 ISBN: 978-86-87043-85-5

Economic Growth (GDP) and Regional Carbon Dioxide Emissions: Synergy Trend Analysis of Geospatial Regions of the Global Economy: BRICS countries, United States, European Union, Latin America, and Caribbean region, and the Countries in Fragile and Conflict-Affected Situations

Jari Kaivo-oja, Jyrki Luukkanen & Jarmo Vehmas

Finland Futures Research Centre, Turku School of Economics, University of Turku
Åkerlundinkatu 2 A, 4th Floor, 33100 Tampere, Finland

Corresponding author: jari.kaivo-oja@utu.fi
Other authors jyrki.luukkanen@utu.fi
jarmo.vehmas@utu.fi‘

Abstract: (This article includes global synergy trend analyses based on the World Development Indicators published by the Work Bank. The focus of the study is on economic growth (GDP) and CO2 emissions. In order to understand globalization and regional developments, it is good to understand global and regional trends and the interactions between spatial trends. The synergy analysis tool was developed to analyze the synergy between two different trends, but it can be used to analyze simultaneously the synergy between three trends representing the three different dimensions of sustainable development. 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 critical interactions between spatial trends. There may be positive, negative or no synergy between trends. These three different forms of synergy are therefore always possible. That is why this study is important and interesting for a broader audience. The research delivers synergy analysis results of electricity consumption in relation to GDP trends in main regions of the world: (1) the BRICS countries, (2) the United States, (3) the European Union, (4) the Latin America and Caribbean region, and (4) the Countries in Fragile and Conflict-Affected Situations. This analysis is a unique synergy analysis study and all empirical results are first time published in this empirical study. This study provides many results, which are relevant for global energy and climate change policy-makers and especially for the World Bank and for the United Nations.

Keywords: BRICS countries, CO_2 emissions per capita, countries in Fragile and Conflict-Affected Situations electrification, European Union, global GDP, Global trends, synergy analysis, USA, Latin America and Caribbean region, world economy, World Bank Data Base, World Development Indicators.

Introduction

In this empirical study we shall analyze synergy trends between GDP and CO_2 emissions in world regions. The question of CO_2 emissions trends is one of the most critical climate change policy questions. We elaborate this global carbon dioxide phenomenon in relation to economic growth. Our methodology is synergy analysis of these two key trends (economic growth and CO_2 emissions). There various background research articles in this field [1, 2,3,4,5,6,7,8,9]. Key articles linked to global sustainability discussions can be found in [10, 11, 12, 13, 14, 15, 16, 17, 18].

 ISBN: 978-86-87043-85-5

Methodological framework of synergy analysis

When we analyse trends, scenarios or weak signals we typically analyse 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 World Bank´s Global Development Indicators data base [19].

The Synergy Index is calculated in the following technical way (Data analysis phases in Steps 5-6) above: We can calculate conventional index number of synergy and average long-run synergy index (see for example [1, 2]). It can be said that there exists 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

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

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 the 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 Figure 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 the Figure 1 (from the original state x0y0 to x1y1) we can determine the change in the area (Δz) to be

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

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 the Figure 3 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.

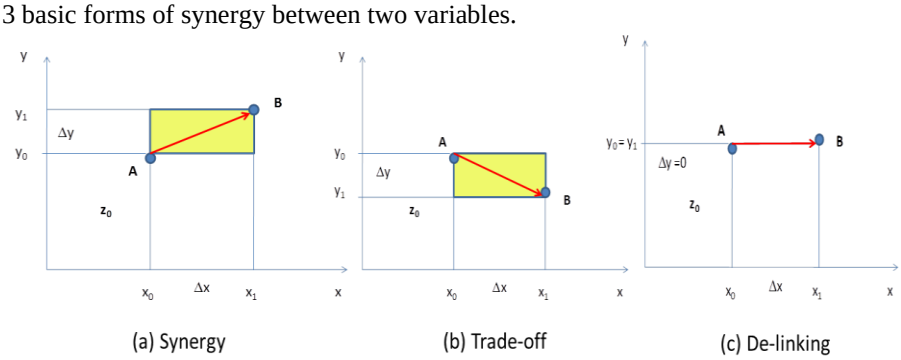

Figure 1: The alternatives of synergy level between two variables, x and y.
The alternatives of synergy level between two variables, x and y.

(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 potential synergy ratio.

(3) Therefore, potential synergy/trade-off between two variables can be measured between -1 to +1.

(4) Where negative sign indicates trade-off between two variables.

Thus, 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)

 ISBN: 978-86-87043-85-5

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 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.

The results of synergy analyses in global regions

BRICS countries

In this section we report the key results of synergy analyses in the BRICS countries. In Fig. 1 we visualize the long-run synergy trend between GDP and CO_2 emissions per cap in Brazil. The synergy trend line is presented in Fig. 2.

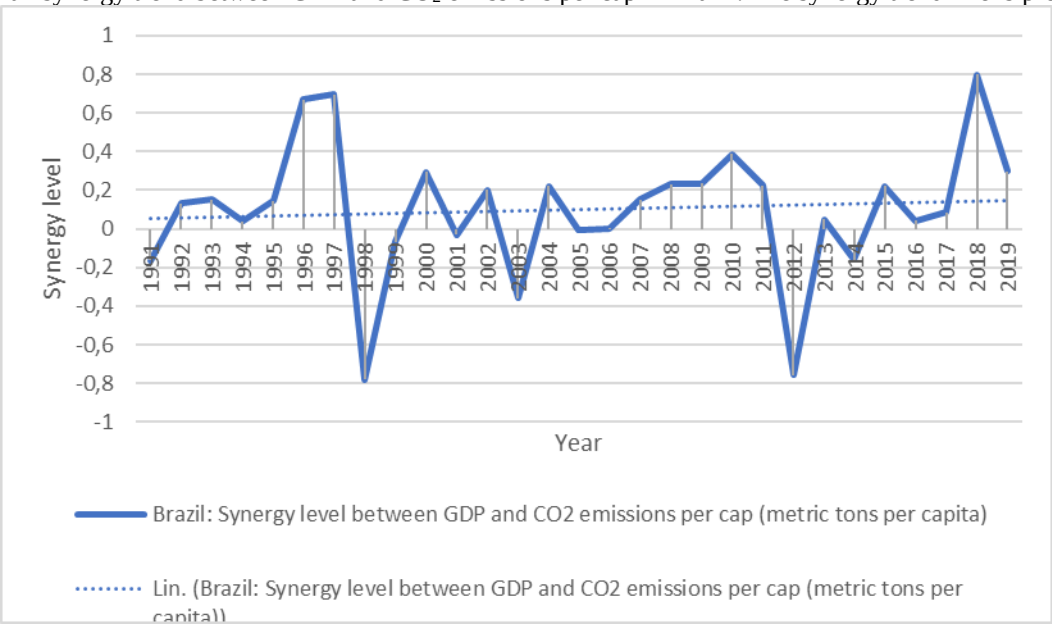

Figure 2: Brazil: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

Average synergy trend line is below + 0,2. In Fig 3 we report the histogram graph of synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita) in Brazil.

