Received: 24 August 2023 | Revised: 30 October 2023 | Accepted: 6 January 2024 | Published online: 16 January 2024

RESEARCH ARTICLE

Green and Low-Carbon Economy
2023, Vol. 00(00) 1–12
DOI: 10.47852/bonviewGLCE42021582

BON VIEW PUBLISHING

Redefining Economic Growth for Green Economy: the Review of Industry 4.0 and Industry 5.0 Progress

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Abstract: The current definition of the gross domestic product (GDP) is based on industrial sectors and technological advancement correlated with Industry 1.0, Industry 2.0, and Industry 3.0. Considering that the economics sectors have shifted toward Industry 4.0 and Industry 5.0, there is a necessity to redefine a key economic development indicator to match the current imperative of the economy and to address technological pathways for green and low-carbon economy. The research question is: How can the GDP definition be improved to address the current imperative of economy to be consistent with the technological advancement of Industry 4.0 and Industry 5.0? The summary, evaluation, and analysis of the existing literature in the emerging field of advanced manufacturing were used to address this research question and to communicate the green and low carbon economy transition. The updated definition of GDP facilitating sustainable production was developed because of this review: *the Sustainable GDP is the standard measure of the value added created through the production of goods and services determining the proportional value of goods and services produced employing renewables, the proportional value of goods and services produced applying digitisation, and the proportional value of goods and services produced using inputs into production from recycling and remanufacturing in a country during a certain period.*

Keywords: economic growth, advanced manufacturing, emissions, gross domestic product (GDP), global value chains (GVCs), direct foreign investment

This review explores the opportunity to refine the gross domestic product (GDP) definition incorporating social and environmental objectives to be consistent with the technological advancement of Industry 4.0 and Industry 5.0.

1. Introduction

1.1 Gross domestic product

The economic growth is measured by a change in the volume of its output or in the real expenditure or income of its residents [1]. Gross domestic product (GDP) is the globally accepted indicator of economic growth. GDP is defined as the standard measure of the value added created through the production of goods and services in a country during a certain period. Furthermore, GDP additionally measures the income earned from that production, or the total amount spent on final goods and services (exports minus imports) [2]. GDP can be measured by three different approaches: an output approach, an expenditure approach, and an income approach. This review will convey the output approach to define the Sustainable GDP indicator.

The economic development was very steady prior to industrial revolutions. Each industrial revolution resulted in economic growth, that is, an increase in the output of production. Industrial revolutions are attributed to as “Industry x.0.” For the reference, Industry 1.0 was the transformation from agricultural activities to the development of steam machines resulting in a productivity increase, while Industry 2.0 was associated with the transition to assembly-line production and electricity power in the 20th century [3]. Onwards, Industry 3.0 employed the analog-to-digital conversion in production. Industry 4.0 was a further innovation delivering interaction and communication over the internet [4]. As a next step, Industry 5.0 facilitates the ability of manufacturing to accomplish social and environmental objectives in addition to economic, that is, to deliver resilience via an appreciation of the planetary boundaries and human-centric approach [5, 6]. Therefore, Industry 5.0 is a value-driven revolution that steers digital transformation toward social and environmental objectives [7].

The current indicator GDP defines economic growth in economic terms disregarding considerations related to social and environmental objectives, that is, social and environmental consequences of economic development are not measured. Similarly, the “value added” is described in economic terms rather than in social and environmental terms. Likewise, the key indicator used to measure the economic development is related to Industry 1.0, Industry 2.0, and Industry 3.0 technological advancement when the output depended on machinery and assembly methods involved. Industry 1.0 generated an output, which grew proportionally to the number of people involved in agricultural activities. Initially, workers moved from agriculture to manufacturing as the output per worker or per hour worked in manufacturing was higher than the labor productivity in agriculture. Subsequently, the earnings increased, the portion of total expenditure spent on services grew, and the proportion of manufacturing fell. This led labor to shift from manufacturing to services because of the better income [8]. Industry 4.0 and 5.0 are further optimizing labor force. As a result, the proportion of

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manual work decreased in favor of cognitive skills [9]. In summary, it is essential to redefine the measure of economic development to match the current progress in technology and to incorporate social and environmental objectives.

Advanced manufacturing is referred to multiple concepts such as sustainable manufacturing, sustainable entrepreneurship, Industry 4.0, and Industry 5.0 [10]. Advanced manufacturing techniques are now perceived as fundamental to the research and development (R&D) of new products and services across multiple industries [11]. Sartal et al. [9] define sustainable manufacturing as manufacturing able to limit environmental damage and consumption of energy and natural resources, while being socially accountable and economically feasible. Correspondingly, sustainable entrepreneurship is future-focused and designed to set up products, services, industrial processes, methods, and methodologies that decrease social and environmental impacts and increase the quality of life [12]. As described by Rainnie [13], Industry 4.0 is remodeling the way businesses produce, develop, and circulate their products and services. In Industry 5.0, manufacturers are accommodating latest technologies, inclusive of Internet of Services, Internet of Things (IOT), big data, cloud computing, artificial intelligence (AI), machine learning (ML), and deep learning (DL) into the production and operations management. The key objective of advanced manufacturing is to produce practical economic output while simultaneously reducing social and environmental impacts by integrating the latest technological advancement. As such, this review will be focused on advanced manufacturing.

