Decomposition of the Kaya identity in the European Mediterranean countries over the 1990-2020 period with respect to CO_2 emissions

Dimitra Kaika[1,*]

[1] School of Applied Arts and Sustainable Design, Hellenic Open University, 26335, Patras, Greece

Abstract. The Kaya identity, proposed by Yoichi Kaya in 1993, attempts to evaluate the impact of total emissions of carbon dioxide (greenhouse gas) as the impact of human activity on the environment. The purpose of this work is the decomposition of CO_2 emissions in the European Mediterranean countries (Cyprus, France, Greece, Italy, Malta, Slovenia and Spain) for a time period spanning from 1990 to 2020, based upon the Kaya identity into scale, technological and structural effect. For this purpose, the Tapio decoupling analysis is adopted. According to results, technology improvements leading to declining rates of carbon per unit of energy used and structural changes indicating the use of less energy per unit of production could help in counterbalancing the positive scale effect of GDP production in CO_2 emissions per capita. This, however, requires the implementation of proper strategies focusing in improvements in technological change and structural changes in order to mitigate CO_2 emissions without hindering the economic growth process.

1 Introduction

The Kaya identity proposed by Yoichi Kaya in 1993 [1], considers total CO_2 emissions (greenhouse gas) as the impact of human activity on the environment. In particular, CO_2 emissions are the product of the interplay of four factors: population, GDP per capita expressing affluence, energy intensity of GDP and carbon intensity of energy or carbon footprint of energy. As a result, the Kaya identity highlights the elements of the economy on which one could act to reduce emissions, notably the energy intensity per unit GDP and the emissions per unit of energy. It should be emphasized that the Kaya identity is a special version of the IPAT formula that describes the environmental impact of human activity (I) as the product of interplay of population size (P), affluence (A) and technology (T) [2].

The Kaya identity enriches the theoretical debate that links environmental degradation with economic activity by considering other than income (economic growth) parameters in analysis. Another popular approach that considers the environmental degradation - economic activity nexus is the Environmental Kuznets Curve (EKC) theory which focuses mainly on the effect of income growth on environmental pressure [3]. According to the EKC speculation, further economic growth is expected to limit environmental pressure created in the early stages of the process of economic growth [3]. The EKC hypothesis has been extensively tested empirically adopting various estimation techniques, samples, time periods etc, however results are at best inconclusive [3-4] since the hypothesis is neither accepted nor rejected adequately, especially with respect to CO_2 emissions. Moreover, the EKC hypothesis suffers from many issues on its theoretical and empirical basis [4-5].

Many studies attempt to evaluate the decoupling (or coupling) degree of CO_2 emissions from the driving factors identified in relevant studies. In this perspective, energy savings and emissions reduction targets [6] would allow the delinking of the growth of CO_2 emissions from the process of economic growth over time [6]. The most dominant decoupling approaches in the literature are the Tapio approach in 2005 and the OECD approach [6-7]. Regardless of methodological differences between these approaches, the purpose, in any case, is to estimate the decoupling degree between CO_2 emissions and its influencing factors over time.

For instance, Wu et al. [7] adopt different decoupling models to compare decoupling trends in world economic growth and CO_2 emissions in typical developed and developing countries from 1965 to 2015. According to their findings, strong decoupling is found in developed countries while developing countries show weak decoupling that fluctuates to a significant extent and no clear trend emerges. Wang et al. [8] consider the case of Taiwan from 2007 to 2013 and explore the decoupling relationship between industrial growth and carbon emissions. According to their findings, Taiwan's industrial growth and carbon emissions experienced a negative decoupling from 2007 to 2009 and a decoupling from 2009 to 2013. The energy intensity effect plays the dominant role in promoting decoupling and both the

* Corresponding author: kaika.dimitra@ac.eap.gr

energy structure effect and the industrial structure effect negatively impact decoupling. Concerning China's manufacturing industry, Ren et al. [9] find that the industry has gone through four stages of decoupling: strong negative decoupling (1996–1999), weak decoupling (2000–2001), expansive negative decoupling (2002–2004), and weak decoupling (2005–2010). Following the Tapio decoupling approach, Tang et al. [10] explore the influences of tourism transportation, accommodation and activities on the total CO_2 emissions of the tourism industry over the period 1990–2012 in China. According to their findings, the decoupling state between economic growth and CO_2 emissions of tourism changes between negative decoupling and weak decoupling, indicating that the tourism industry's economic growth was faster than the growth of CO_2 emissions in China over this period. With respect to the Tapio and OECD decoupling analyses, Lin et al. [11] assess the decoupling state between CO_2 emissions and GDP in South Africa from 1990 to 2012. Their results show that the decoupling states between CO_2 emissions and GDP are expansive negative decoupling during 1990–1994, weak decoupling during 1994–2010 and strong decoupling during 2010–2012. Chen et al. [12] adopt the Tapio decoupling approach to explore the impacts of CO_2 emissions intensity of fossil energy, energy consumption structure, energy intensity, per capita GDP, population distribution and population size on CO_2 emissions in the OECD countries from 2001 to 2015 and they conclude that the influence of technical factors on the decoupling elasticity between CO_2 emissions intensity of fossil energy, energy consumption structure, energy intensity, per capita GDP, and population size and CO_2 emissions is greater than that of the non-technical factors.