 ISBN: 978-86-87043-85-5

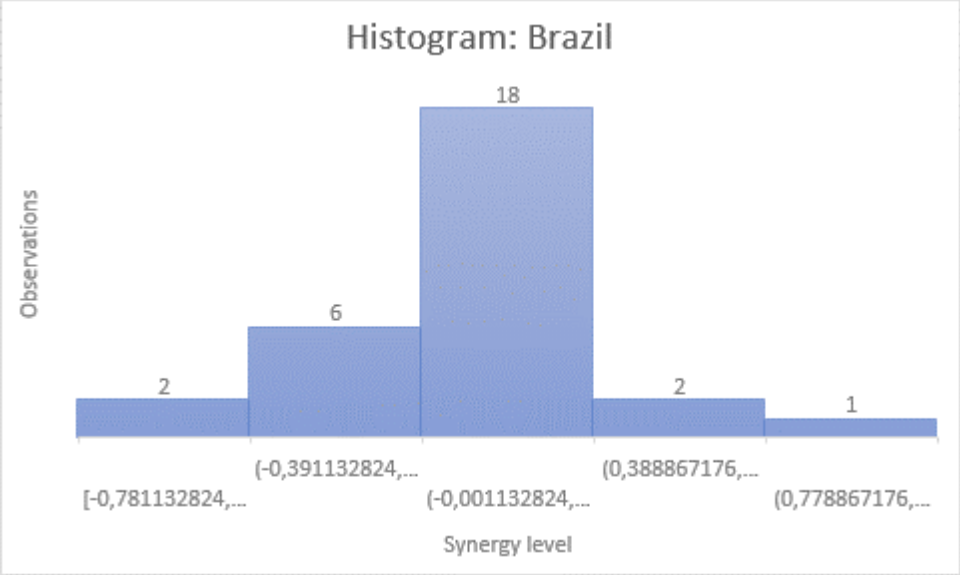

Figure 3: Histogram. Brazil. Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita)

In the case of Brazil, synergy observations are mostly in between -0,001-+0,39 (18 observations). We see that this histogram follows almost the conventional shape of normal distribution, however having a slightly negatively skewed distribution.

In Fig. 4 we report the synergy trend line of the Russian Federation. We find that the synergy trend between GDP and CO_2 per capita in Russia is quite stable and even. It is neither bullish nor bearish.

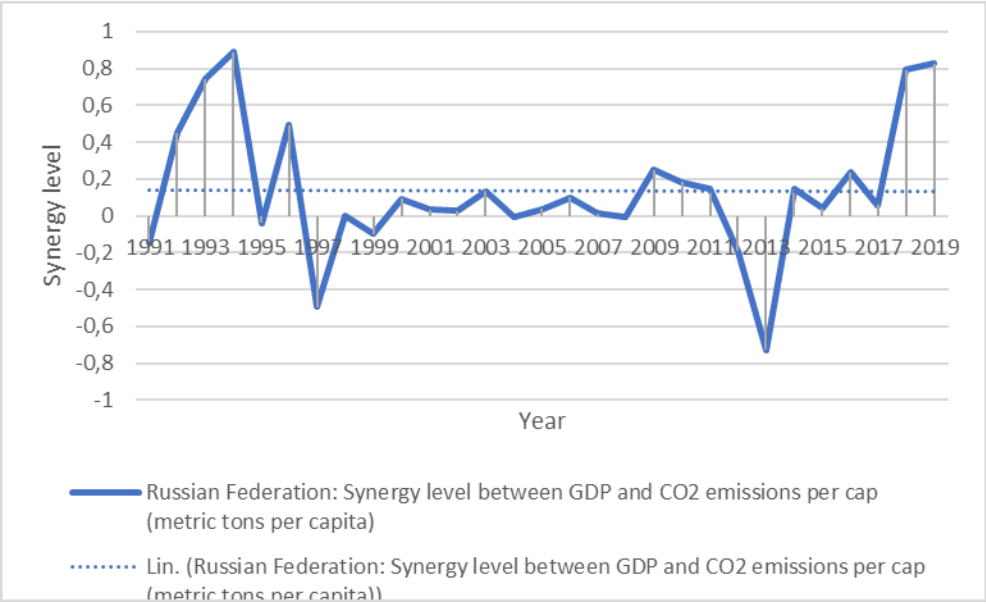

Figure 4: The Russian Federation: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

Key finding is that the synergy trend in the Russian case is slightly positive in the long range. In early 1990s it was very positive, but in the mid of 1990s, it started to turn to a very low negative level. In years 2011 and 2013 is reached negative synergy levels. Again, in 2019 positive synergies were observed.

In Fig 5, we report a histogram figure of the Russian Federation. Figure 5 reports a right-skewed distribution. There is some positive synergy between analyzed trend variables (GDP add CO_2 per capita), but only on a very low level.

 ISBN: 978-86-87043-85-5

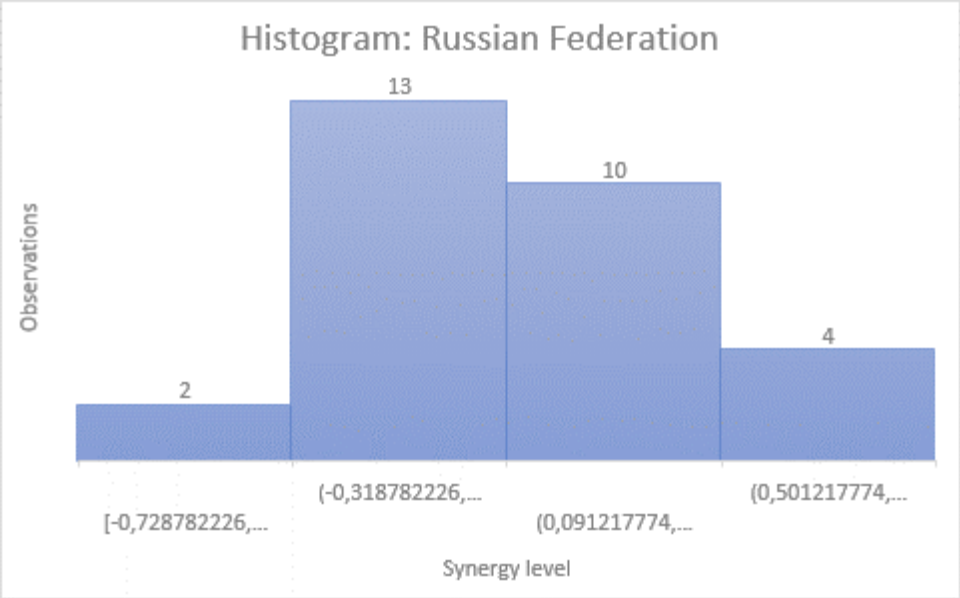

Figure 5: Histogram. The Russian Federation. Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita)

In Fig. 6 we report the synergy level between GDP and CO_2 emissions per cap (metric tons per capita) in India. The synergy trend is slightly upward-sloping in this special case of the Russian Federation.

