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## **Introduction to the report**

The aim of this report is give an overview of how the different approaches, ASA, MuSIASEM, and SUMMA can be applied to the study of synergies and trade-offs. The report is divided into three parts for each of the approaches. In the first part we give examples how ASA approach can be used to study synergies and trade-offs between different unsustainable trends identified in EU. We use ASA approach to identify whether there is synergy or trade-off between different dimensions of sustainable development by concentrating on 2 and 3 variable calculations in which the nature of the relationship between two or three trends are studied. The second part concentrates on the applicability of MuSIASEM approach to the analysis of synergies and trade-offs. The MuSIASEM approach is used to study the effects, synergies and trade-offs associated to i) structural changes in the economy, and ii) demographic changes, immigration and ageing society. In the third part we present results from a study carried out by the SUMMA approach.

# **PART 1: Synergies and trade-offs between unsustainable trends identified in the EU – analysis carried out with ASA approach**

## ***Introduction***

The aim of this part of the report is to look at the possibilities to analyse synergies and trade-offs between selected unsustainable trends identified in the EU sustainable development strategy and to develop new tools for analysis. The study of synergies and trade-offs conducted here builds on previous work carried out in deliverables 3.1 and 3.2. In the deliverable 3.1 we carried out analysis for the ten unsustainable trends identified in the EU SDS and based on the most promising results, in deliverable 3.2 we studied inter-linkages between selected unsustainable trends and conducted forecasts for those trends. The emphasis in the previous reports has been on two trends: climate change and energy, and poverty and social exclusion. The former is measured with an indicator on CO<sub>2</sub> emissions (CO<sub>2</sub>), whilst the latter is measured with a headline indicator on At-risk-of poverty (PS). In this report we use these two headline indicators and different dimensions of sustainable development, for example GDP, transport, ageing society and health, as examples to analyse the methodology that has been developed to study synergies and trade-offs between.

In order to explore synergies and trade-offs between different trends we need to provide definitions for the terms. We can say that there is synergy between two factors when their combined effect is greater or smaller than the sum of their separate effects. Trade-off can be defined as a balance achieved between two desirable but incompatible features or as a situation where the selection of one feature results in the loss of another feature.

Two different kind of analysis are carried out. First we determine whether there is synergy or trade-off (or neither) between two trends under investigation. Second we determine the same for three trends simultaneously. Ideally the trends investigated represent different dimensions of sustainable development, although synergies and trade-offs within any of the dimensions is equally interesting.

## Method and material

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 with following equation:

$$z = ax + by + cxy$$

Where  $x$ ,  $y$  and  $z$  are variables and  $a$ ,  $b$  and  $c$  are coefficients that determine how the output  $z$  depends on inputs  $x$  and  $y$ . If  $y$  is zero, the output is determined by  $x$  and the coefficient  $a$ . Coefficients  $a$  and  $b$  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.

If we look at a change from A to B in the Fig. 1 we can determine the change in the area ( $\Delta z$ ) to be determined by

$$\Delta z = a\Delta x + b\Delta y + c\Delta x\Delta y = y_0\Delta x + x_0\Delta y + \Delta x\Delta y$$

We can interpret the synergy of the inputs to be determined by the yellow area which is determined by  $\Delta x\Delta y$ .

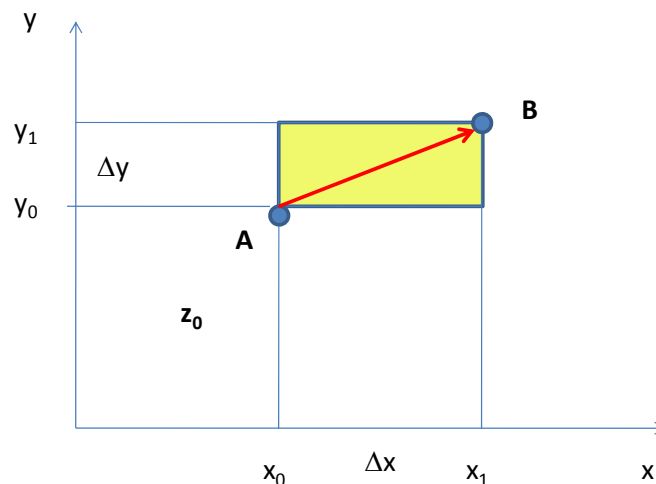


Figure 1 a. Synergy between two variables  $x$  and  $y$  determined by their changes  $\Delta x\Delta y$ .