This paper adopts the Tapio [13] decoupling approach and explores the underlying factors, through a Kaya identity formulation, that have driven the evolution of CO_2 emissions in the European Mediterranean countries (Cyprus, France, Greece, Italy, Malta, Slovenia and Spain) from 1990 to 2020.

The choice of the European Mediterranean countries as a sample is done because it comprises a varied sample with countries being at different economic growth stages and showing different growth rates of CO_2 emissions over time [14]. For instance, Italy, Greece and Spain, experienced fast economic growth from early 1990 [15-17]. Slovenia underwent a transition from centrally planned to market economy after 1990, followed by fast economic growth after 2000 [15]. Cyprus, Malta and Slovenia are EU member states since 2004. France is characterized by the dominant share of nuclear power in its electricity production [15]. However, all countries in the sample face similar climate challenges as they are located in the Mediterranean basin and the Mediterranean region is warming 20% faster than the global average [18]. Climate change impacts are expected to exert additional pressure on already strained ecosystems and on vulnerable economies and societies while, coastal zones face heightened disaster risks, including flooding and erosion, and the salinization of river deltas and aquifers that sustain food security and livelihoods [18].

Therefore, the study evaluates the contribution of each factor of the Kaya identity over time to the shaping of CO_2 emissions over time in the aforementioned European Mediterranean countries. This allows separation of the scale effect from improvements in technology which, in turn, helps to reveal the deterrent elements of each country's economic structure in mitigating carbon dioxide emissions. Results could be helpful for the implementation of proper strategies focusing in mitigating CO_2 emissions without hindering the economic growth process in countries in question.

2 Methodology and Data

2.1 Methodology

According to the Kaya identity proposed by Yoichi Kaya in 1993 [1], CO_2 emissions (CO2) at a given time are the product of the interplay of four factors: population (P), affluence as expressed by Gross Domestic Product (GDP) and Technology (T). In order to consider, as well, the effect of energy use (E), we get:

$$CO2 = P \times GDP \times T \Leftrightarrow$$
$$CO2 = P \times \frac{GDP}{P} \times \frac{CO2}{GDP} \Leftrightarrow$$
$$CO2 = P \times \frac{GDP}{P} \times \frac{CO2}{E} \times \frac{E}{GDP} \Leftrightarrow$$
$$\frac{CO2}{P} = \frac{GDP}{P} \times \frac{CO2}{E} \times \frac{E}{GDP} \tag{1}$$

In (1), the first term from the left is CO_2 emissions per capita (CO2pc). The fist term from the right is GDP per capita (GDPpc) which measures the scale effect. The second term represents the carbon intensity of energy (CO2_E) as an index of technological changes since a declining index implies less carbon per unit of energy used (and vice versa). Finally, the third term is the energy intensity of GDP (E_GDP) representing an index of structural changes since a declining index implies less use of energy per unit of production (and vice versa).

In the present work the Tapio decoupling analysis [13] is adopted in order to analyze the decoupling states of CO_2 emissions from GDP per capita, carbon intensity of energy and energy intensity of GDP respectively during 1990-2020 in seven European Mediterranean countries. According to this method, the decoupling of CO_2 emissions per capita can be expressed as elasticity values e under 1.0 and is defined by the percentage change of CO_2 emissions per capita (dependent variable Y) divided by the percentage change in a given time period of an independent variable X. The independent variables are GDP per capita (GDPpc), carbon intensity of energy (CO2_E) and energy intensity of GDP (E_GDP). Therefore, elasticity e of CO_2 emissions per capita (CO2pc) with respect to each independent variable between two periods t=1 and t=0, is defined as:

$$e_{CO2pc,GDPpc} = \frac{\Delta(CO2pc)/CO2_0}{\Delta(GDPpc)/GDP_0} \quad (2)$$

$$e_{CO2pc,CO2\_E} = \frac{\Delta(CO2pc)/CO2_0}{\Delta(CO2\_E)/(CO2\_E)_0} \quad (3)$$

$$e_{CO2pc,E\_GDP} = \frac{\Delta(CO2pc)/CO2_0}{\Delta(E\_GDP)/(E\_GDP)_0} \quad (4)$$

Depending on the value of the elasticity index D and on the signs of changes in Δ(Y) and Δ(X), Tapio [13] distinguishes in states of decoupling, negative decoupling and coupling. Subsequently, for each of these states, Tapio [13] further distinguishes in sub-states as described in Table 1:

Table 1. Description of decoupling states

State	
1. Decoupling	
Strong (SD)	$\Delta Y < 0, \Delta X > 0$ $e_{Y,X} < 0$
Weak (WD)	$\Delta Y > 0, \Delta X > 0$ $0 < e_{Y,X} < 0.8$
Recessive (RD)	$\Delta Y < 0, \Delta X < 0$ $e_{Y,X} > 1.2$
2. Negative Decoupling	
Expansive (END)	$\Delta Y > 0, \Delta X > 0$ $e_{Y,X} > 1.2$
Strong (SND)	$\Delta Y > 0, \Delta X < 0$ $e_{Y,X} < 0$
Weak (WND)	$\Delta Y < 0, \Delta X < 0$ $0 < e_{Y,X} < 0.8$
3. Coupling	
Expansive (EC)	$\Delta Y > 0, \Delta X > 0$ $0.8 < e_{Y,X} < 1.2$
Recessive (RC)	$\Delta Y < 0, \Delta X < 0$ $0.8 < e_{Y,X} < 1.2$

2.2 Sample

The study considers European countries Cyprus (CYP), France (FRA), Greece (GRC), Italy (ITA), Malta (MLT), Slovenia (SVN) and Spain (ESP) in its sample which are Mediterranean countries.

2.3 Data

The initial data are derived from The World Development Indicators (WDI) database provided by the World Bank [19]. In particular, initial data are CO_2 emissions (CO2) expressed in kt, GDP per capita (GDPpc) expressed in constant 2015 US$, energy use per capita (E) expressed in kg of oil equivalent per capita, carbon intensity of energy (CO2_E) expressed in kg per kg of oil equivalent energy use and total population (P).

Initial data from WDI [19] cover at full the time period 1990-2020 only for the variables of CO2, GDPpc and P. Concerning energy use per capita (E) and carbon intensity of energy (CO2_E), initial data from WDI cover only the period up to year 2015. In order to overcome this limitation in data availability, the following procedure is adopted: Taking into consideration the Greenhouse Gas Emissions from Energy (2022 Highlights) reported by IEA [20], and in particular the CO_2 emissions and Drivers (Kaya decomposition) which reports growth rates of each Kaya element considering year 2000 as a base year (2000=100), all variables from WDI and their respective values in 2000 are recalculated into new time series. It should be emphasized that the differences between initial data reported by WDI and the data after transformations based upon the IEA indices are marginal and, in all cases, the annual growth rates are moving to the same direction (increasing or decreasing).

The time period under consideration (1990-2020) is divided in two sub-periods, since, according to Tapio [13], the time period used should comprise several, say, 5-10 years as there is supposedly a lag in the economic variables. Therefore, the respective elasticities *e* are reported for each time period as follows:

- 1st sub-period: 1990-2005 (16 years)
- 2nd sub-period: 2006-2020 (15 years)

3 Results and Discussion

3.1 Evolution of variables over time

The evolution of all variables from 1990 up to 2020, are depicted in Figures 1-5. All growth rates are calculated considering year 1990 as the base year.

In Fig.1, GDP per capita in all countries show an upward trend until mid 2010. From late 2010s, due to the effect of economic crisis, there is a slowdown in growth rates but most countries begin to recover from 2015. Malta in 2019 reaches 2,1 times the respective 1990s levels of per capita GDP.

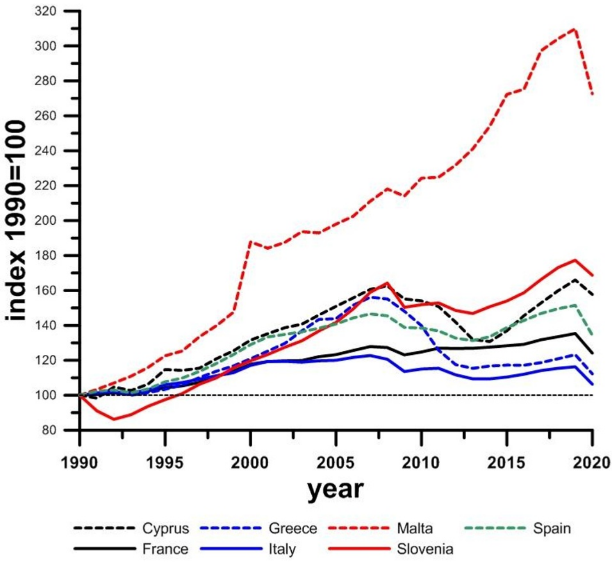

Fig. 1. Evolution of GDP per capita (1990-2020), base year 1990=100

Considering population growth from 1990 to 2020 in Fig.2, most countries of the sample (France, Greece, Italy, Slovenia and Spain) depict a moderate growth rate reaching maximum 0,20 times the 1990s levels. The highest growth rate of population is depicted in Cyprus since, in 2020, the population is almost 53% above 1990s levels. Malta follows with growth of population reaching in 2020 almost 48% compared to population in1990.

