A paper presented in the 16th International Conference on Sustainable Development at the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) Bangkok, Thailand, 2022.

Economic Growth and Circular Economy in the European Union: Novel Empirical Synergy Analyses Between Key Variables of Circular Economy and Gross Domestic Growth (GDP) and Gross National Income (GNI)

Jari Kaivo-oja, Jarmo Vehmas & Jyrki Luukkanen
Finland Futures Research Centre, Turku School of Economics, University of Turku
Åkerlundinkatu 2 A, 4th Floor, 33100 Tampere, Finland
Corresponding autours: jari.kaivo-oja@utu.fi

OIDA International Journal of Sustainable Development, Ontario International Development Agency, Canada.
ISSN 1923-6654 (print) ISSN 1923-6662 (online) www.oidaijsd.com
Also available at http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html

Abstract: Sustainable development has been at the heart of European sustainability policy for a long time, firmly anchored in the European Treaties. The 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs), adopted by the UN General Assembly in 2015, have given a new impetus to global efforts to achieve sustainable development. One key challenge of sustainable development policy is the smart orchestration of the circular economy in relation of economic growth processes. In our current economy, we take materials from the Earth, make products from them, and eventually throw them away as waste – the process is very linear. The linear operating model is also short-term. In a circular economy, by contrast, we stop waste being produced in the first place. We can re-plan, re-use and re-cycle. We may note that it is not possible to reach a sustainable growth process without well-functioning material recycling systems and functions of the circular economy. The well-functioning circular economy is good for business, people and the environment. The circular economy is a systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. There are needs and questions to transform every element of our take-make-waste system: (1) how we manage resources, (2) how we make and use products, and (3) what we do with the materials afterwards and (4) how we make trade with recycled materials. Only then when answer to these questions, can we create a thriving circular economy that can benefit everyone within the limits of our planet. Eliminating waste and pollution, circulating materials and products and regenerating nature are key functions of the circular economy. We must admit that waste is a human invention. If we move to a regenerative sustainability model, we begin to emulate natural systems. There is no waste in nature. This is a new invention of the circular economy.

We have seen a lot of discussions about the circular economy, but less attention has been paid to the critical links between the circular economy and economic growth. The study provides an empirical contribution to this research gap. This empirical research can open up new insights and avenues into the development of sustainability science. If policymakers are not aware of the links between the circular economy and economic growth, it will seriously hamper the development of the circular economy in the world. In this sense, research in the field of circular economy is very important and it should be promoted in the world.

The conference paper has a strong focus on the circular economy and changing dynamics of economic growth with key variables of the circular economy (CE). This comprehensive and empirical EU study elaborates following key variables of the circular economy: (1) Material footprint [CEI_PC020], (2) Resource productivity [CEI_PC030], (3) Generation of municipal waste per capita [CEI_PC031], (4) Generation of packaging waste per capita [CEI_PC040], (5) Recycling rate of municipal waste [CEI_WM011], (6) Recycling rate of e-waste [CEI_WM050], (7) Recycling of biowaste [CEI_WM030], (8) Trade in recyclable raw materials, Imports extra-EU27 (from 2020) [CEI_SRM020], (9) Exports extra-EU27 (from 2020) [CEI_SRM020], (10) Private investments, jobs and gross value added related to circular economy sectors [cei_cie010] and (11) Patents related to recycling and secondary raw materials [cei_cie020]. These 11 key CE variables are analyzed with synergy analysis method in relation to two key indicators of economic growth, Gross Domestic Product (GDP) and Gross National Income (GNI).

The study is based on synergy analysis method, which reveals both positive and negative synergies of key variables, and also growth processes without any synergy. The analysis provides additional strategic information for decision-makers concerning SDGs in the long-run. Presenting regular monitoring tool of progress towards the SDGs in the EU context is essential for this conference paper. The method can be applied also in other global sustainability assessments. The data of study is collected from the Eurostat Circular Economy databases and data set covers years 2000-2020. The indicators of economic growth are from the World Bank Key Indicator database. This 20 years database provides a reliable empirical foundation to analyze interlinkages between economic growth and key variables of the circular economy.

The conference paper reports various interesting empirical findings about the circular economy logic in the European Union. One key finding is that in the European Union the synergy levels between GDP and GNI indicator variables and the key variables of the circular economy are not at the same positive or negative levels, but may differ significantly from each other. This is an interesting finding for the management of economic growth policy in the European Union.

Keywords: Circular economy, economic growth, gross domestic product, gross net income, synergy analysis

Introduction

This empirical study presents the interaction of key global trends based on synergy analyses. It is good for decision-makers to be aware - not only of the development of the trends themselves, but they should be aware also of the interactions between the trends. That is why this study of the European Union is important and interesting. In this study, we present empirical findings in terms of interactions based on synergy analyses. The results presented in this study show synergy interactions, from 2000 until 2020 between economic growth variables (GDP, GNI) and circular economy variables. This is a statistical assessment of about two dozen years, which can be considered a long enough period to look at the trends of the global economy. We know certainly that we have seen a lot of discussions about the circular economy, but less attention has been paid to the critical synergy links between the circular economy and economic growth. The study provides an empirical contribution to this research gap. This empirical research can open up new insights and avenues into the development of sustainability science. If policymakers are not aware of the links between the circular economy and economic growth, it will seriously hamper the development of the circular economy in the world. In this sense, research in the field of circular economy is very important and it should be promoted in the world.

There may be positive, negative or no synergy between trends. These three different forms of synergy are therefore always possible. The form and direction of synergy trends can change over time and if decision-makers are not aware of the changes in synergy, they can already make the wrong decisions due to this lack of relevant information. For this logical reason alone, this empirical research is important for the global community.