The synergy can also be negative as is shown in the Fig. 1b where the change in  $y$  is negative and  $\Delta x\Delta y$  becomes negative.

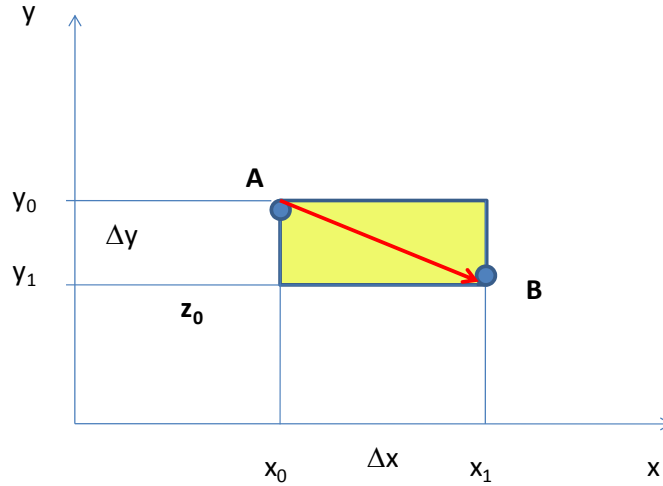


Figure 1 b. Negative synergy between x and y in the case where  $\Delta y$  is negative.

Figure 1c shows a case where synergy equals zero in a case where  $\Delta y$  is zero. This is the trade-off situation between the variables.

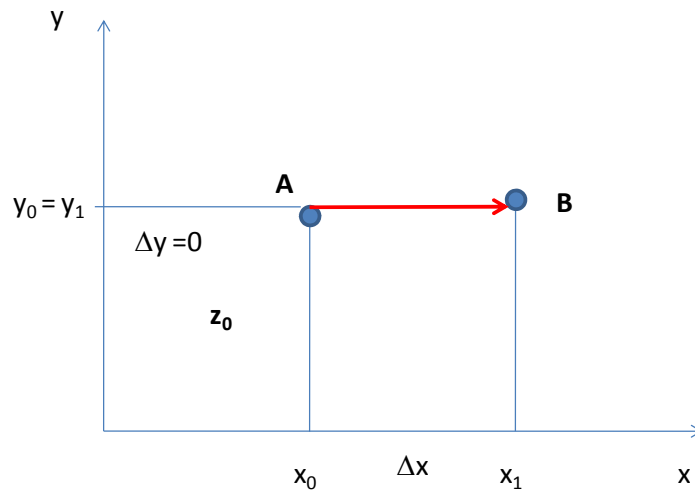
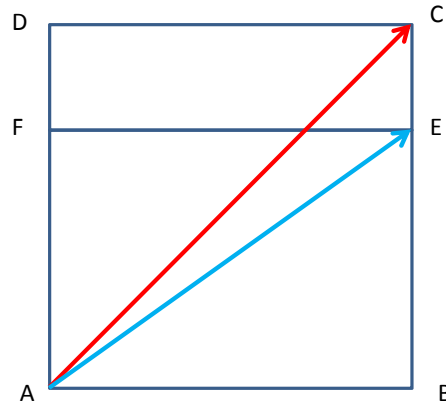


Figure 1 c. Synergy between x and y equals zero.

Maximum synergy can be obtained when relative changes  $\Delta x$  and  $\Delta y$  are equal ( $x_0$  and  $y_0$  are first normalized, i.e. the initial year values are normalized to be 1 or 100). This means that synergy between two variables can be measured in the scale  $-1 \dots +1$  as