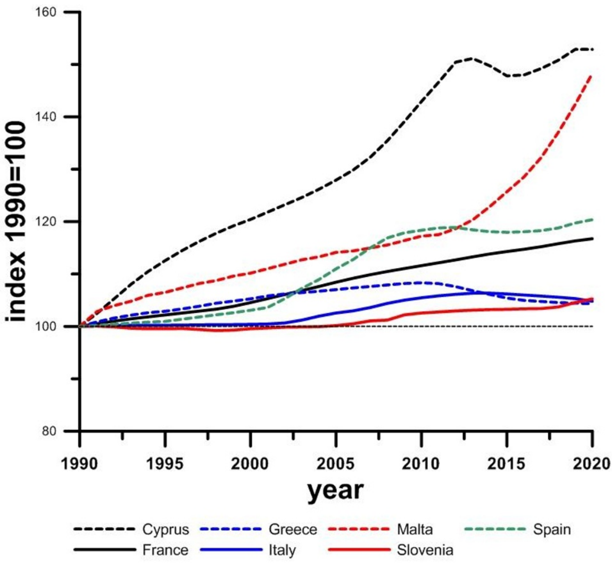

Fig. 2. Evolution of population (1990-2020), base year 1990=100

Considering the carbon intensity of energy which stands as an index of technological changes, in Fig.3, Cyprus is the only country that manages hardly in late 2020s to lower its levels compared to 1990. France and Italy are the two countries of the sample that show steadily a decreasing growth rate over the period compared to 1990s levels indicating steady improvements in technological changes with less carbon per unit of energy used.

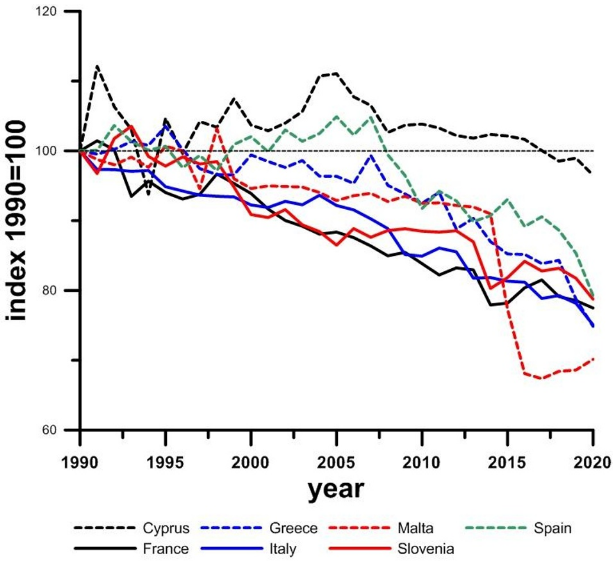

Fig. 3. Evolution of carbon intensity of energy (1990-2020), base year 1990=100

With respect to the evolution of energy intensity of GDP depicted in Fig.4, Malta is the only country from the sample that reaches the lowest growth rates over time compared to 1990, reaching -75% in 2020 compared to respective 1990 level, indicating a strong structural change with less use of energy per unit of production over time. All other countries manage to lower energy intensity of GDP in late 2020 approximately from -16% up to -37% compared to 1990s levels.

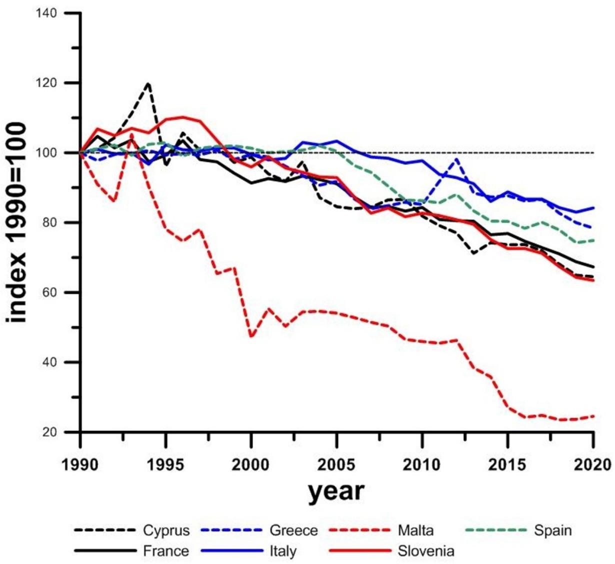

Fig. 4. Evolution of energy intensity of GDP (1990-2020), base year 1990=100

Finally, considering CO_2 emissions in Fig.5, Cyprus is the only country that fails to lower CO_2 emissions in late 2020 compared to 1990 respective levels. Most countries (France, Greece, Italy, Malta and Slovenia) manage to lower CO_2 emissions compared to 1990s levels during the last decade.