In recent years, it has been noticed that synergy analysis is a very useful methodological approach to studying sustainability challenges and processes [1, 2, 3, 4, 5, 6, 7, 8,]. In the study of sustainable development, a very central issue is the temporal development of economic variables, social development variables, and environmental variables [9, 10, 11, 12, 13, 14, 15, 16, 17, 18]. For example, taking demographic trends into account as part of the assessment of sustainable development challenges is a very broad research theme [19]. The same consideration applies to the progress of climate change and the associated social, ecological, and economic trends and processes. [20]. It is good to note that synergy analyses are always related to knowledge management and decision-maki2ng [21]. Several studies have found that sustainability indicators are not always put to good use or are simply not used [22]. Decision-makers should be aware of the synergy between key variables, be it positive or negative synergies [23]. For example, the application and assessment of the well-known nexus model cannot be done properly without synergy analyses [24, 25, 26, 27]. Synergy analyses should be used more integrated into sustainable development policies.

The methodological framework of synergy analysis

When we analyse trends, scenarios, or weak signals we typically analyze dynamic social and economic systems. One key aspect of trend analysis is nowadays the interlinkages of trends. This study focuses on the issue of interlinkages of global trends. The data of the study is from the Eurostat´s Circular Economy Indicators and World Bank´s World Development Indicators database [28, 29]

The Synergy Index is calculated in the following technical way (Data analysis phases in Steps 5-6) above: We can calculate the conventional index number of synergy and average long-run synergy index (see for example [1, 2]). It can be said that there exists a synergy between two factors when their combined effect is greater or smaller than the sum of their separate effects. In mathematical form, this can be expressed as

$$z = ax + by + cxy + d. \qquad (1)$$

where x, y and z are variables and a, b, c and d are coefficients that determine how the output z depends on inputs x and y. In this case, we assume a time-invariant system, where the parameters remain constant. If y is 0, the output is determined by x and the coefficients a and d. Coefficients a, b, and d determine the impact of the single inputs on the output. The synergy of the inputs x and y is determined by the component cxy, i.e. the co-effect of both inputs. The idea of synergy indicates choosing variables x and y such that an increase in the value of both variables x and y is desirable and refers to a commonly accepted direction of sustainable development. If we look at a change from A to B in the Fig. 1, (from the original state xy0 to x1y1) we can determine the change in the area (Δz) to be

If we look at a change from A to B in Fig. 1 (from the original state x0y0 to x1y1) we can determine the change in the area (Δz) to be

$$\Delta z = a\Delta x + b\Delta y + c\Delta x\Delta y = y0\Delta x + x0\Delta y + \Delta x\Delta y. \qquad (2)$$

We can interpret the synergy of the inputs to be determined by the shaded area in Figure 3, which equals ΔxΔy. The synergy can also be negative, as is shown in Fig. 1 where the change in y is negative, and ΔxΔy becomes negative. This is a trade-off situation: when one factor increases the other factor decreases. In Figure 3. we have presented 3 basic forms of synergy between two variables.

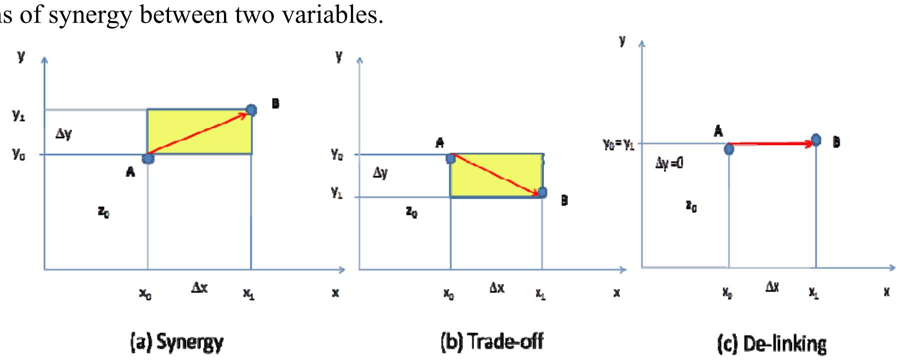

Figure 1. The alternatives of synergy level between two variables, x and y.
The alternatives of synergy level between two variables, x and y.

(1) Maximum synergy can be obtained when relative changes Δx and Δy are equal.
(2) In case the change in y i.e. Δy is larger than changes in x i.e. Δx, the quotient must be inverted to estimate the potential synergy ratio.
(3) Therefore, potential synergy/trade-off between two variables can be measured between -1 to +1.
(4) Where the negative sign indicates a trade-off between two variables.

Thus, the synergy level can be positive, negative or there is no synergy at all (de-linking). This idea can be applied in health care and industry field, but maybe in other industrial context contexts, too. Interpretation of the results is straightforward: the closer the calculated synergy factor is to 1 the stronger the synergy between the two (or three) variables can potentially be, and the closer the ratio is to −1 the potential for a trade-off is stronger. When the synergy factor is close to 0 there is delinking between the trends. This kind of analysis does not imply that synergy is necessarily good and the trade-off is bad, or vice versa. Such interpretation is case specific; to interpret the results in more depth, we need to determine how we would like the trends to involve.

Data and variables

In Table 1 we present key data and variables of the European circular economy study.