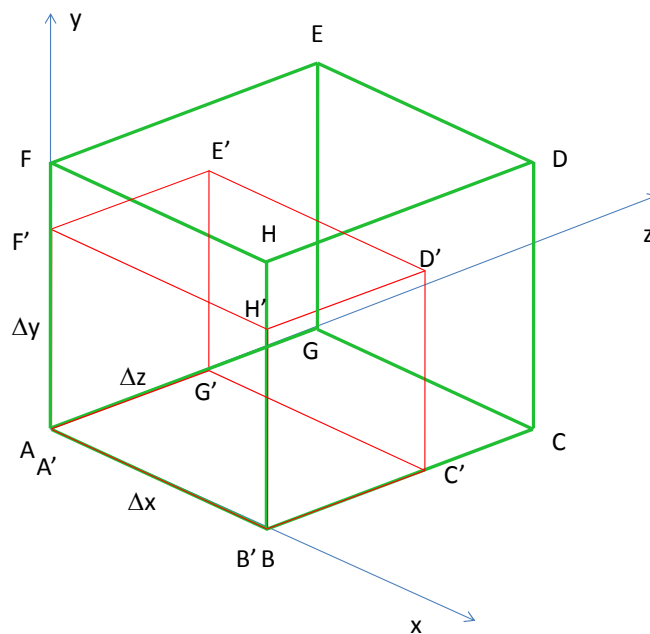
$$s = \frac{\Delta x}{\Delta y}$$

Where  $\Delta y$  is in this case the larger change. If  $\Delta y$  is smaller than  $\Delta x$  the quotient must be inverted. The synergy can be also measured by the ratio of the area of the real change ( $\Delta x \Delta y$ ) to the area of the maximum change, i.e. the ratio of the area of rectangular ABEF to the area of ABCD in Fig. 1d.



**Figure 1 d. Measuring the synergy as a ratio of the area ABEF to the maximum areas ABCD (max  $\Delta x \Delta y$ ).**

Synergy between three variables can be calculated in a similar way. In Fig 1.f the synergy can be calculated as a ratio of the volume of the cube  $\Delta x \Delta y \Delta z$  ( $A'B'C'D'E'F'G'$ ) to the volume of the maximum cube ABCDEFG, where the changes in x, y and z would be equal.



**Figure 1 f. Determination of the synergy between three variables.**

The data of GDP, POP, and CO<sub>2</sub> for the case studies of the method were taken from the International Energy Agency (IEA), the employment data from the International Labor Organization (ILO) and the data for at-risk-of poverty, ageing society and health from the Eurostat. All the calculations are done for EU-15 countries due to better data availability. However for comparison, we have also calculated some examples for two EU countries, UK and Greece.

## **Results for 2 variable calculations**

For the 2 variable calculations we have selected 8 cases under investigation:

- Case 1: GDP per capita and CO<sub>2</sub> per capita
- Case 2: GDP per capita and poverty
- Case 3: CO<sub>2</sub> per capita and poverty
- Case 4: GDP per capita and employment
- Case 5: GDP per capita and healthy life years
- Case 6: CO<sub>2</sub> per capita and final energy consumption of transport
- Case 7: CO<sub>2</sub> per capita and healthy life years
- Case 8: Poverty and ageing society

Table 1 below shows the results of the calculations (the change in the trend between 1995 and 2005, and the synergy ratio) for each of the cases. In order to portray how the synergy ratio has changed in time we have calculated the synergy factor (ratio) from each of the years from 1995 to 2005. These results are shown in Table 2. The results presented in both tables will be further discussed later per case. For cases 1, 4 and 6 we have done additional calculations for UK and Greece. The data is presented in Tables 3 and 4 for UK, and Tables 5 and 6 for Greece.

Normalized data for EU-15 countries 1995 - 2005, except for * 1999 - 2003			
<b>C1: GDP and CO<sub>2</sub></b>	$\Delta$ GDP	$\Delta$ CO <sub>2</sub>	$\Delta$ CO <sub>2</sub> / $\Delta$ GDP
	19,73	1,32	<b>0,07</b>
<b>C2: GDP and PS</b>	$\Delta$ GDP	$\Delta$ PS	$\Delta$ PS/ $\Delta$ GDP
	19,73	-5,88	<b>-0,30</b>
<b>C3: CO<sub>2</sub> and PS</b>	$\Delta$ CO <sub>2</sub>	$\Delta$ PS	$\Delta$ CO <sub>2</sub> / $\Delta$ PS
	1,32	-5,88	<b>-0,22</b>
<b>C4: GDP and</b>	$\Delta$ GDP	$\Delta$ EMP	$\Delta$ EMP/ $\Delta$ GDP