 https://doi.org/10.1051/e3sconf/202343605001

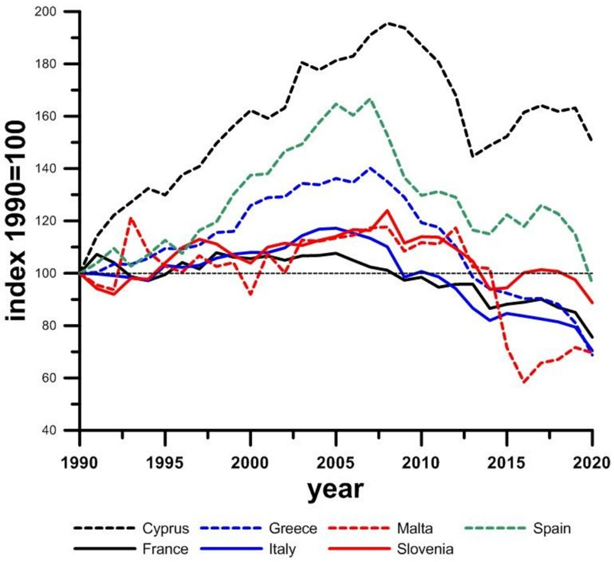

Fig. 5. Evolution of CO_2 emissions (1990-2020), base year 1990=100

3.2 Elasticity *e*

Based upon calculations as described in equations (2), (3) and (4), Table 2 summarizes results concerning the elasticity of per capita CO_2 emissions with respect to GDP per capita (GDPpc), carbon intensity of energy (CO2_E) and energy intensity of GDP (E_GDP) respectively, indicating the decoupling state in the first sub-period (1990-2005).

Table 2. Elasticity and decoupling states (1st sub-period)

1st Sub-period (1990-2005)						
	GDPpc		CO2_E		E_GDP	
	e	state (*)	e	state (*)	e	state (*)
CYP	0,819	EC	3,775	END	-2,700	SND
FRA	-0,032	SD	0,063	WND	0,083	WND
GRC	0,622	WD	-7,484	SND	-3,332	SND
ITA	0,714	WD	-1,827	SND	4,303	END
MLT	-0,006	SD	0,080	WND	0,012	WND
SVN	0,333	WD	-1,027	SND	-1,955	SND
ESP	1,185	EC	9,872	END	108,740	END

***Notes:**
SND: strong negative decoupling — *WD: weak decoupling*
WND: weak negative decoupling — *RD: recessive decoupling*
END: expansive negative decoupling — *EC: expansive coupling*
SD: strong decoupling — *RC: recessive coupling*

Similarly, Table 3 summarizes results concerning the elasticity of per capita CO_2 emissions with respect to GDP per capita (GDPpc), carbon intensity of energy (CO2_E) and energy intensity of GDP (E_GDP) respectively, indicating the decoupling state in the following sub-period (2006-2020).

Table 3. Elasticity and decoupling states (2nd sub-period)

2nd Sub-period (2006-2020)						
	GDPpc		CO2_E		E_GDP	
	e	state (*)	e	state (*)	e	state (*)
CYP	-23,374	SD	2,907	RD	1,307	RD
FRA	27,042	RD	2,834	RD	1,423	RD
GRC	1,831	RD	2,210	RD	4,901	RD
ITA	3,171	RD	2,224	RD	2,457	RD
MLT	-1,533	SD	2,121	RD	0,992	RC
SVN	-2,115	SD	2,406	RD	0,998	RC
ESP	6,392	RD	1,953	RD	1,968	RD

***Notes:**
SND: strong negative decoupling — *WD: weak decoupling*
WND: weak negative decoupling — *RD: recessive decoupling*
END: expansive negative decoupling — *EC: expansive coupling*
SD: strong decoupling — *RC: recessive coupling*

3.3 Graphical presentation of elasticity *e*

3.3.1 Elasticity of CO_2 emissions with respect to GDP per capita

Based on the analysis above, Fig. 6 and 7 illustrate the elasticity of per capita CO_2 emissions with respect GDP per capita (GDPpc), classified by state of decoupling according to the Tapio decoupling analysis [13], in the two respective sub-periods.