Table 1. Variable and definitions of data

Variable	Definition	Measurement
Gross Domestic Product	This indicator provides values for gross domestic product (GDP) expressed in current international dollars, converted by purchasing power parity (PPP) conversion factor. GDP is the sum of gross value added by all resident producers in the country plus any product taxes and minus any subsidies not included in the value of the products. PPP conversion factor is a spatial price deflator and currency converter that eliminates the effects of the differences in price levels between countries. From April 2020, “GDP: linked series (current LCU)” [NY.GDP.MKTP.CN.AD] is used as underlying GDP in local currency unit so that it’s in line with time series of PPP conversion factors for GDP, which are extrapolated with linked GDP deflators.	Current USD, European Union
Gross National Income	Gross National Income (GNI) is the total amount of money earned by a nation's people and businesses. It is used to measure and track a nation's wealth from year to year. The number includes the nation's gross domestic product (GDP) plus the income it receives from overseas sources. The more widely known term GDP is an estimate of the total value of all goods and services produced within a nation for a set period, usually a year. GNI is an alternative to gross domestic product (GDP) as a means of measuring and tracking a nation's wealth and is considered a more accurate indicator for some nations.	Atlas method (current US$), European Union
Material footprint [CEI_PC020]	The indicator quantifies the worldwide demand for material extractions (biomass, metal ores, non-metallic minerals and fossil energy materials/carriers) triggered by consumption and investment by households, governments and businesses in the EU. Raw material consumption indicator (RMC) is a measure of material footprints. It represents the amount of material in terms of Raw materials equivalent (RME) needed (or, the amount of extraction, domestic and abroad, required directly and indirectly) to produce the products consumed in the geographical reference area. It is calculated as Raw material input (RMI) minus exports in RME (calculated at the aggregate product level, by material). The indicator RMC gives insight into the quantity and type of materials required to meet the EU's demand for products.	Tonnes per capita,
Resource productivity [CEI_PC030]	The indicator is defined as the gross domestic product (GDP) divided by domestic material consumption (DMC). DMC measures the total amount of materials directly used by an economy. It is defined as the annual quantity of raw materials extracted from the domestic territory of the local economy, plus all physical imports minus all physical exports. It is important to note that the term 'consumption', as used in DMC, denotes apparent consumption and not final consumption. DMC does not include upstream flows related to imports and exports of raw materials and products originating outside of the local economy.	In euro per kg, chain-linked volumes (2015). Volume figures show the development of aggregates excluding inflation; to be used when comparing over time (various years) one single country

Generation of municipal waste per capita [CEI_PC031]	The indicator measures the waste collected by or on behalf of municipal authorities and disposed of through the waste management system. It consists to a large extent of waste generated by households, though similar wastes from sources such as commerce, offices and public institutions may be included.	Kilograms per capita
Generation of packaging waste per capita [CEI_PC040]	Packaging' in this context means all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer. 'Non-returnable' items used for the same purposes shall also be considered to constitute packaging. 'Packaging waste' means any packaging or packaging material covered by the definition of waste in the Waste Framework Directive 2008/98/EC, excluding production residues (Art.3(1): ‘waste’ means any substance or object which the holder discards or intends or is required to discard).	Kilograms per capita
Generation of plastic packaging waste per capita [CEI_PC050]	This indicator includes plastic packaging waste. 'Packaging' in this context means all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer. 'Non-returnable' items used for the same purposes shall also be considered to constitute packaging. 'Packaging waste' means any packaging or packaging material covered by the definition of waste in the Waste Framework Directive 2008/98/EC, excluding production residues (Art.3(1): ‘waste’ means any substance or object which the holder discards or intends or is required to discard).	Kilograms per capita
Recycling rate of municipal waste [CEI_WM011]	The indicator measures the share of recycled municipal waste in the total municipal waste generation. Recycling includes material recycling, composting and anaerobic digestion. The ratio is expressed in percent (%) as both terms are measured in the same unit, namely tonnes.	Percentage.
Recycling rate of e-waste [CEI_WM050]	The indicator is calculated by multiplying the 'collection rate' as set out in the WEEE Directive with the 'reuse and recycling rate' set out in the WEEE Directive; where: o The 'collection rate' equals the volumes collected of WEEE in the reference year divided by the average quantity of electrical and electronic equipment (EEE) put on the market in the previous three years (both expressed in mass unit). o The 'reuse and recycling rate' is calculated by dividing the weight of WEEE that enters the recycling/preparing for re-use facility by the weight of all separately collected WEEE (both in mass unit) in accordance with Article 11(2) of the WEEE Directive 2012/19/EU, considering that the total amount of collected WEEE is sent to treatment/recycling facilities. The indicator is expressed in percent (%) as both terms are measured in the same unit.	Percentage

Recycling of biowaste [CEI_WM030]	The indicator is indirectly measured as the ratio of composted/methanised municipal waste (in mass unit) over the total population (in number). The ratio is expressed in kg per capita. The underlying assumption is that, by and large, the only reasonable treatment of biowaste is composting or anaerobic digestion.	Kilograms per capita.
Trade in recyclable raw materials, Imports extra-EU27 (from 2020) [CEI_SRM020]	The indicator measures the quantities recyclable waste and scrap as well as other secondary raw materials (by-products) that are imported to the EU borders (extra-EU). This data set is taken from International Trade in Goods Statistics (ITGS) published by Eurostat. The data measure the physical quantity of goods traded between the EU Member States (intra-EU trade) and of goods traded by the EU Member States with non-EU countries (extra-EU trade).	Trade value in thousand euro
Trade in recyclable raw materials, Exports extra-EU27 (from 2020) [CEI_SRM020]	The indicator measures the quantities recyclable waste and scrap as well as other secondary raw materials (by-products) that are exported across the EU borders (extra-EU). This data set is taken from International Trade in Goods Statistics (ITGS) published by Eurostat. The data measure the physical quantity of goods traded between the EU Member States (intra-EU trade) and of goods traded by the EU Member States with non-EU countries (extra-EU trade).	Trade value in thousand euro
Private investments, jobs and gross value added related to circular economy sectors [cei_cie010]	The indicator includes “Gross investment in tangible goods”, “Number of persons employed” and “Value added at factor costs” in the following three sectors: the recycling sector, repair and reuse sector and rental and leasing sector. The recycling, repair and reuse and rental and leasing sectors are defined and approximated in terms of economic activity branches of the NACE Rev. 2 classification. The following NACE codes have been selected to compute this indicator: (see list of codes selected) [0]. This indicator is collected within the frame of the Structural Business Statistics (SBS), as required in Commission Regulation N° 250/2009[1].	Value added at factor cost - million euro
Patents related to recycling and secondary raw materials [cei_cie020]	The indicator measures the number of patents related to recycling and secondary raw materials. The attribution to recycling and secondary raw materials was done using the relevant codes in the Cooperative Patent Classification (CPC) (list of CPC codes selected [0]). The term 'patents' refers to patent families, which include all documents relevant to a distinct invention (e.g. applications to multiple authorities), thus preventing multiple counting. A fraction of the family is allocated to each applicant and relevant technology.	Number

Now we have presented key variables of this study. In the next chapter, we present key results in short form.