<b>employment</b>	19,73	12,28	<b>0,62</b>
<b>C5: GDP and health*</b>	$\Delta$ GDP	$\Delta$ HLT	$\Delta$ HLT/ $\Delta$ GDP
	6,36	2,76	<b>0,43</b>
<b>C6: CO<sub>2</sub> and transport</b>	$\Delta$ CO <sub>2</sub>	$\Delta$ TR	$\Delta$ CO <sub>2</sub> / $\Delta$ TR
	1,32	18,04	<b>0,07</b>
<b>C7: CO<sub>2</sub> and health*</b>	$\Delta$ CO <sub>2</sub>	$\Delta$ HLT	$\Delta$ HLT/ $\Delta$ CO <sub>2</sub>
	3,46	2,76	<b>0,80</b>
<b>C8: PS and AS</b>	$\Delta$ PS	$\Delta$ AS	$\Delta$ AS/ $\Delta$ PS
	-5,88	5,51	<b>-0,94</b>

**Table 1: summary of synergy factors for EU-15**

As can be seen from the values in Table 1 Cases 7 and 8 are the closest to synergy, while Cases 1 and 6 almost present a trade-off situation. All the other Cases show weaker synergy.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
<b>GDP and CO<sub>2</sub></b>	0,60	0,10	0,23	0,03	0,04	0,16	0,09	0,23	0,18	0,07
<b>GDP and PS</b>	-0,25	-0,67	-0,57	-0,61	-0,87	-0,77	-0,74	0,00	-0,32	-0,30
<b>CO<sub>2</sub> and PS</b>	-0,41	-0,07	-0,13	-0,05	-0,04	-0,20	-0,12	0,00	-0,56	-0,22
<b>GDP and employment</b>	-0,18	0,39	-0,57	-0,76	-0,60	0,56	-0,94	-0,54	-0,38	0,62
<b>CO<sub>2</sub> and TR</b>	0,85	0,08	0,17	0,03	0,04	0,17	0,10	0,24	0,19	0,07
<b>PS and AS</b>	0,30	0,14	0,00	-0,10	-0,11	-0,16	-0,23	0,00	-0,72	-0,94
<b>GDP and HLT*</b>					0,18	0,23	0,41	0,43		
<b>CO<sub>2</sub> and HLT*</b>					0,35	0,57	0,50	0,80		

**Table 2. Synergy factors between the different unsustainable trends in EU (normalized to 1995, except with \* normalized to 1999).**

Below, Tables 3 – 6 present the results for Cases 1, 4 and 6 relative to UK and Greece. The values reported for UK are similar to those for EU-15, while Greece shows much stronger synergies in respect to Cases 1 and 6, whereas in respect to Case 4 the synergy is much weaker. These differences will be discussed in more detail, when analyzing the individual Cases.

Normalized data for UK 1995 - 2005			
<b>C1: GDP and CO<sub>2</sub></b>	$\Delta$ GDP	$\Delta$ CO <sub>2</sub>	$\Delta$ CO <sub>2</sub> / $\Delta$ GDP
	27,19	-3,20	<b>-0,12</b>
<b>C4: GDP and EMP</b>	$\Delta$ GDP	$\Delta$ EMP	$\Delta$ EMP/ $\Delta$ GDP
	27,19	8,22	<b>0,30</b>
<b>C6: CO<sub>2</sub> and transport</b>	$\Delta$ CO <sub>2</sub>	$\Delta$ TR	$\Delta$ CO <sub>2</sub> / $\Delta$ TR
	-3,20	13,57	<b>-0,24</b>

Table 3: summary of synergy factors for UK

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
<b>GDP and CO<sub>2</sub></b>	0,91	-0,37	-0,17	-0,25	-0,16	0,05	-0,13	-0,01	-0,03	-0,12
<b>GDP and EMP</b>	0,45	0,56	0,49	0,47	0,44	0,48	0,47	0,31	0,30	0,30
<b>CO<sub>2</sub> and TR</b>	0,74	-0,40	-0,25	-0,29	-0,25	0,10	-0,29	-0,03	-0,06	-0,24

Table 4. Synergy factors between the different unsustainable trends in UK (normalized to 1995).