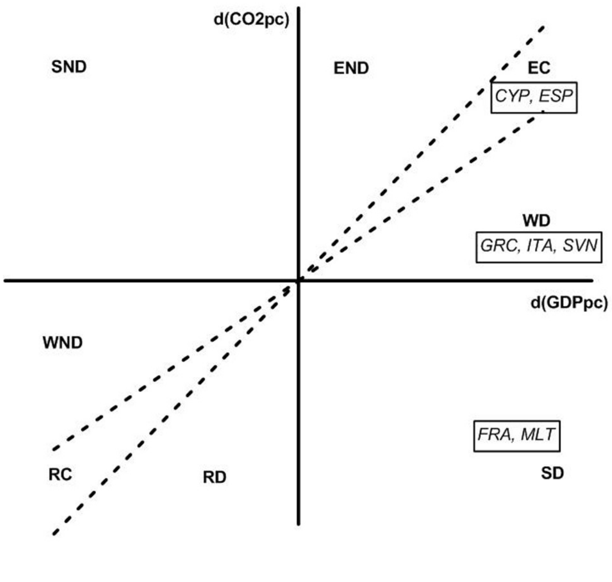

Fig. 6. Elasticity of CO_2 emissions per capita with respect to GDP per capita, 1990-2005

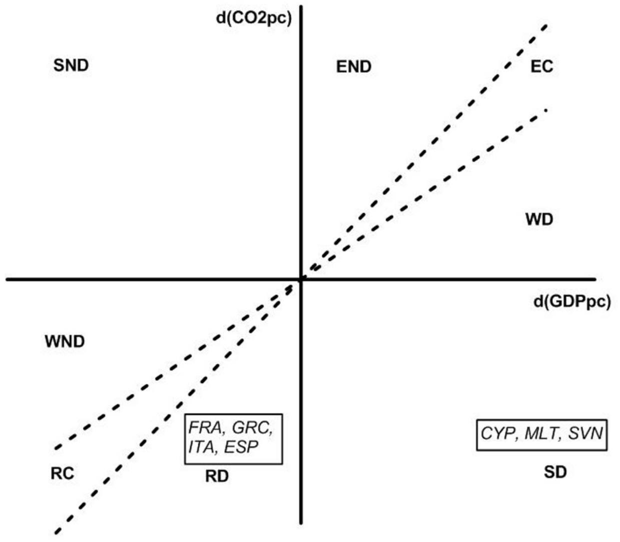

Fig. 7. Elasticity of CO_2 emissions per capita with respect to GDP per capita, 2006-2020

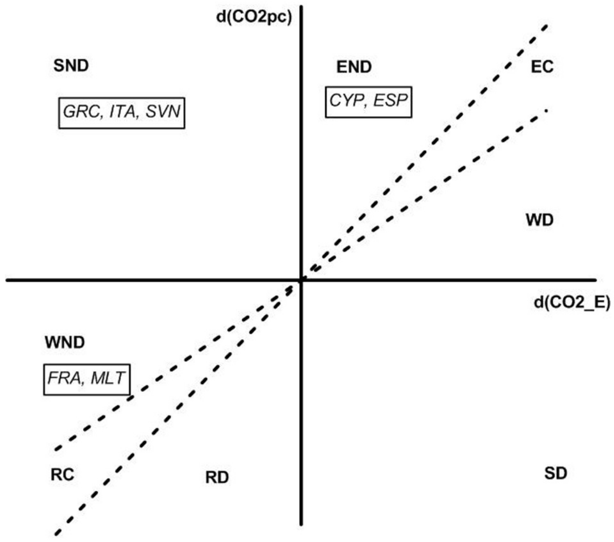

Fig. 8. Elasticity of CO_2 emissions per capita with respect to carbon intensity of energy, 1990-2005

From Fig. 6 and 7, we observe the following: Malta is the only country of the sample that reports strong decoupling of per capita CO_2 emissions with respect to GDP per capita in both sub-periods since, positive changes in GDP per capita cause negative changes in per capita CO_2 emissions. France, the most developed country of the sample, turns from strong decoupling in the first sub-period to recessive decoupling in the second sub-period. Greece and Italy turn from weak decoupling in the first sub-period, to recessive decoupling in the second sub-period with negative changes in per capita GDP causing larger negative changes in CO_2 emissions per capita. Spain turns from expansive coupling in the first sub-period to recessive decoupling in the second sub-period. Cyprus, from expansive decoupling over the first 16-year period turns to strong decoupling over the second 15-year period. Finally, Slovenia from weak decoupling with positive changes in per capita GDP causing smaller positive changes in per capita CO_2 emissions, turns to strong decoupling in the second sub-period, with positive changes in GDP per capita causing negative changes in per capita CO_2 emissions.

3.3.2 Elasticity of CO_2 emissions with respect to carbon intensity of energy

The following Fig. 8 and 9, illustrate the elasticity of per capita CO_2 emissions with respect to carbon intensity of energy in the two sub-periods respectively, classified by state of decoupling according to Tapio [13].