Economic growth and the circular economy in the European Union: Results, key findings and discussion

In this section, we focus on key results and findings of synergy levels between economic growth indicators and circular economy indicators. First, we report synergy analyses between growth indicators (GDP and GNI) and circular economy indicators. We shall summarize the key results in the form of tables 2-5. First in Table 2 we report synergy analysis results between Gross Domestic Growth (GDP) and eleven circular economy variables.

Table 2. Synergy analysis between Gross Domestic Product and 11 circular economy indicators. European Union.

	Average Synergy	Max Synergy	Min Synergy	Standard Deviation in Synergy	Skewness
GDP-Material footprint [CEI_PC020]	0,23	0,91	-0,51	0,34	0,13
GDP-Resource productivity [CEI_PC030]	0,01	0,91	-0,96	0,53	-0,24
GDP-Generation of municipal waste per capita [CEI_PC031]	0,03	0,98	-0,97	0,43	0,21
GDP-Generation of packaging waste per capita [CEI_PC040]	0,18	0,91	-0,65	0,43	-0,12
GDP-Recycling rate of municipal waste [CEI_WM011]	0,06	0,88	-0,96	0,51	-0,73
GDP-Recycling rate of e-waste [CEI_WM050]	0,17	0,69	-0,66	0,42	-0,53
GDP-Recycling of biowaste [CEI_WM030]	-0,07	0,86	-0,72	0,41	0,47
GDP-Trade in recyclable raw materials, Imports extra-EU27 (from 2020) [CEI_SRM020]	0,35	0,94	-0,62	0,40	-0,61
GDP-Trade in recyclable raw materials, Exports extra-EU27 (from 2020) [CEI_SRM020]	0,26	0,98	-0,77	0,56	-0,28
GDP-Private investments, jobs and gross value added related to circular economy sectors	0,26	0,97	-0,39	0,48	0,25
GDP-Patents related to recycling and secondary raw materials	-0,19	0,65	-0,90	0,56	0,50

In Fig. 2 we report the skewness of synergy observations. Key empirical finding is that skewness varies concerning synergy observation between gross domestic product and various synergy indicators. We can also observe that normal distribution cases cannot be observed. This empirical finding creates a big challenge for decision-makers in sustainability policy of the circular economy because synergy levels are not only positive or negative but synergies vary in a considerable way. Some indicators are having very positive synergy levels with Gross Domestic Product developments, but some are having very negative synergies with GDP indicator. This fact can create policy dilemmas for the European decision-makers.

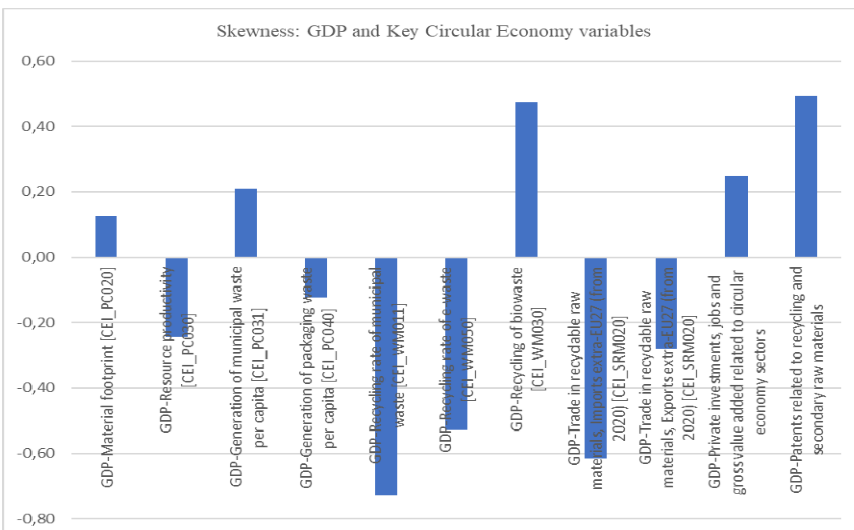

Figure 1. Skewness of synergy observations between Gross Domestic Product and various synergy variables.

In Fig. 2. we report a visualization of key statistical indicators of synergy level observations (in relation GDP in the EU).

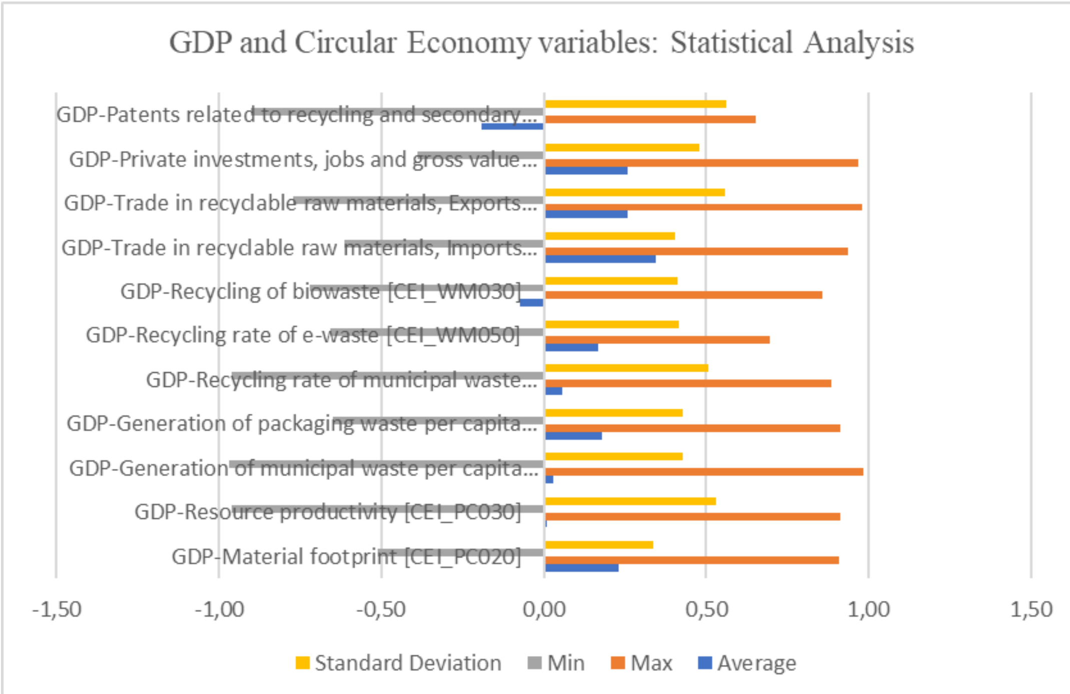

Figure 2. Gross Domestic Product and Circular Economy Variables. A data visualization of the basic statistical analysis.