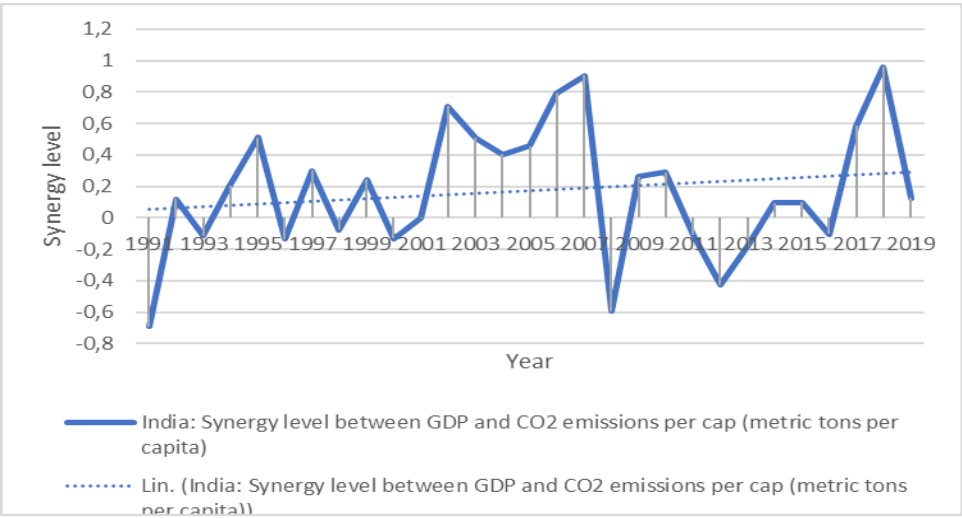

Figure 6: India: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

In Fig. 7, we report a histogram of synergy observations in the analysis of India. We can observe that the distribution, in this case, is not normal and positive skewness can be observed. Most observations are between -0,22 - + 0,25 (14 observations).

 ISBN: 978-86-87043-85-5

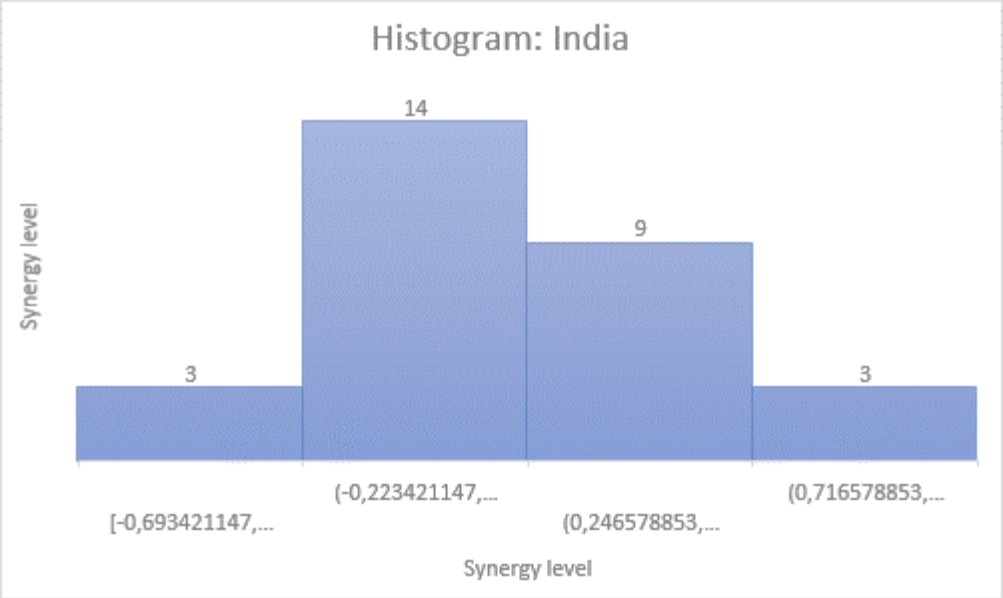

Figure 7: Histogram. India. Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita)

In Fig. 8 we report the synergy level between GDP and CO_2 emissions per cap (metric tons per capita) in China. In this case, we see that the synergy trend is clearly downward-sloping in China.

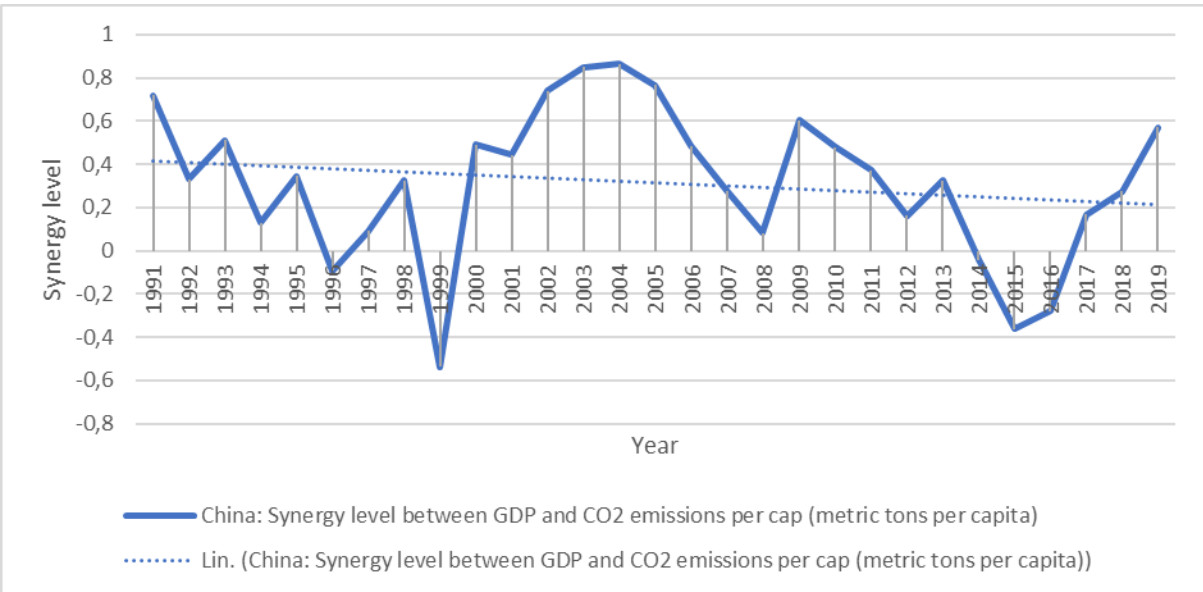

Figure 8: China: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

The histogram of synergy observations in China is reported in Fig. 9. We see that histogram is negatively skewed in the case of China. Most synergy observations are between +0,26 - +0,66 (14 observations).

