European Union countries. *Sustainable Development*, 2020, 28(4):723–740. IF: 6.159

[2] GARDINER, R., HAJEK, P. Municipal waste generation, R&D intensity, and economic growth nexus – A case of EU regions. *Waste Management*, 2020, 114: 124–135. IF: 7.145.

[3] GARDINER, R., HAJEK, P. Effect of GDP, energy consumption and material consumption on waste generation - The case of 28 EU countries. In *Eurasian Economic Perspectives*, 2020, 12(1), pp. 73–85.

[4] GARDINER, R., HAJEK, P. Impact of GDP, capital and employment on waste generation-The case of France, Germany and UK Regions. In *Proceedings of the 8th International Conference on E-business, Management and Economics*, 2017, pp. 94–97. ACM.

[5] GARDINER, R., HAJEK, P. Impact of GDP, gross capital formation and employment on waste generation - The case of EU regions. In *6th Central European Conference in Regional Science, CERS 2017*, Banska Bystrica, 2017, pp. 138–145.

[6] GARDINER, R., HAJEK, P. The role of innovative SMEs to the growth of regional economy: The case of Czech Republic. In *Economic and Social Development: Book of Proceedings*, 2016, pp. 630–637.

[7] GARDINER, R., HAJEK, P. The causal relationship among sustainable development indicators and economic growth – The case of EU28 countries. In *16th International Scientific Conference Globalization and Its Socio-Economic Consequences Proceedings*. Zilina, 2016, pp. 468–474.