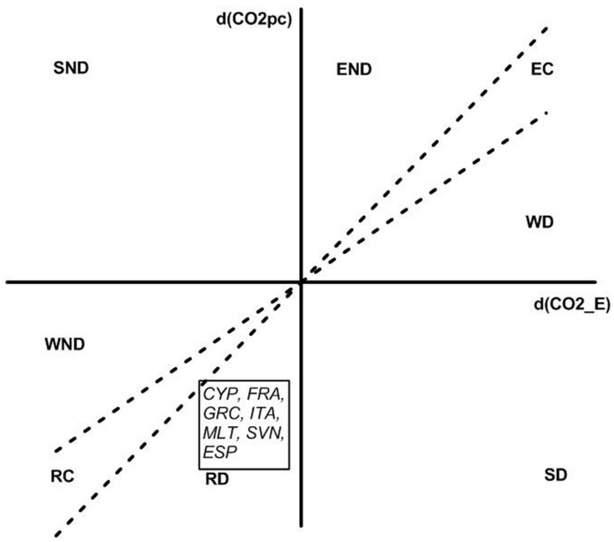

Fig. 9. Elasticity of CO_2 emissions per capita with respect to carbon intensity of energy, 2006-2020

Considering the elasticity of per capita CO_2 emissions with respect to carbon intensity of energy in Fig. 8 and 9, we highlight that, irrespective of the decoupling state that the countries report in the first sub-period (1990-2005), in the second sub-period (2006-2020) all countries report recessive decoupling since, negative changes in carbon intensity of energy cause larger negative changes in per capita CO_2 emissions. In other words, improvements in carbon intensity of energy (negative change) result in larger reductions in per capita CO_2 emissions. Therefore, technological improvements have resulted in strong negative growth of CO_2 emissions per capita.

3.3.3 Elasticity of CO_2 emissions with respect to energy intensity of GDP

Finally, the following Fig. 10 and 11, illustrate the elasticity of per capita CO_2 emissions with respect to energy intensity of GDP in the two sub-periods respectively, classified by state of decoupling according to Tapio [13].

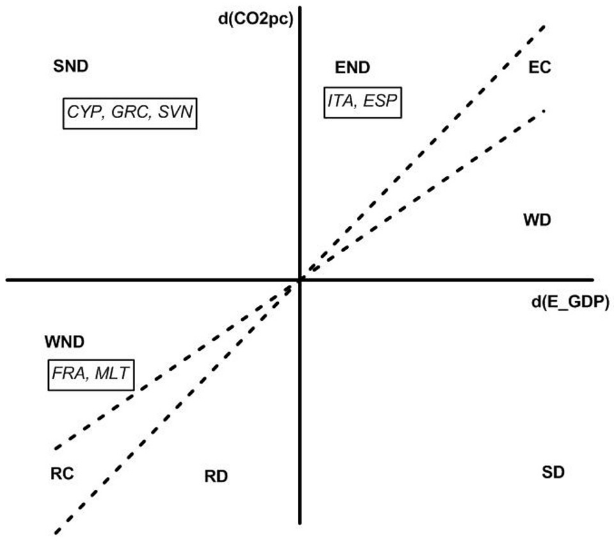

Fig. 10. Elasticity of CO_2 emissions per capita with respect to energy intensity of GDP, 1990-2005

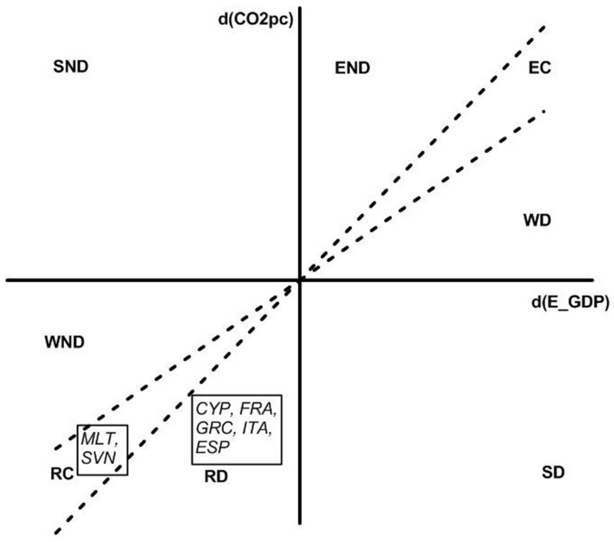

Fig. 11. Elasticity of CO_2 emissions per capita with respect to energy intensity of GDP, 2006-2020

Considering the decoupling state of the elasticity of per capita CO_2 emissions with respect to energy intensity of GDP, five countries (Cyprus, France, Greece, Italy and Spain) turn, in the second sub-period (2006-2020) to recessive decoupling, since, negative changes in energy intensity of GDP cause larger negative changes in per capita CO_2 emissions. Therefore, in these countries, improvements in the use of (less) energy per unit of production (structural changes) result in moderate negative changes in per capita CO_2 emissions.