 ISBN: 978-86-87043-85-5

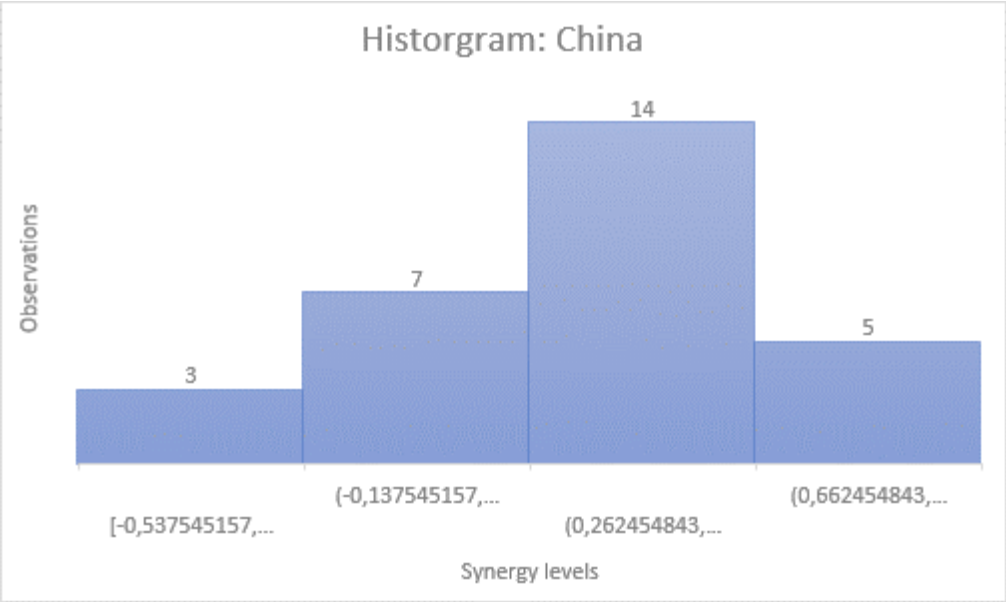

Figure 9: Histogram. China. Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita)

Figure 10 shows the trend curve of synergy development in South Africa. It is a stable linear synergy trend curve, but average synergy level is very small and negative value.

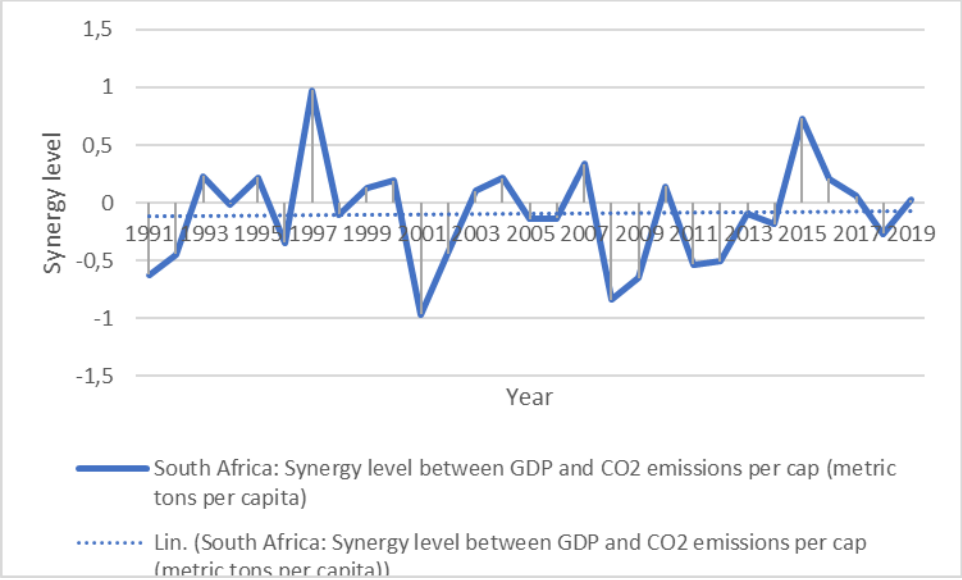

Figure 10: South Africa: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

In Fig. 11 we have reported a histogram of South Africa, in which the distribution of observations is quite normal, but slightly negatively skewed. Most of the synergy observations fall between -0,46 - and +0,03 (11 observations).

 ISBN: 978-86-87043-85-5

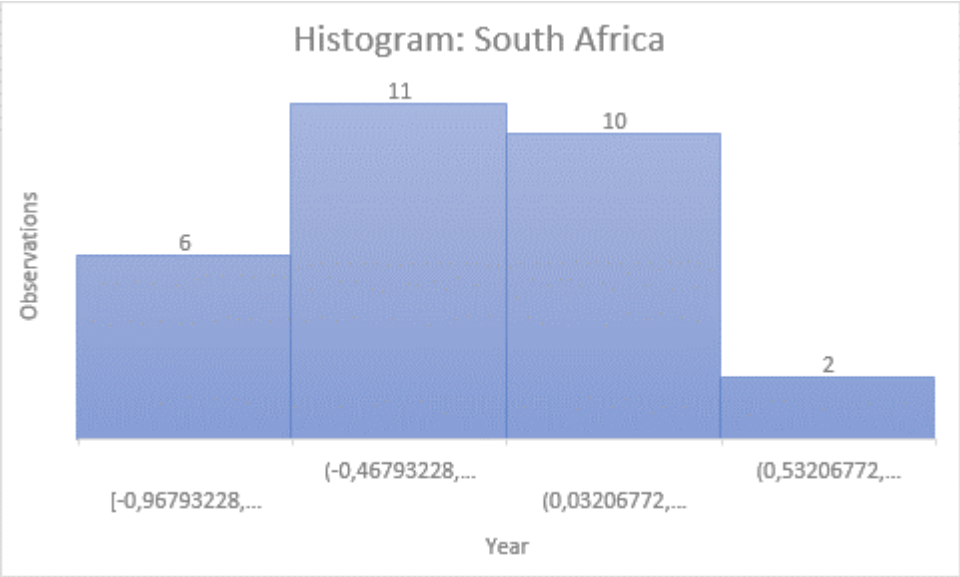

Figure 11: Histogram. South Africa. Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita)

European Union, United States, Latin America and the Caribbean and Fragile and Countries in fragile and conflict-affected situations

Next, we will move on to reporting on the synergy results of other regions of the world. In Fig. 12 we can observe the synergy level trend curve of the European Union. The long-run synergy trend is turning to negative synergy values.