Fig. 2 informs us about considerable standard deviations and range between max and min synergy observations.

Secondly, in Table 3, we report synergy analysis results between Gross National Income (GNI) and eleven circular economy variables.

Table 3. Synergy analysis between Gross National Income and 11 circular economy indicators. European Union.

	Average Synergy	Max Synergy	Min Synergy	Standard Deviation of Synergy	Skewness
GNI-Material footprint [CEI_PC020]	0,05	0,84	-0,63	0,348	-0,17
GNI-Resource productivity [CEI_PC030]	-0,01	0,45	-0,67	0,305	-0,46
GNI-Generation of municipal waste per capita [CEI_PC031]	-0,22	0,86	-0,78	0,439	0,48
GNI-Generation of packaging waste per capita [CEI_PC040]	0,13	0,97	-0,67	0,461	0,05
GNI-Recycling rate of municipal waste [CEI_WM011]	-0,01	0,83	-0,98	0,526	-0,42
GNI-Recycling rate of e-waste [CEI_WM050]	-0,10	0,38	-0,89	0,366	-0,80
GNI-Recycling of biowaste [CEI_WM030]	-0,07	0,86	-0,72	0,412	0,47
GNI-Trade in recyclable raw materials, Imports extra-EU27 (from 2020) [CEI_SRM020]	0,21	0,91	-0,26	0,418	0,62
GNI-Trade in recyclable raw materials, Exports extra-EU27 (from 2020) [CEI_SRM020]	0,25	0,82	-0,85	0,413	-1,00
GNI-Private investments, jobs and gross value added related to circular economy sectors	-0,038	0,656	-0,738	0,495	-0,01
GNI-Patents related to recycling and secondary raw materials	-0,097	0,414	-0,615	0,295	-0,01

In Fig. 3 we report the skewness of synergy observations. Key empirical finding is that skewness varies concerning synergy observation between gross national income and various synergy indicators. We can also observe that normal distribution cases can be observed in two cases, concerning a variable (1) private investments, jobs and gross value added to CE sectors and concerning a variable (2) patents related to recycling and secondary raw materials. Also, this empirical finding creates a big challenge for decision-makers in sustainability policy of the circular economy because synergy levels are not only positive or negative but synergies vary in a considerable way. Some indicators are having very positive synergy levels with Gross Domestic Product developments (for example, import trade variable), but some are having very negative synergies (for example, export trade variable) with the GNI indicator of the European Union. This fact can create policy dilemmas for the European decision-makers. Observed difference between export and import trade synergy can be such a source of serious policy dilemmas.

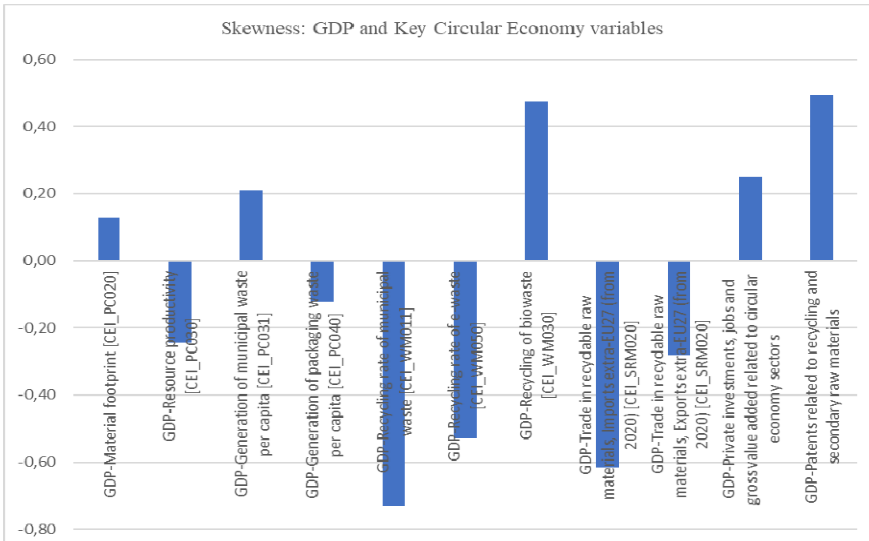

Figure 3. Skewness of synergy observations between Gross Net Income and various synergy variables.

In Fig. 4. we report a visualization of key statistical indicators of synergy level observations (in relation GNI in the EU).