However, Malta and Slovenia, turn from negative decoupling in the first sup-period, to recessive coupling in the following sub-period (2006-2020), since, negative changes in energy intensity of GDP cause similar negative changes in per capita CO_2 emissions.

4 Conclusions

The decoupling analysis of CO_2 emissions with respect to GDP per capita (GDPpc) based upon the Tapio approach, shows that over the recent 15-years period (2006-2020) most European Mediterranean countries (France, Greece, Italy and Spain) indicate a recessive decoupling with negative changes in per capita GDP causing larger negative changes in CO_2 emissions per capita, as a result, however, of the economic crisis which resulted in lower growth rates of GDP per capita. Cyprus, Malta and Slovenia manage to turn into strong decoupling in the second sub-period.

Considering the decoupling state of CO_2 emissions with respect to carbon intensity of energy (CO2_E), all countries of the sample, in the second sub-period, report recessive decoupling indicating that improvements in carbon intensity of energy (negative change) result in larger reductions in per capita CO_2 emissions. Therefore, technological improvements have resulted in strong negative growth of CO_2 emissions per capita.

Finally, as far as the decoupling state of the elasticity of per capita CO_2 emissions with respect to energy intensity of GDP is concerned, five countries (Cyprus, France, Greece, Italy and Spain) turn, in the second sub-period (2006-2020), to recessive decoupling, indicating that improvements in the use of (less) energy per unit of production (structural changes) result in moderate negative changes in per capita CO_2 emissions. Only Malta and Slovenia, turn to recessive coupling in the second sub-period (2006-2020), since, negative changes in energy intensity of GDP cause similar negative changes in per capita CO_2 emissions.

Therefore, technology improvements leading to declining rates of carbon per unit of energy used and structural changes indicating the use of less energy per unit of production could help in counterbalancing the positive scale effect of GDP production in CO_2 emissions per capita. This, however, requires the implementation of proper strategies focusing in improvements in technological change and structural changes in order to mitigate CO_2 emissions without hindering the economic growth process.

References

1. Y. Kaya, K. Yokobori, *Environment, Energy, and Economy Strategies for Sustainability*. (United Nations University Press, Tokyo 1997)

2. B. O'Neill, F.L. MacKellar, W. Lutz, *Population, greenhouse gas emissions and climate change. The End of Population Growth in the 21st Century: New Challenges for Human Capital Formation and Sustainable Development,* (ed W Sanderson, W Lutz and S Scherbov, London, Earthscan, 283–314 2004)
3. D. Kaika, E. Zervas, Energy Policy **62**, 1392 (2013)
4. D. Kaika, E, Zervas, Energy Policy **62**, 1403 (2013)
5. D. Kaika, E, Zervas, *7th International Conference on Energy, Environment, Ecosystems and Sustainable Development* (–EEESD'11, November 17-19 Angers, France 2011)
6. X. Zhao, X. Zhang, S. Shao, Energy Econ. **60**, 275 (2016)
7. Y. Wu, Q. Zhu, B, Zhu, J. Cleaner Prod. **190**, 94 (2018)
8. Q. Wang, Y. Hang, P. Zhou, Y. Wang, Energy **113**, 728 (2016)
9. S. Ren, H. Yin, X. Chen, Environ. Dev. **9**, 61 (2014)
10. Z. Tang, J. Shang, C. Shi, Z. Liu, X. Bi, Ecol. Indic. **46**, 390 (2014)
11. S.J. Lin, M. Beidari, C. Lewis, Aerosol. Air Qual. Res. **15**, 2676 (2015)
12. J. Chen, P. Wang, L. Cui, S. Huang, M. Song, Applied Energy **231**, 937 (2018)
13. P. Tapio, J. Transp. Policy **12**, 137 (2005)
14. P. Fernández González, M. Landajo, M.J. Presno, Environ. Sci. Policy **38**, 11 (2014)
15. P. Ciais, J.D. Paris, G. Marland, P. Peylin, S.L. Piao, I. Levin, T. Pregger, Y. Scholz, R. Friedrich, L. Rivier, S. Houwelling, E.D. Schulze, Glob. Change Biol. **16**, 1395 (2010)
16. E. Kotroni, D. Kaika, E. Zervas, Intern. J. of Energy Econ. and Policy **10**, 4, 364 (2020)
17. D. Kaika: Evaluating the IPAT formula in Greece over the 1960-2019 period with respect to CO_2 emissions. IOP Conference Series: Earth and Environmental Science **1123** (2022)
18. United Nations, *Environment Programme/ Mediterranean Action Plan and Plan Bleu. State of the Environment and Development in the Mediterranean.* Nairobi. (2020)
19. World Development Indicators database at World Bank (2023)
20. International Energy Agency, *Greenhouse Gas Emissions from Energy – 2022 Highlights, Annual Historical Series* (last update September 2022).