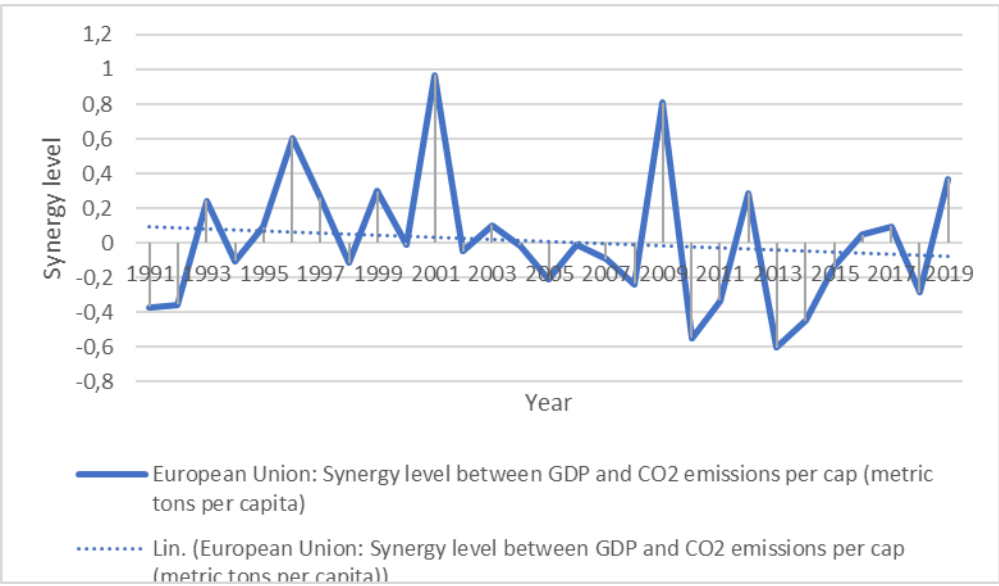

Figure 12: European Union: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

The European Union's histogram graph of synergy findings is reported in Figure 12. The distribution is quite normal, however, tilted to the right. Most of the synergy observations fall between -0,17 - and +0,25 (13 observations).

 ISBN: 978-86-87043-85-5

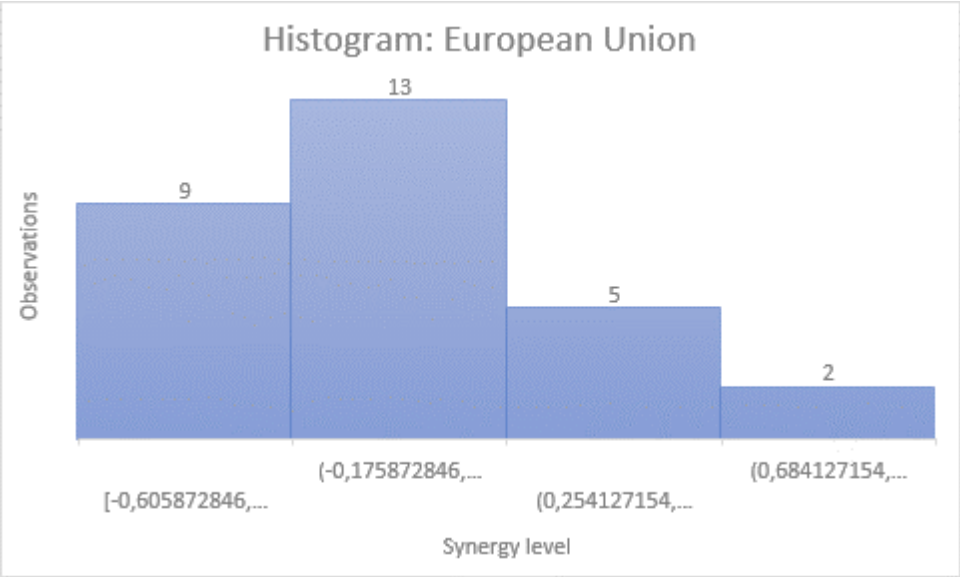

Figure 13: European Union. Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita)

In Fig. 14 we can observe the synergy level trend curve of the United States of America. The long-run synergy trend curve is strongly downward-sloping. Synergy levels are decreasing clearly.

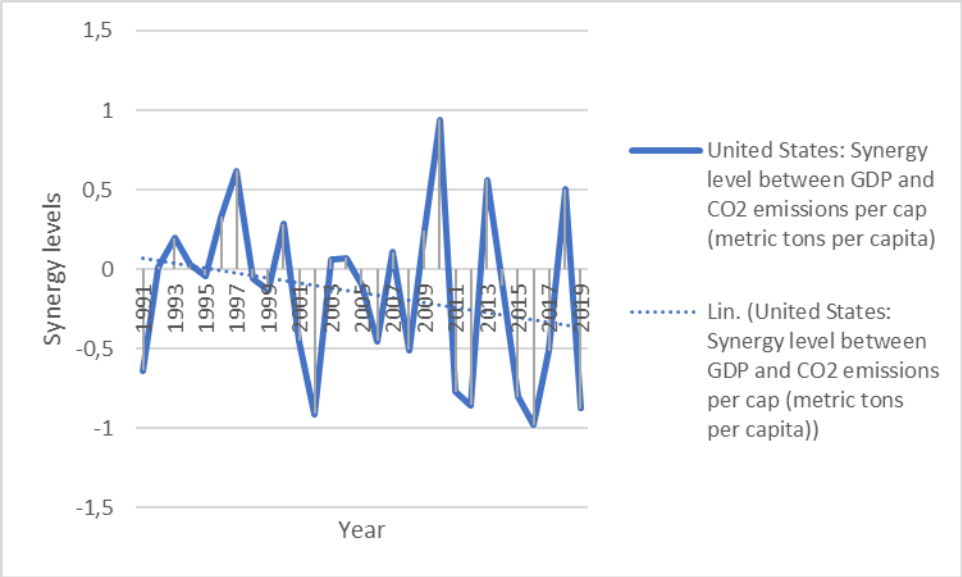

Figure 14. United States: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

The histogram of synergy observation in the USA is reported in Fig. 14. We see that histogram is strongly negatively skewed in the case of the USA. Most synergy observations are between -0,98- +0,20 (22 observations).