1.2. Theoretical framework

This review establishes the agenda on the necessity of economic development to exercise economic, social, and environmental objectives associated with quaternary (Industry 4.0) and quinary (Industry 5.0) sectors of economy. The economic development is growing with the consumption. Consumption is increasing with the expansion of the consumer base. Despite this, there are green and low-carbon economy targets established to minimize consumption. Accordingly, there is a perceived conflict between economic stability based on the current definition of economic development and green and low-carbon economy targets. This review aims to redefine one of the key indicators of economic development – GDP to be aligned with green and low-carbon economy targets and to be consistent with the technological advancement of Industry 4.0 and Industry 5.0. This review will contribute to the emerging field of study on advanced manufacturing. The research question is: *How can the Gross Domestic Product (GDP) definition be improved to address the current imperative of economy to be consistent with the technological advancement of Industry 4.0 and Industry 5.0?*

1.3. Systematic literature review

In addition to research on advanced manufacturing, this review will contribute to the broad field of literature on Green GDP by employing the productivity lenses. The Green GDP concept was applied from 1980s in the attempt to account for environmental and social impacts resulted from economic growth. The search term "Green GDP" returns 1,890,000 results on Google Scholar. The most cited papers with the number of citations over 95 were analyzed [14–24]. The major discussion in these papers is built around the complexity of Green GDP measurement in addition to the challenge of the establishment of green accounting systems across all levels of government such as local, state, and federal. Even though the Green GDP indicator has a simple formula — Green GDP is equal to GDP minus GDP minus Environmental Costs and minus Social Costs (Green GDP = GDP – Environmental Costs – Social Costs) — it is difficult to put these figures in monetary terms because of the qualitative nature of social and environmental costs. The implementation side makes it difficult to apply Green GDP indicator globally. Therefore, this review is focused on developing the Sustainable GDP definition using the literature on advanced manufacturing as advanced manufacturing has a direct effect on the outputs. The proposed Sustainable GDP formula provided in Section 4 is expressed in output measures, which are simple to calculate and apply globally at any level of governance.

The summary, evaluation, and analysis of the existing literature in the field of advanced manufacturing were used to address the research question. Primary peer-reviewed articles were sources from SAGE Publishing, Sage Open, Springer, Wiley, and Elsevier with the publication date with most articles published from 2018 to 2023. The keywords used for search are economic growth, economic development, carbon, emissions, digital, recycling, Industry 4.0, Industry 5.0, manufacturing, production, sustainable, and environmental.

The pivotal publications are a book chapter by Coe et al. [25] "Globalizing regional development: a global production networks perspective"; an article "Plastics recycling: challenges and opportunities"; and a book "The machine that changed the world." The most sited studies are focused on digital renewables, innovation, environmental sustainability, population growth, economic growth, and reverse logistics. Other studies reflect on numerous manufacturing concepts, for example, smart manufacturing, lean manufacturing, sustainable manufacturing, etc. Various researchers describe different concepts used to reduce waste in outputs such as lean manufacturing, reverse logistics, and "smart factories" to deliver green and low-carbon economic development. Additionally, researchers use multiple notions of circular economy, for example, R strategies – 3R, 6R, 9R, or 5S methodology.

This review assessed the data on the top largest economies in the world the United States, China, Japan, Germany, India, the United Kingdom, Canada, Russia, Brazil, South Korea, and Australia.

The Sustainable GDP definition is a gap in the literature. The Google Scholar search does not return relevant searches containing all keywords. Additionally, there is a research gap whether global indictors are subject to systematic review, monitoring, and update to match the current state of R&D. The global indictor framework developed for sustainable development goals (SDGs) is an example of the implementation of this principle that might be widely adopted to other global indictors. Currently, SDG Goal 8 "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" is based on the actual GDP indicator by using annual growth rate of real GDP per capita provided by the World Bank accompanied with sustainable targets. However, due to data scarcity, more than half of the SDG targets could not be monitored in the Asia-Pacific area in 2020; according to the UNEP, data are lacking for 68% of the environment-related indicators [26]. As such, the complexity of calculations and data gathering impose barriers to the implementation of numerous SDG indicators. This review will provide the opportunity to calculate the Sustainable GDP indicator by basic arithmetic.

The review of the literature of advanced manufacturing reveals five main topics affecting GDP, which will be discussed further in Section 2: economic development and emissions; population growth; renewables and decoupling; digitization and global value chains (GVCs); recycling, remanufacturing, and circular economy.