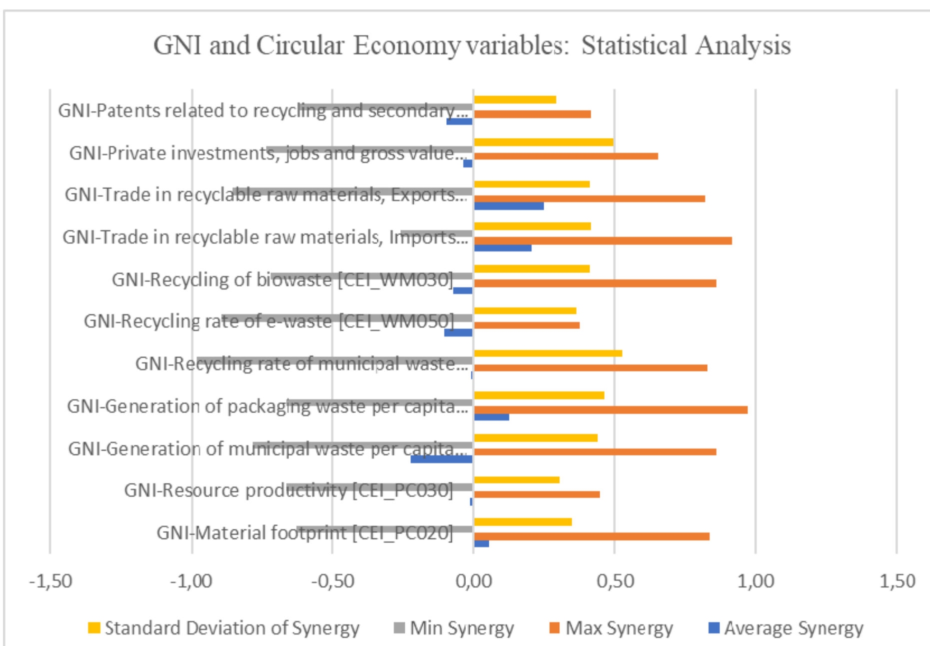

Figure 4. Gross National Income and Circular Economy Variables. A data visualization of the basic statistical analysis.

In Table 4 we report a statistical comparison of statistical skewness results of synergy observations. Table 4 shows differences of skewness levels of synergy observations of two key economic growth variables, Gross Domestic Product (GDP) and Gross Net Income (GNI).

GDP, skewness of synergy observations		**GNI, skewness of synergy observations**	
0,13	Weakly positively skewed distribution	-0,17	Weakly negatively skewed distribution
-0,24	Negatively skewed distribution	-0,46	Negatively skewed distribution
0,21	Positively skewed distribution	0,48	Positively skewed distribution
-0,12	Weakly negatively skewed distribution	0,05	Very weakly positively skewed distribution
-0,73	Strongly negatively skewed distribution	-0,42	Negatively skewed distribution
-0,53	Negatively skewed distribution	-0,80	Strongly negatively skewed distribution
0,47	Positively skewed distribution	0,47	Positively skewed distribution
-0,61	Strongly negatively skewed distribution	0,62	Very strongly positively skewed distribution
-0,28	Negatively skewed distribution	-1,00	Strongly negatively skewed distribution
0,25	Positively skewed distribution	-0,01	Very weakly negatively skewed distribution, almost normal
0,50	Positively skewed distribution	-0,01	Very weakly negatively skewed distribution, almost normal

Table 4 shows very clearly that there is not linear relationship between economic growth variables (GDP and GNI) and CE variables. Decision-makers in the European Union will face complexity of the circular economy issues in various policy topics.

We performed some synergy trend analyses with both GDP and GNI indicators in relation to CE indictors. We shortly summarize these synergy analysis in a form of Table 5 just in order to report main directions of synergies between growth and CE variables.

Table 5. The directions of synergy trends associated with Gross Domestic Product and Gross New Income.

	GDP, linear synergy trend line	**GNI, linear synergy trend line**
Material footprint	Slightly decreasing linear synergy trend	Slightly ascending synergy trend
Resource productivity	Slightly decreasing linear synergy trend	Slightly ascending synergy trend
Generation of municipal waste per capita	Slightly decreasing linear synergy trend	Slighly ascending synergy trend
Generation of packaging waste per capita	Clearly ascending linear trend	Slightly ascending synergy trend
Recycling rate of municipal waste	Clearly ascending linear synergy trend	Cleary decreasing synergy trend
Recycling rate of e-waste	Clearly decresing linear synergy trend	Decreasing synergy trend
Recycling of biowaste	Clearly decresing linear synergy trend	Clearly decreasing synergy trend
Trade in recyclable raw materials, Imports extra-EU27 (from 2020)	Decreasing linear synergy trend	Clearly ascending synergy trend
Trade in recyclable raw materials, Exports extra-EU27 (from 2020)	Steady unchanged neutral trend	Upward sloping synergy trend
Private investments, jobs and gross value added related to circular economy sectors	Clearly ascending linear trend	Slighly decreasing synergy trend
Patents related to recycling and secondary raw materials	Decreasing linear synergy trend	Slightly ascending synergy trend

In Fig. 5 we report synergy developments between gross domestic product (GDP) and recycling biowaste and gross net income (GNI) and recycling biowaste. In this case there is not big differences between GDP and GNI indicators.

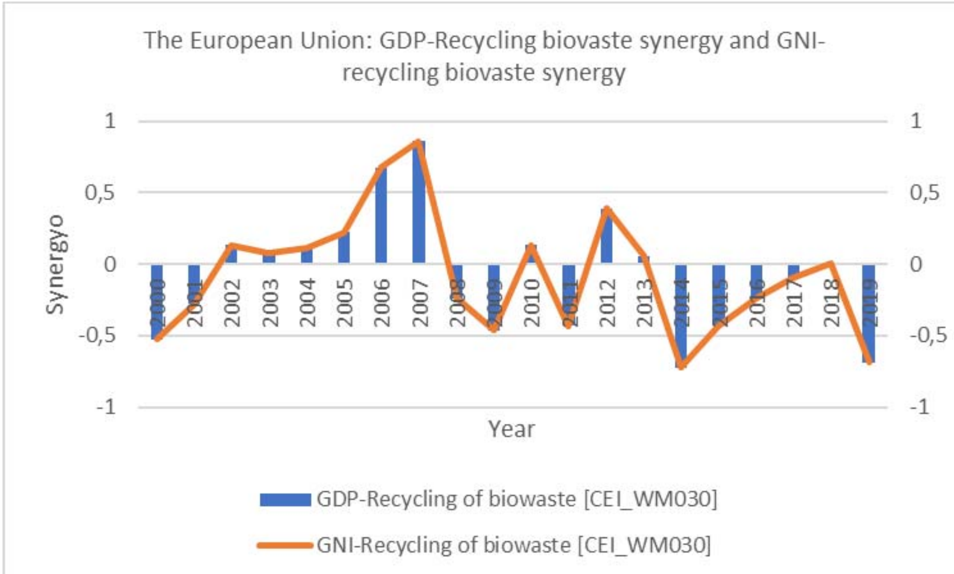

Figure 5. European Union: GDP-Recycling biowaste synergy and GNI-recycling biowaste synergy.