 ISBN: 978-86-87043-85-5

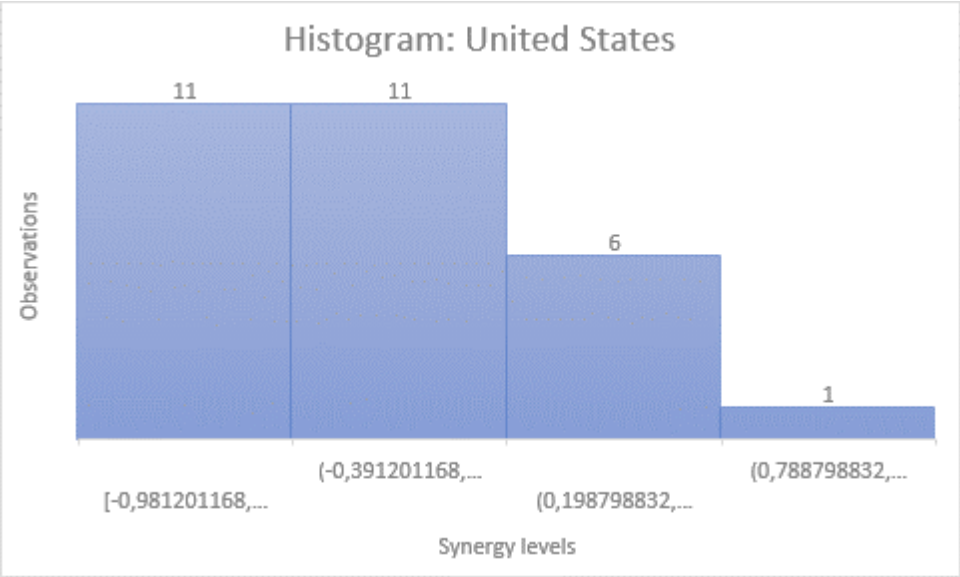

Figure 15: United States: Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita)

In Fig. 16 we report a synergy trend analysis of the region of Latin America and the Caribbean. The long-run synergy trend curve is clearly upward-sloping in this case.

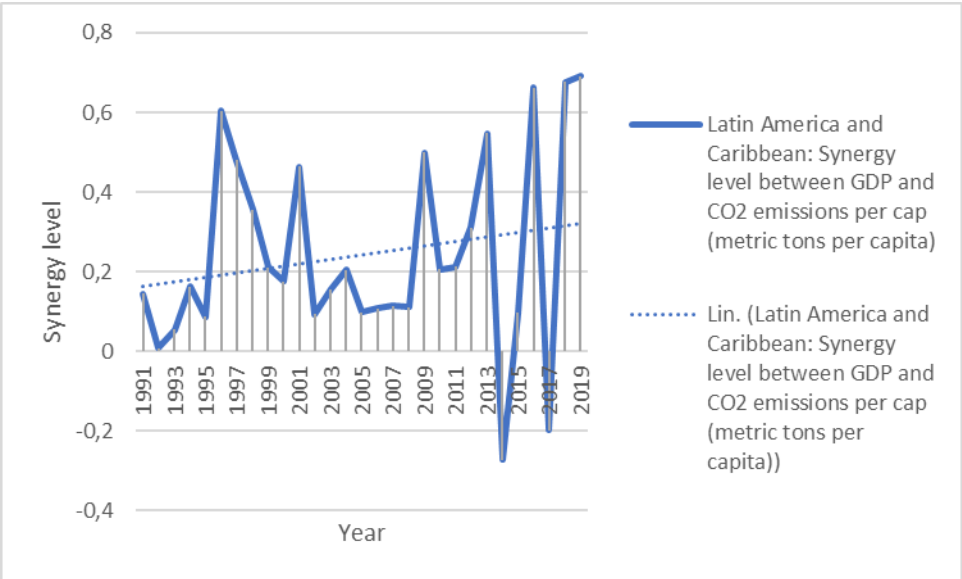

Figure 16: Latin America and the Caribbean region: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

The histogram of synergy observation in the region of Latin America and Caribbean region is reported in Fig. 17. We see that histogram is positively skewed in the case of the Latin America and Caribbean region. Most synergy observations are between 0 - +0,28 (17 observations).

 ISBN: 978-86-87043-85-5

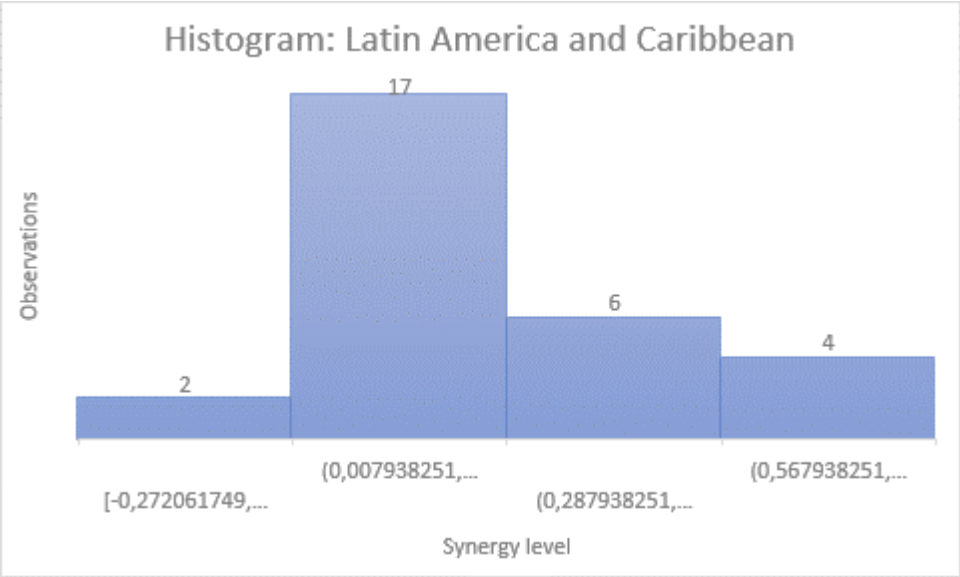

Figure 17: Latin America and Caribbean region: Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita)

In Fig. 18 we report the synergy trend level between GDP and CO_2 emissions per capita in the country group of fragile and conflict-affected situations defined by the World Bank.[1] In Fig. 18, we can see that the trend curve is slightly downward-sloping. The average synergy level has been positive and close to zero. Variations in the level of synergy have been big.