2. Materials

The next two sections of this review will analyze the data on GDP in relation to primary industries as well as the shift toward services, which indicates the transition from developing to developed countries. The population growth as a consumer base is also an import factor affecting GDP. The data were collected from open sources such as United Nations, IPCC, OECD Data, Word Bank Data, International Monetary Fund, Earth System Science Data, the Breakthrough Institute, World Steel Association, the European Chemical Industry Council, European Cement Association, and business reports for industry sectors.

2.1. Economic development and emissions

Many researchers have studied the impact of economic development on emissions [27–34]. This section will review the correlation between the GDP growth and emissions.

There is a statistically significant effect of the rapid growth in the economy on CO2 emissions [31]. The countries with the fastest growing GDP and with the rapidly expanding population are emitting the most. Carbon intensity as the measure of CO2 produced per dollar of GDP is reflecting the efficiency of the economic development. In accordance with the data presented in Table 1, the smallest carbon intensity is driven by the United Kingdom, Germany, and the United States.

Besides this, Table 2 [36] demonstrates that the top largest economies in the world have significantly shifted their structure of industry toward services with the proportion of services varied from 48% to 80% out of one 100% (Industry 3.0).

As a result, the current GDP definition captures the primary (agriculture – Industry 1.0), secondary (industry and manufacturing – Industry 2.0), and tertiary (services – Industry 3.0) sectors of the economy and their technological advancements, Although Industry 4.0 and Industry 5.0 introduced additional economic sectors such as the quaternary sector (technology) and quinary economic sector (social, government, education, and healthcare), which are not reflected in the current GDP measurement from technological advancement point of view.

Moreover, primary sectors of the economy steel, cement/concrete, paper and pulp, and chemicals/petrochemicals are the top four emitting industries [37] presented in Table 3 "Most emitting industries by country in output." Thus, these primary sectors of economy have the maximum energy-saving potential [38].

These four primary industries are high-growing industries. The global steel demand is being expected to grow from 1.6 Gt in 2020 to 2.4 Gt in 2100 [43]. Similarly, the global market for chemicals increased from $4700.13 billion in 2022 to $5079.29 billion in 2023 [44]. Likewise, the global pulp and paper market was estimated at USD 374.34 billion in 2021 [45]. Also, the global market for cement is growing from $340.61 billion in 2022 to $481.73 billion by 2029 [46]. The largest industries in revenue by market size are being projected to be chemicals and petrochemicals, which use gas and oil in production, with steel, which uses coal in the initial production cycle, having the second highest revenue.

All countries listed in Table 3, except for the United Kingdom and Australia, are in the top 20 major steel-producing countries. Each country is indexed in the top 20 global cement-producing countries. Every country, except for the United Kingdom, Australia, and South Korea, is registered in the top 10 paper and pulp producers. All countries, except for the United Kingdom, Australia, and Canada, are at the top of the list of chemical producers. However, Australia, the United Kingdom, and Canada have minimal output in steel production. Generally, the top-performing countries by GDP are the top primary industry producers by outputs disregarding the shift of economy toward services.

These four primary most emitting industries produce outputs that are used as inputs (intermediate goods) in other production lines such as construction, automotive, aircraft, space, heavy industrial equipment, medical equipment, printing, clothing, transport infrastructure, household appliances, packaging, plastics, fertilizers, and digital devices. The demand for these products is growing with population growth (the consumer base growth). The most emitting primary industries are the production of steel and the production of cement, which are used in housing, infrastructure, and transportation.

2.2. Population growth

The two major measures of economic growth are an increase in input and an increase in productivity [8]. The growth in dominant Asian economies was achieved via the increase in input and/or intermediate goods without the association with the increase in productivity [47]. Total factor productivity (TFP), also known as

Table 1
The correlation between economic development and emissions

Country	GDP millions of US dollars [35]	Carbon emissions million Mt [29]	Carbon intensity[1] CO2 Mt emission per dollar (tons)
United States	26,190	5,007	0.191 (191000)
China	19,240	11,472	0.596 (596000)
Japan	4,370	1,067	0.244 (244000)
Germany	4,120	675	0.163 (163000)
India	3,820	2,710	0.709 (709000)
United Kingdom	3,480	346	0.099 (99000)
Canada	2,330	545	0.233 (233000)
Russia	2,140	1,756	0.820 (820000)
Brazil	2,060	489	0.237 (237000)
South Korea	1,790	616	0.344 (344000)
Australia	1,790	391	0.218 (218000)

Table 2
The structure of industry in selected countries

Country	Agriculture	Industry ISIC divisions 05–43	Manufacturing ISIC divisions 15–37	Services
United States	1.1	18.4	11.2	80.1
China	7.7	37.8	26.3	54.6
Japan	1.0	29.0	19.7	69.5
Germany	0.7	26.5	18.2	63.3
India	18.2	24.5	13.7	48.4
United Kingdom	0.6	17.1	8.7	72.7
Canada	1.7	24.6	9.9	66.9
Russia	4.0	29.8	13.4	56.1
Brazil	5.9	17.7	9.7	62.8
South Korea	1.8	32.6	24.8	57.1
Australia	2.0	25.5	5.7	66.3