In this special case economic growth and CE synergies are quite similar and follow the same logic. Just to show another interesting case with the EU import and export data of recyclable raw materials, we visualize this case with Fig. 6, where can see a case, where economic growth and CE variable synergies are not following similar analogical logic.

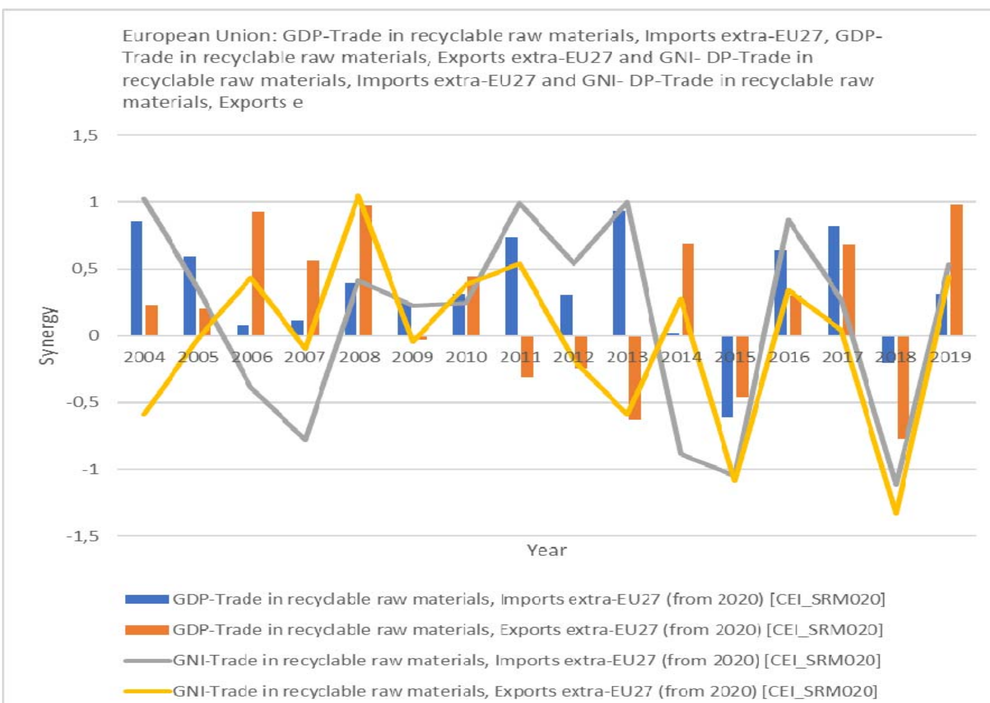

Figure 6. European Union: GDP-Trade in recyclable raw materials, Imports, extra-EU27, GDP-Trade in recyclable raw materials, Exports, extra-EU27 and GNI- DP-Trade in recyclable raw materials, Imports extra-EU27 and GNI-DP-Trade in recyclable raw materials, Exports extra-EU27.

In this case there is big differences between GDP and GNI indicators. This kind of information may be useful background information for decision-makers.

Conclusions

In international scientific discussions have seen a lot of discussions about the circular economy, but less attention has been paid to the critical links between the circular economy and economic growth. The synergy study provides an empirical contribution to this obvious research gap. This empirical research can open up new insights and avenues into the development of sustainability science. This empirical synergy study focused on the circular economy of the European Union, and it is clear that situations in EU Member States and other regions of the word may vary in terms of circular economy and economic growth variables. Still, this EU-wide synergy study offers a lot to think about how the circular economy works in relation to economic growth. The results contribute to confirming the not linear nature of the circular economy. It is more about complex interactions and evolutionary development.

This study made it clear that the synergy between very key circular economy variables and economic growth variables varies considerably between both positive and negative synergies. Synergies between GDP and GNI variables and CE variables were also found be quite different in this empirical synergy study. Interesting case of import and export of renewables trade with cyclical positive and negative synergies was found in this empirical study. If policymakers are not aware of the synergy links between the circular economy and economic growth, it will seriously hamper the future development of the circular economy in the world.

We propose that research in the field of circular economy is very important and more research should be systematically promoted in this field in the world.

References

[1] Luukkanen, J., Vehmas, J., Panula-Ontto, J., Allievi, F., Kaivo-oja, J., Pasanen, T. & Auffermann, B. (2012). Synergies or trade-offs? A new method to quantify synergy between different dimensions of sustainability. *Environmental Policy and Governance*, 22, 337–349.
[2] Mainali, B., Luukkanen, J., Silveira, S. & Kaivo-oja, J. (2018). Evaluating synergies and trade-offs among Sustainable Development Goals (SDGs): Explorative analyses of development paths in South Asia and Sub-Saharan Africa. *Sustainability* 2018, 10, Article 815.
[3] Banerjee, O., Cicowiez, M., Horridge, M. & Vargas, R. (2019). Evaluating synergies and trade-offs in achieving the SDGs of zero hunger and clean water and sanitation: An application of the IEEM Platform to Guatemala. *Ecological Economics*, 161 (July 2019), 280–291.
[4] Duguma, L.A., Wambugu, S.W., Minang, P.A. & van Noordwijk, M. (2014). A systematic analysis of enabling conditions for synergy between climate change mitigation and adaptation measures in developing countries. *Environmental Science and Policy*, 42, 138–148.
[5] Pace, N., Daidone, S., Davis, B., Handa, S., Knowles, M. & Pickmans, R. (2018). One plus one can be greater than two: Evaluating synergies of development programmes in Malawi. *The Journal of Development of Studies*, 54, 2023–2060.
[6] Kearney, S., Fonte, S., García, E., Siles, P., Chan, K. & Smukler, S. (2019). Evaluating ecosystem service trade-offs and synergies from slash-and-mulch agroforestry systems in El Salvador. *Ecological Indicators*, 105, 264–278.
[7] McCarthy, N., Lipper, L. & Mann, W. (2013). Evaluating synergies and trade-offs among food security, development, and climate change. In *Climate Change Mitigation and Agriculture*; Routledge: London, UK, 2013, 70–80.
[8] Meerow, S. (2019). A green infrastructure spatial planning model for evaluating ecosystem service tradeoffs and synergies across three coastal megacities. *Environmental Research Letters,* 2019, 14(12), Article 125011.
[9] Kaivo-oja, J., Luukkanen, J. & Malaska, P. (2002). Methodology for the analysis of critical industrial ecology trends: An Advanced Sustainability analysis of the Finnish Economy. *Futura*, 21(2), 45–61.
[10] Kaivo-oja, J. (1999). Alternative scenarios of social development: Is analytical sustainability policy analysis possible? How? *Sustainable Development*, 7(3), 140-150.
[11] Kaivo-oja, J. (2001). Scenario learning and potential sustainable development processes in spatial contexts: Towards risk society or ecological modernization scenarios? *Futures Research Quarterly*, 17(2), Summer 2001, 33-55.