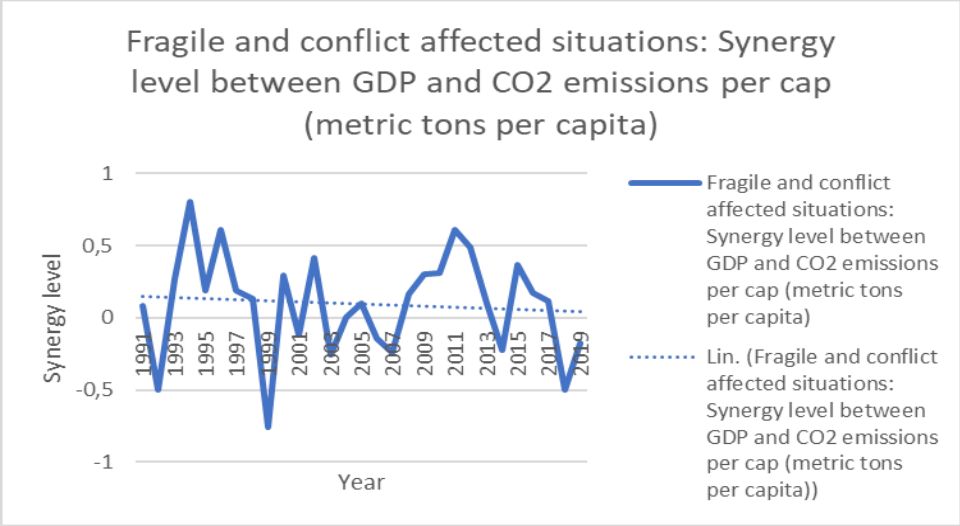

Figure 18: Countries in fragile and conflict-affected situations: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

[1] The definition of a country group of Fragile and conflict-affected countries is presented here: FCSList-FY23.pdf (worldbank.org). Conflict-affected countries are Afghanistan, Burkina Faso, Cameroon, the Central African Republic, the Democratic Republic of Congo, Ethiopia, Iraq Mali, Mozambique, Myanmar, Niger, Nigeria, Somalia, South Sudan, the Syrian Arab Republic, Ukraine, the Republic of Yemen. Countries of institutional and social fragility are Burundi, Chad, Comoros, Congo, the Republic of Eritrea, Guinea-Bissau, Haiti, Kosovo, Lebanon, Libya, Marshall Islands, Micronesia, the Federated States of Papua, New Guinea, Solomon Islands, Sudan, Timor-Leste, Tuvalu, Venezuela, RB West Bank, and Gaza (territory), and Zimbabwe.

 ISBN: 978-86-87043-85-5

In figure 19 we have reported a histogram of the countries in fragile and conflict-affected situations, in which the distribution of observations is negatively skewed. Most of the synergy observations fall between +0,04 - and +0,44 (15 observations).

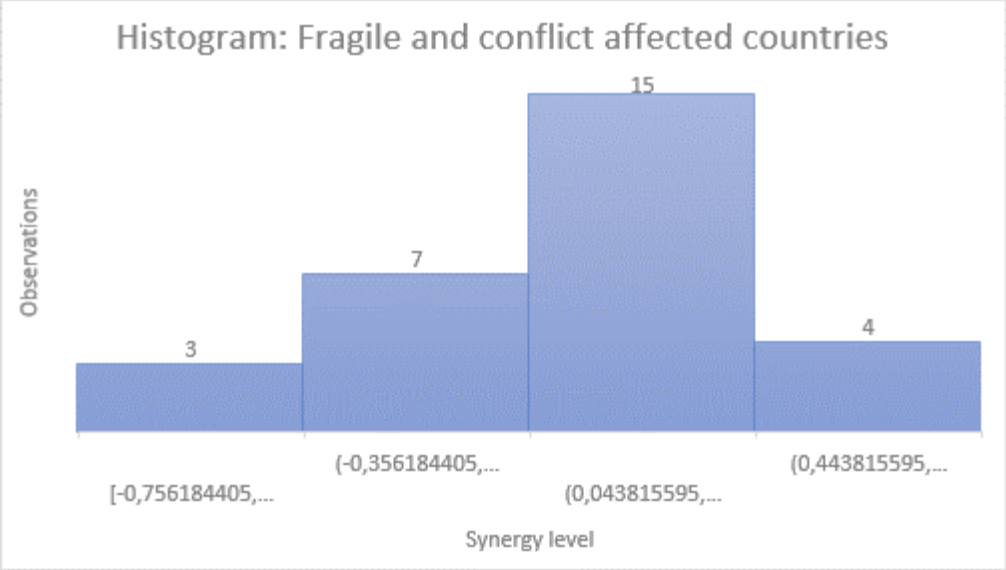

Figure 19: Countries in fragile and conflict-affected situations: Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita)

World

In Fig. 20 we report the synergy trend level between GDP and CO_2 emissions per capita in the World. In Fig. 20 we can see that the trend curve is slightly upward-sloping. The average synergy level has been negative, from 1991 to 2002, but later, in 2005-2019, it has been positive. Again, variations in synergy levels have been big. The maximum level of synergy level has been about 0,5, and the minimum level has been -0,8.

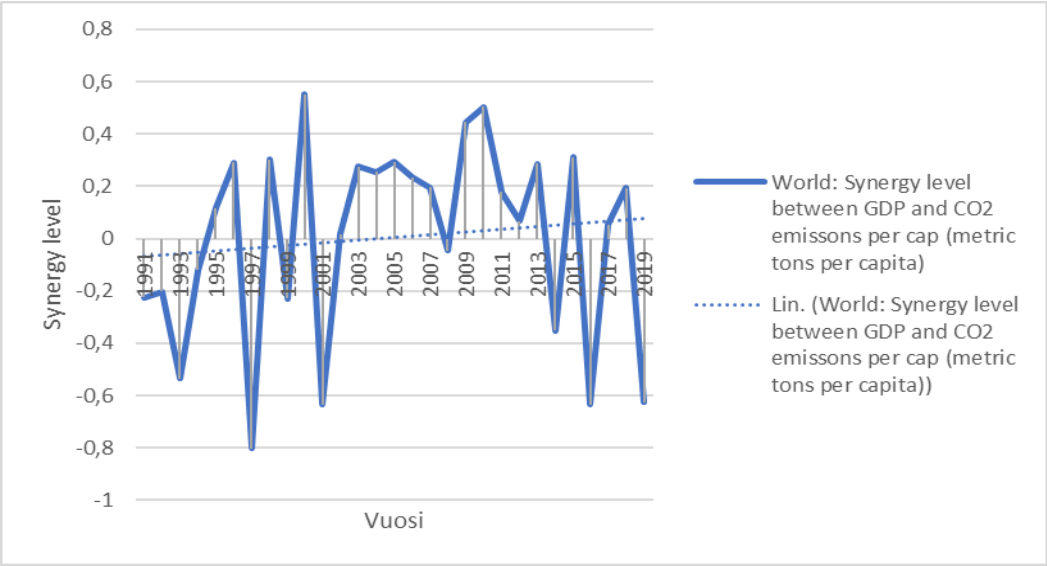

Figure 20: World: Synergy level between GDP and CO_2 emissions per cap (metric tons per capita)

 ISBN: 978-86-87043-85-5

The histogram of synergy observations in the World is reported in Fig. 21. We see that the histogram graph is negatively skewed in the World, which is a very important finding as such. Most synergy observations are between + 0,05 - +0,49 (14 observations).