Table 3
Most emitting industries by country in output

Country	Chemicals sales Euro billions [39]	Steel millions of tons [40]	Paper pulp millions of tons [41]	Concrete/Cement millions of tons [42]
United States	437	85.8	50.9	89
China	1,729	1032.8	14.5	2376.9
Japan	190	96.3	7.2	52.1
Germany	130	40.1	2.3	35.5
India	104	118.2	3.4	290.0
United Kingdom	–	7.2	–	8.0
Canada	–	13.0	15.4	13.0
Russia	58	75.6	8.8	56.0
Brazil	77	36.2	21.6	60.6
South Korea	133	70.4	–	48.0
Australia	–	5.8	–	9.6

Solow's residual, is a measure of the proportion of production growth that cannot be explained by increases in inputs such as capital and labor [48]. It captures the impact of technological advancement, manufacturing increases, and other unforeseen aspects. Gains in TFP indicate the portion of output resulting from resource efficiency or the implementation of new technologies. Energy, use of technology, and benefits of circular economy as inputs are not included in the current GDP calculation. However, these inputs may result in better understanding of TFP outside labor and capital.

Post-growth and degrowth studies inform that after a certain period, economic growth will not be feasible or achievable. The growth might be affected by resource limitations as well as social and environmental impacts. Therefore, it is important to "innovate without growth" [49]. The demand for products and services is based on population growth, that is, the growth in consumer markets. Population growth is projected to slow down or decline by 2070–2090 as in Figure 1 [50].

There is no direct correlation between a country's population growth and the economic output with the exception for TFP, which includes labor as an input, that is, even with a declining population, the country can still have economic growth [51]. Russia and Japan are two countries with a declining population that are constantly in the top 10 countries by GDP. Moreover, GDP per capita can be negative if population growth outpaces GDP growth in a given period, that is, the economic output of the country is not covering the population's needs [52]. Therefore, the population decrease in high-income countries decreases economic growth due to customer loss, although the population increase in low-income countries decreases their economic growth per capita [53]. Additionally, GDP increases when there is a trade surplus. When exports exceed imports (trade surplus), the country is successful in international trade as the country is trading across global consumer markets.

The Kuznets curve hypothesis as in Figure 2 [54] is irrespective of population growth (the population in this model is considered to be stable). The Kuznets curve hypothesis defines the relationships between economic development and environmental degradation. But, when the population reaches a certain income level, the growth in the economy facilitates environmental remediation at the stage of the economy change from industry to services. Table 2 [36] demonstrates that the change from industry to services has already occurred in all countries with the highest GDP performance. Hence, the most developed countries will choose to exercise environmental preservation via the latest technological innovations to recoup the short-term loss of profit in economic greening [55].

3. Methods

The literature on advanced manufacturing is mainly build around three major themes: renewables, digitization, and recycling/remanufacturing. The below sections will synthesize and analyze the information from the literature on advanced manufacturing in detail on each of these themes.

Figure 1
World: Total population

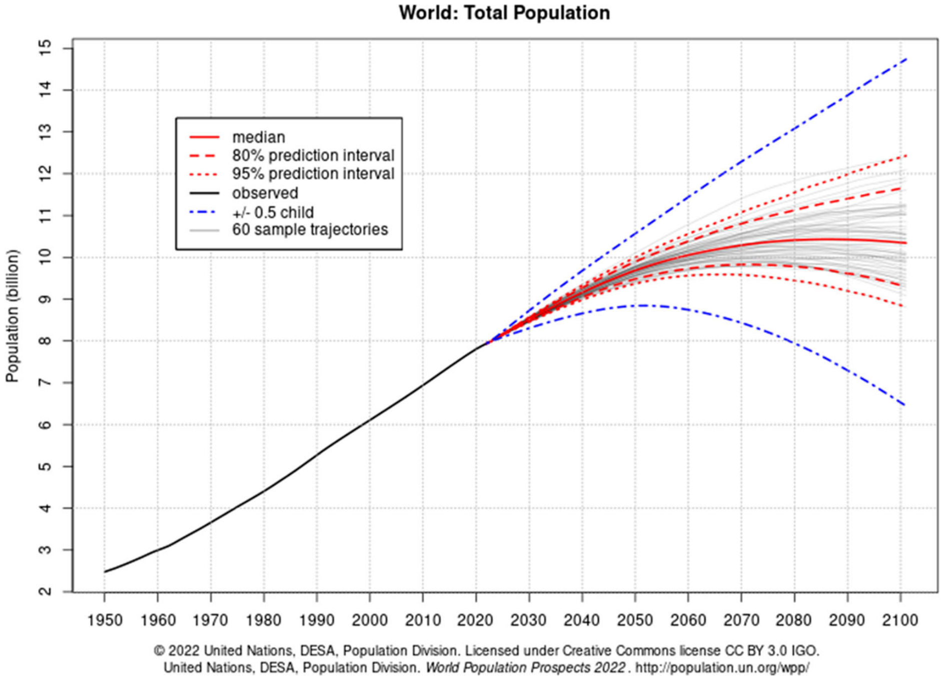
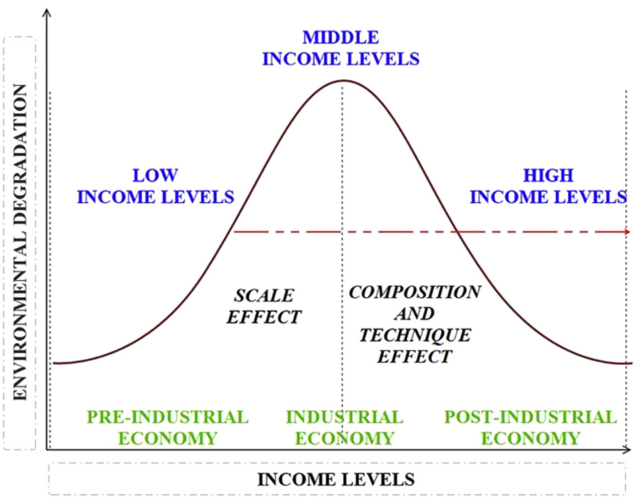