[12] Kaivo-oja, J. (2002). Social and ecological destruction in the first class: A plausible social development scenario. *Sustainable Development*, 10(1), 63-66.
[13] Kaivo-oja, J., Panula-Ontto, J., Luukkanen, J. & Vehmas, J. (2014). Relationships of the dimensions of sustainability as measured by the sustainable society index framework. *International Journal of Sustainable Development and World Ecology,* 21(1), 39-45.
[14] Vehmas, J., Malaska, P., Luukkanen, J., Kaivo-oja, J., Hietanen, O., Vinnari, M. & Ilvonen, J. (2003). *Europe in the Global Battle of Sustainability: Rebound Strikes Back? Advanced Sustainability Analysis*. Publications of the Turku School of Economics and Business Administration, Discussion and Working Papers 7:2003. Turku. Finland.
[15] Vehmas, J., Luukkanen, J. & Kaivo-oja, J. (2007). Linking analyses and environmental Kuznets curves for material flows in the European Union 1980-2000. *Journal of Cleaner Production,* 15(7), 1662-1673.
[16] Vehmas, J., Kaivo-oja J. & Luukkanen J. (2016). Sustainability cycles in China, India, and the world? *Eastern European Business and Economics Journal*, 2(2), 139-164.
[17] Spaiser, V., Ranganathan, S., Ranjula Bali Swain, R.B. & Sumpter, D.J.T. (2017). The sustainable development oxymoron: quantifying and modelling the incompatibility of sustainable development goals. *International Journal of Sustainable Development & World Ecology*, 24(6), 457-470.
[18] Blohm, M. (2021). An enabling framework to support the sustainable energy transition at the national level. *Sustainability*, 13, Article 3834.
[19] Bander, J. (2007). Viewpoint: Sustainability: Malthus revisited. *Canadian Journal of Economics*, 40(1), 1-38.
[20] Halsnæs, K. & Garg, A. (2011). Assessing the role of energy in development and climate policies—Conceptual approach and key indicators. *World Development*, 39(6), 987–1001.
[21] Davenport, T.H. & Prusak, L. (1998). *Working Knowledge. How Organizations Manage What They Know;* Harvard Business School Press: Boston, MA, USA.
[22] Rosenström, U. (2009). *Sustainable Development Indicators: Much Wanted, Less Used?* Monographs of the Boreal Environment Research 33. University of Helsinki. Helsinki. Finland.
[23] Zhao, Z., Cai, M., Wang, F., Winkler, J.A., Connor, T., Chung, M.G. & Liu, J. (2021). Synergies and tradeoffs among sustainable development goals across boundaries in a metacoupled world. *Science of Total Environment*., 751, Article 141749.
[24] Sanderson, I. (2002). Evaluation, policy learning and evidence-based policy making. *Public Administration* , 80, No. 1 (2002), 1–22.
[25] Barbier, E.B. & Markandya, A. (1990). The contractions achieving environmentally sustainable development. *European Economic Review*, 34(2-3), 659-669.
[26] Blanc, D.L. (2015). *Towards Integration at Last? The Sustainable Development Goals as a Network of Targets; DESA,* Working Paper No. 141; United Nations Department of Economic and Social Affairs (UN DESA): New York, NY, USA.
[27] Weitz, N.; Nilsson, M. & Davis, M. (2014). *A Nexus Approach to the Post-2015 Agenda: Formulating Integrated Water, Energy, and Food SDGs*. SAIS Review of International Affairs, 34(2), 37–50.
[28] Eurostat (2022). *Circular Economy Indicators*. Eurostat. Retrieved 26.10.2022.
[29] World Bank (2022). *World Indicators Data Base. Global Development Indicators*. World Bank. Retrieved 26.10.2022.

About the authors

Name: Dr, Adjunct Professor, Professor Jari Kaivo-oja
Brief description of the affiliation and your work: Dr Jari Kaivo-oja is Research Director at Finland Futures Research Centre, Turku School of Economics, University of Finland.
Tel: +358 41 753 0244
e-mail : jari.kaivo-oja@utu.fi

Name: Dr, Adjunct Professor Jarmo Vehmas
Brief description of the affiliation and your work: Dr Jarmo Vehmas is the Regional Director at Finland Futures Research Centre, Turku School of Economics, University of Finland.
Tel: +358 50 342 3912
e-mail : jarrmo.vehmas@utu.fi

Name: Dr, Adjunct Professor Jyrki Luukkanen
Brief description of the affiliation and your work: Dr Jari Jyrki Luukkanen is Special Expert at Finland Futures Research Centre, Turku School of Economics, University of Finland.

Tel: +358 50 337 0710
e-mail: jyrki.luukkanen@utu.fi