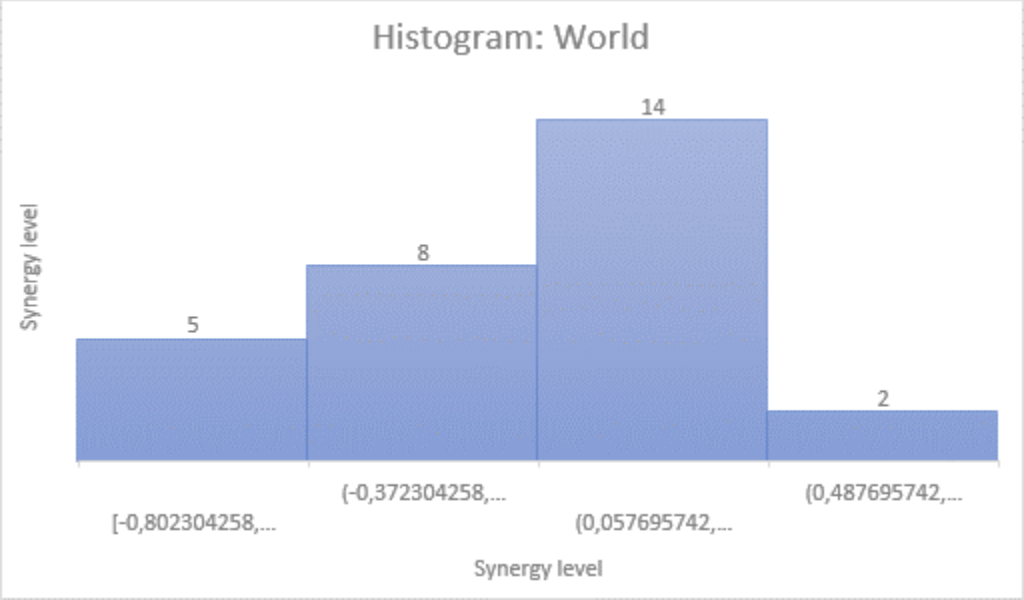

Figure 21: World: Synergy level observations level between GDP and CO_2 emissions per cap (metric tons per capita).

Conclusions and summary of results

This empirical study was focused on regional CO_2 emissions per capita and economic growth in the world and in various regions of the world. The results we interesting in many ways. Histogram analyses revealed both negatively skewed and positively skewed distributions. Negatively skewed distributions were observed in the world, in fragile and conflict-affected countries, in Latin America and the Caribbean region, in China, in Brazil, in the USA, and also in the European Union. Positively skewed distribution was observed in South Africa, India and in the Russian Federation. Normal distribution was not observed in the spatial analysis of this synergy study, which is a very interesting finding, as such. In Fig 22, we report key statistical indicators of regional synergy levels between GDP and CO_2 emissions per cap (metric tons per capita).

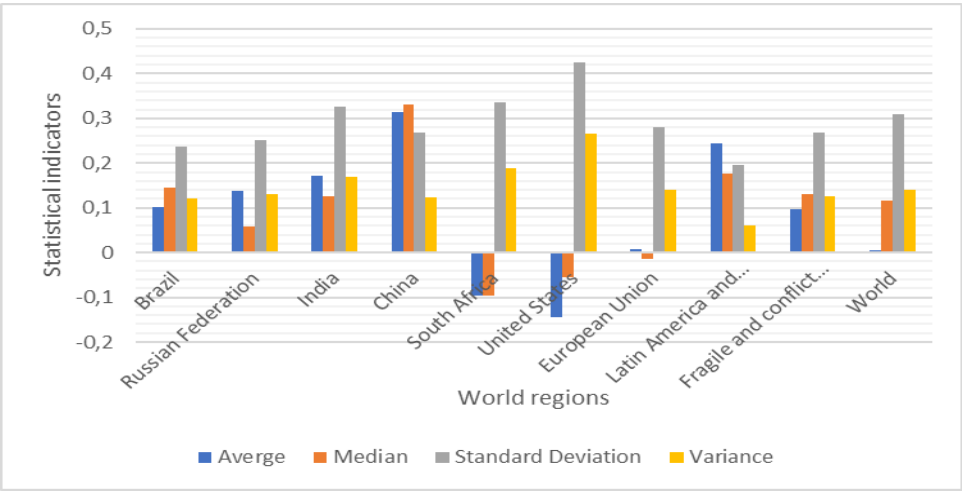

Figure 22: Key statistical indicators of regional synergy levels between GDP and CO_2 emissions per capita

From Fig. 22 we can see that synergy levels vary considerably in different regions of the world. If decision-makers are not aware of the difference in synergy levels, they can evaluate political and economic decisions incorrectly and

biasedly. In this sense, the results presented now in this study, are useful and policy-relevant for future decisions on global climate change and energy policy. The reason why the synergy levels are different is partly due to the fact that the developments of economies are at different stages in different global regions of the world. Obviously, the reasons for regional synergy differences should be investigated in more detail in further studies.

ACKNOWLEDGEMENTS: We acknowledge all professional feedback from research fellows of the project Manufacturing 4.0, and from the IRIS projects, which are funded by the Academy of Finland.

FUNDING: The Strategic Research Council (SRC) at the Academy of Finland has partly funded Professor Jari Kaivo-oja, in the Manufacturing 4.0 project (Strategic Research Council, project decision n:o 335989). The authors also want to thank the Academy of Finland for funding the "Cuban energy transformation Integration of Renewable intermittent sources in the power system (IRIS)" project, decision n:o 320229.

CONFLICT OF INTEREST: No conflicts of interest.

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.

 ISBN: 978-86-87043-85-5

[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] World Bank. *World Indicators Data Base. Global Development Indicators*. World Bank. Retrieved 14.10.2022.

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 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

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