Figure 2
Environmental sustainability curve and economic growth



3.1. Renewables and decoupling

Decoupling defines the correlation between the growth of the economy, the consumption of resources, and environmental consequences [30]. Decoupling takes place when the growth in environmental damage is less than that of its' economic activity (GDP) over a given period [49]. An absolute decoupling occurs when the growth of the economy is not connected to CO2e released from fossil fuels consumption. Relative decoupling happens when GDP and CO2e increase, with the GDP rate increasing faster. Absolute decoupling occurs when the GDP increases but CO2e declines [56]. An example of the absolute is presented below in Figure 3 [34].

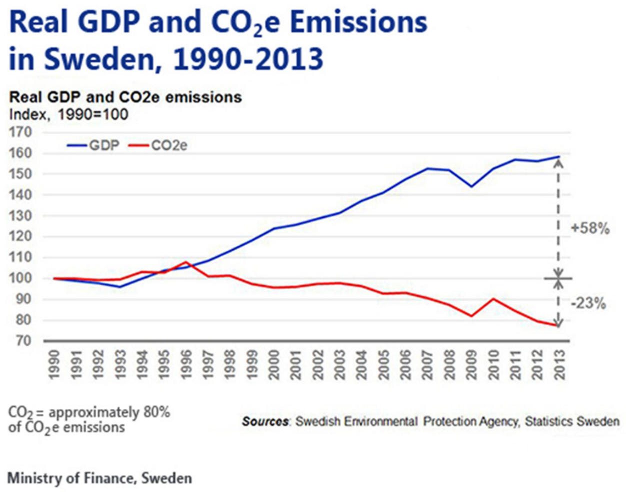
This dissociation of GDP and emissions could be interpreted as a flag of the sustainable manufacturing revolution and the employment of environmental and social objectives like Figure 4 [33] that require reasonable R&D expenditure. As R&D activities are associated with increased risk, big investments, and an extended return cycle, businesses with high debts tend to limit R&D spending [57]. Despite this, there are two major financial instruments to address emissions: subsidies and charges or taxes. Based on research data, pollution charges are more successful in addressing emission reduction, while environmental subsidies (net cash flow) are more efficient in energy conservation [58].

The efficiency of green development is significantly greater in areas with the access to high-tech knowledge spillovers and GVCs [59]. Developed countries with access to high-tech knowledge spillovers and GVCs have a greater likelihood of emissions' reduction as shown in Figure 4 [33]. Furthermore, renewable energy and international trade in the form of direct foreign investment have a strong association with decoupling [60]. However, nations that have accomplished absolute decoupling are continuing to contribute to emissions, as emissions' reduction is not emissions' elimination. This demonstrates the ceiling of "green growth" and the ceiling of an absolute decoupling [30]. A long-term policy exercise is needed to address decoupling by reducing emissions across supply chains. As such, the transition to renewable energy is vital.

3.2. Digitization and GVCs

The access to GVCs and direct foreign investment is allowing companies to develop faster and spend more resources on environmental policies. GVCs are connections of interrelated activities and procedures through which products and services are manufactured, administered, and consumed on a global scale [61, 62]. Medium- and high-technology manufacturing sectors are

Figure 3
Emissions and GDP



reliant on global supply chains [63]. Advancement in technological progress and modernization are a fundamental and dynamic part of the accelerated pace of globalization [32]. Information technology has promoted the evolution of the digital economy. Virtual products and services proportionally grew into a valuable contribution to economic development [27].

The scale of trade is growing by accelerating better coordination between buyers and sellers via global platforms. The notion of "platform capitalism" refers to a changing array of innovative methodologies that are moderated by global platforms and have been developed via the progress in information and communication technologies (ICTs) [64]. The introduction of ICT platforms (Google, Facebook, and Yahoo) and marketplaces (Amazon or Alibaba) supports the shift closer to the consumer via sophisticated logistics and real-time data. These global platforms assimilate production and communication structures while building global supply chains more explicitly and facilitating the reduction of waste, packaging, and energy [9]. The total embodied emissions of ICT have shown a considerable declining trend, but the percentage of embodied carbon emissions associated with trade travel is increasing due to the longer distances of GVCs [28]. As such, the greening of the transportation logistics for these global supply chains is necessary.

Digitization — the mass adoption of ICT by governments, businesses, and consumers — become credible nowadays [65]. The application of ICT allows businesses to adjust instantly to unstable consumer demands and the inclusion of new products into production line – demand-driven manufacturing [66]. "The technologies most used in digital sustainability activities include distributed ledger technologies (blockchain), artificial intelligence, machine learning, deep learning (AI/ML/DL), big data, analytics, mobile technology and applications, sensors and other IOT devices, and other telemetry tools like satellites and drones" [10]. Moreover, the scalability and ecosystem coordination of these technologies come at low costs, which implies lower market barriers. Digitization allows to correlate expenditure among different participants, allocate a share of the remaining public goods profits, and allow the global market to assess the implication of social and environmental expenditure.

The example of digitization in manufacturing is the "Smart Factory." The "Smart Factory" incorporates consumers into the production process, which in turn can increase advanced manufacturing in leading economies. "Smart factories" advantage technical equipment connecting end-users and other appliances, enterprise automation, and real-time contact between the smart factory and the market users to facilitate effective transformation and enhance adaptability by instantly transforming processes via adjustment, virtual examination, and communication [67]. As such, smart manufacturing requires locations where a highly skilled workforce is accessible and where virtual infrastructure is adequately supplied [13]. The "Smart Factory," where equipment is managed by ICT, manufacturing is virtually communicating with suppliers and customers, and operations are under real-time continuous analysis and monitoring, demands highly skilled labor while gaining productivity and reducing the entire workforce [68].

Technological transformation is generating a different type of global business that prioritizes non-material resources over material resources. The future of production and consumption is transformed into the mode of digital products and services, which can be consumed virtually [69]. Regrettably, outside the locations accessible for high-tech knowledge spillovers via labor, ICT, and foreign investment, regional areas continuously employ low-tech industries and, therefore, miss the opportunity for technological transformation [55]. Thus, an access to foreign investment and high-tech knowledge spillovers facilitates the reduction in CO2 emissions and enriches primary industry production through technological transformation, sustaining the economic development [32].

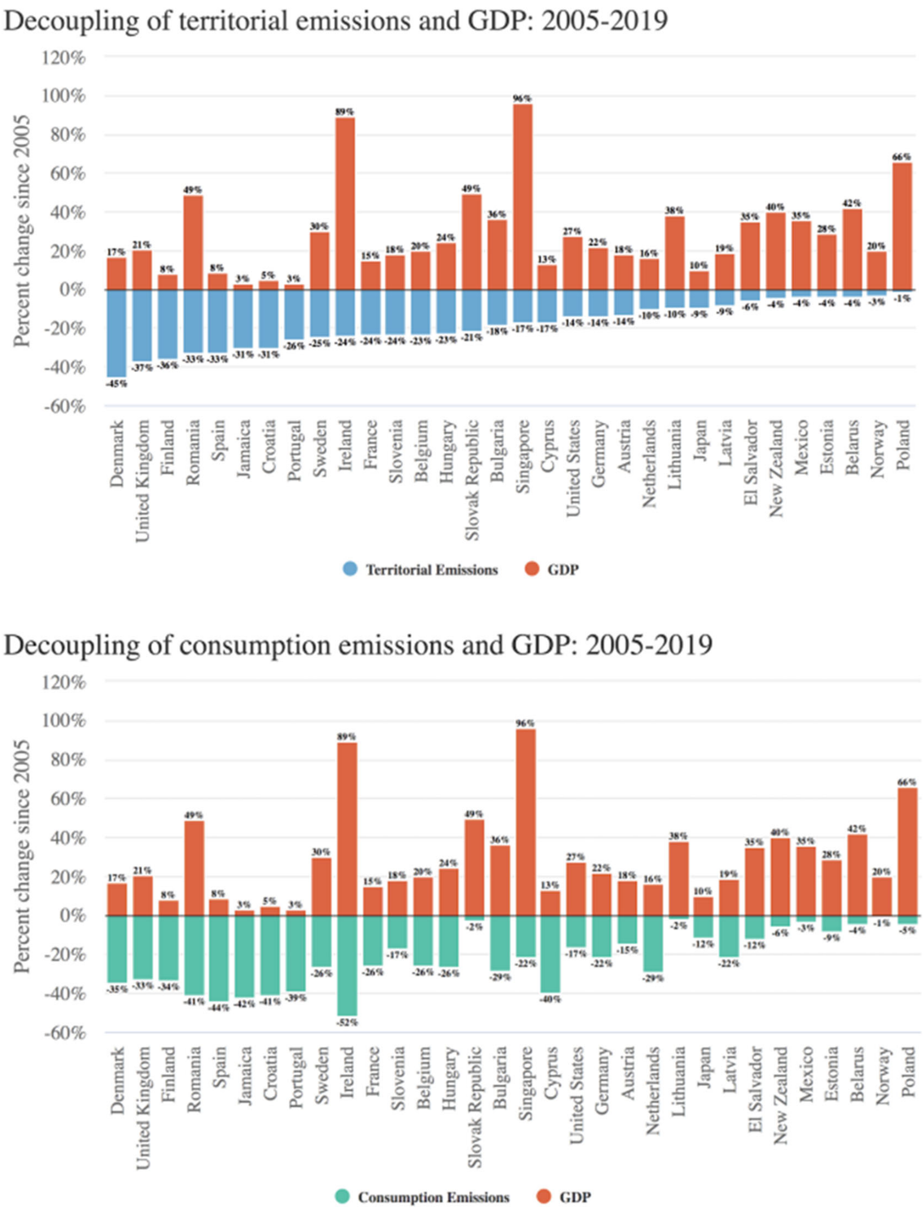
3.3. Recycling, remanufacturing, and circular economy

Knowledge spillovers are typically understood as a flow of knowledge from one entity to another. It is a process of the transmission of knowledge to others beyond the intended boundaries and represents the positive externality of the creation of knowledge, accruing to parties other than the creator [70]. Knowledge spillovers are expanding returns to intermediate inputs in processing final goods [69]. Global trade and globally supply chains drive the development of high-tech knowledge spillovers. This results in productivity gains and the growth of the economy via productivity gains [8]. One of the most widely used concepts of productivity is labor productivity [71]. Productivity grows when a higher output is generated without raising the input or when the same output is generated with fewer inputs [72].

Various researchers describe different concepts used to reduce waste in outputs such as lean manufacturing, reverse logistics, and smart factories to deliver green and low-carbon economic development. The concept of lean manufacturing intends to "use less of everything" in contrast with mass production, that is, less materials, less workforce, less capital in equipment, and less area [73]. Lean manufacturing is a technique that aims to reduce waste within operational processes while at the same time gaining productivity. Therefore, lean manufacturing methods demonstrate a positive correlation with CO2 reduction, including waste recycling, and are associated with environmental certification [74].

There is also a shift from linear to circular perception in manufacturing. Merkisz-Guranowska [75] described the composition of recycling systems as an element of a larger subject area recognized as reverse logistics. Reverse logistics in supply

Figure 4
Decoupling of territorial emissions/consumption emissions and GDP



chain management has received interest as an efficient response to the problem of overconsumption of raw materials and waste disposal in landfills [76]. Reverse logistics is identified as the forecasting, implementation, and management of the reverse flows of raw materials, technological inventories, packaging, and manufactured goods from the point of production, distribution, or use to the point of recovery or point of appropriate disposal [77, 78]. As such, products and services must be designed in the first place for recycling and remanufacturing to keep recycling and remanufacturing operations lean and to ensure cyclicality in the supply chain [79]. For example, plastic materials can be recycled in a variety of ways, and the ease of recycling varies among polymer types, package designs, and product types [80]. Similarly, recycling steel requires 75% less energy than manufacturing steel from crude stock. All types of steel are 100% recoverable and can be reprocessed an infinite number of times [81]. Correspondingly, aggregates of recycled concrete are utilized in existing green building composites to help preserve the environment and address social issues [82].

Moreover, Li et al. [83] developed the contemporary green supplier evaluation methodology, which can reduce social and environmental policy costs and increase economic competitiveness. Remanufacturing and recycling need to be elements of a sustainable supply chain management framework [79]. Fundamentally, the greening of global supply chains can be facilitated by using reverse logistics.

4. Sustainable GDP Definition

Based on the information presented in previous sections of this review, the key indicator of economic development can be redefined to be aligned with the Industry 4.0 and Industry 5.0 technological advancement employing renewables, digitization, and recycling:

The Sustainable GDP is the standard measure of the value added created through the production of goods and services determining the proportional value of goods and services produced employing renewables, the proportional value of goods and services produced applying digitization, and the proportional value of goods and services produced using inputs into production from recycling and remanufacturing in a country during a certain period [abc].

a – renewable energy rate is the proportional value (%) of the contribution of renewables to total primary energy supply [84].
b – digitization of economy rate is the proportional value (%) – the Digital Economy and Society Index (DESI) which incorporates human capital, connectivity, integration of digital technology, and digital public services and was developed by the European Commission [85].
c – recycling rate is the proportional value (%) of waste recycled from the total waste generated [86].

It is important to stress that Sustainable GDP is different to Green GDP. This research reviewed only GDP measured by the output method. Income and expenditure methods of a GDP measurement were not considered. The output method measures GDP as the value of output (what is produced) minus the value of goods and services used up in producing these outputs (the inputs or Intermediate Consumption) plus all Taxes on Products like VAT minus all Subsidies on Products like renewable energy subsidies. Therefore, taxes are more effective than subsidies as taxes contribute to the GDP value positively and subsidies, in turn, affect GDP negatively.

However, the elements of this formula can be adapted to the Sustainable GDP definition as follows: the value of output determining the proportional value of goods and services produced employing renewables, the proportional value of goods and services produced applying digitization, and the proportional value of goods and services produced using inputs into production from recycling and remanufacturing; and the value of goods and services used up in producing these outputs determining the proportional value of goods and services produced employing renewables, the proportional value of goods and services produced applying digitization, and the proportional value of goods and services produced using inputs into production from recycling and remanufacturing.

5. Discussion

The Sustainable GDP indicator will have certain policy implications for developed and developing countries:

Developed countries with stabilized population growth and stabilized industrial growth may implement the following policy objectives: ensure that new infrastructure and built environment developed for the primary industries will be green; establish additional provisions and investment to provide an access to ICT in rural areas; facilitate the transition to Industry 5.0 with the focus on government, education, and healthcare while investing into robotics and smart machines; organize the sharing of knowledge and technological spillovers via the global companies' expansion in developing countries; ensure the transition to renewable energy by taxation measures; facilitate greening of the existing ICT infrastructure mainly focusing on transportation costs; organize the direct investment into "smart factories" while considering the location of highly skilled labor and existing ICT infrastructure; implement smart manufacturing and lean manufacturing; improve reverse logistics by product design and supply chain greening; and deliver the advanced manufacturing transformation via innovation, R&D, and direct state investment.

Developing countries with a growing population as a consumer base and growing primary industries may implement the following policy objectives: ensure that new infrastructure and built environment developed for the primary industries will be green; allow the direct adoption of low-carbon technologies, including built environment and infrastructure; introduce smart manufacturing and lean manufacturing; implement direct transition to services (Industry 3.0) and information and telecommunication technology (Industry 4.0) by skipping the primary industry and secondary industry development step (Industry 1.0 and Industry 2.0) [87]; facilitate by statutory policy instruments the direct investments in green ICT infrastructure; introduce reverse logistic frameworks such as recycling and remanufacturing; and facilitate the transformation via innovation, R&D, and direct foreign investment.

Additional policy measures may include but not limited to the following:

1. Using R strategies such as 3R (reduce, reuse, recycle), 6R (reduce, reuse, recycle, recover, remanufacture, redesign), and 9R (R0 refuse, R1 rethink, R2 reduce, R3 reuse, R4 repair, R5 refurbish R6 remanufacture, R7 repurpose, R8 recycle, and R9 recovery) [88].
2. Incorporating the 5S methodology, which is a cyclical methodology: sort, set in order, shine, standardize, and sustain the cycle [89]. For example, the sustainable organizational structure consisted of eight dimensions: greening the supply chain, green product development, addressing the base of the pyramid, a waste-to-profit reuse and recycling program, a science community education program, an employee wellness program, carbon management, and energy and resource efficiency [90].
3. Adopting "Smart Factory" that requires vertical and horizontal integration within the company, that is, integrating not only all the related production areas from different facilities but also, in turn, the links with distributors and customers through ICT platforms and applications that integrate production and information systems, making global supply chains more transparent and helping to reduce packaging, waste, and energy [91].

6. Conclusion

This article reviewed the existing literature in the emerging field of advanced manufacturing and contributed to the broad field of literature on Green GDP by employing the productivity lenses. The Sustainable GDP definition is a gap in the literature. Additionally, there is a research gap whether global indictors are subject to systematic review, monitoring, and update to match the current state of R&D. The research question was addressed by the systematic literature review: How can the GDP definition be improved to address the current imperative of economy to be consistent with the technological advancement of Industry 4.0 and Industry 5.0? Further research is needed to be completed in relation to the policy implications specific to country profile based on the industry sectors, projected population growth, population distribution, and major projected GDP revenue streams.

This review does not provide an explicit formula for measuring the Sustainable GDP. The development of the explicit formula for measuring the Sustainable GDP is subject to further research.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by the author.

Conflicts of Interest

The author declares that she has no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Natalia Bliznina: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

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How to Cite: Bliznina, N. (2023). Redefining Economic Growth for Green Economy: the Review of Industry 4.0 and Industry 5.0 Progress. *Green and Low-Carbon Economy*, https://doi.org/10.47852/bonviewGLCE42021582