Normalized data for Greece 1995 - 2005			
<b>C1: GDP and CO<sub>2</sub></b>	$\Delta$ GDP	$\Delta$ CO <sub>2</sub>	$\Delta$ CO <sub>2</sub> / $\Delta$ GDP
	40,27	25,13	<b>0,62</b>
<b>C4: GDP and EMP</b>	$\Delta$ GDP	$\Delta$ EMP	$\Delta$ EMP/ $\Delta$ GDP
	40,27	14,6	<b>0,36</b>
<b>C6: CO<sub>2</sub> and transport</b>	$\Delta$ CO <sub>2</sub>	$\Delta$ TR	$\Delta$ CO <sub>2</sub> / $\Delta$ TR
	25,13	20,14	<b>0,80</b>

Table 5: summary of synergy factors for Greece

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
<b>GDP and CO<sub>2</sub></b>	0,62	0,66	0,62	0,99	0,92	0,97	0,80	0,80	0,65	0,62
<b>GDP and EMP</b>	0,79	0,17	0,69	0,52	0,47	0,36	0,39	0,40	0,37	0,36
<b>CO<sub>2</sub> and TR</b>	0,49	0,45	0,92	0,82	0,54	0,57	0,63	0,71	0,82	0,80

Table 6. Synergy factors between the different unsustainable trends in Greece (normalized to 1995).

### Case 1: GDP per capita and CO<sub>2</sub> per capita

For GDP per capita and CO<sub>2</sub> emission per capita in EU-15 countries, the synergy factor (ratio) is 0.07 as presented in Table 1. This indicates that there is almost a trade-off between the two trends from 1995 to 2005. In Figure 3, the synergy trend between these two variables shows that there has been slight change in the strength of positive synergy between the two during the examined time. For example in 1999 and 2000 the ratio has been even closer to zero than between 1995 and 2005. The reason for lack of synergy between the two comes from the relatively small increase of CO<sub>2</sub> emission per capita during the examined years. This indicates that at the EU-15 level the CO<sub>2</sub> emissions have been decoupled quite successfully from economic growth.

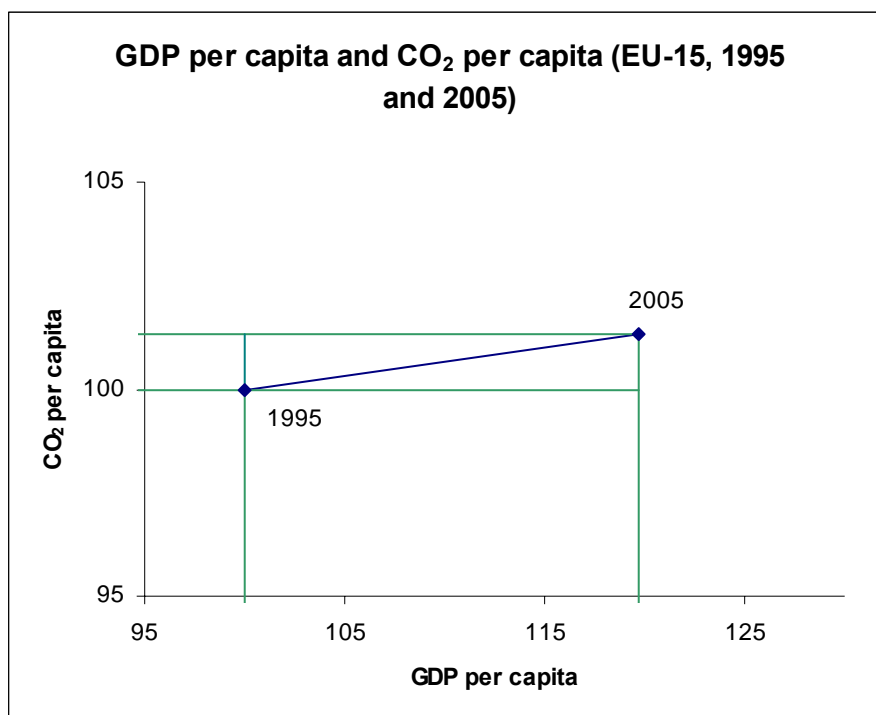


Figure 2 close-up of the synergy effect between the changes in GDP per capita and CO<sub>2</sub> per capita in EU-15

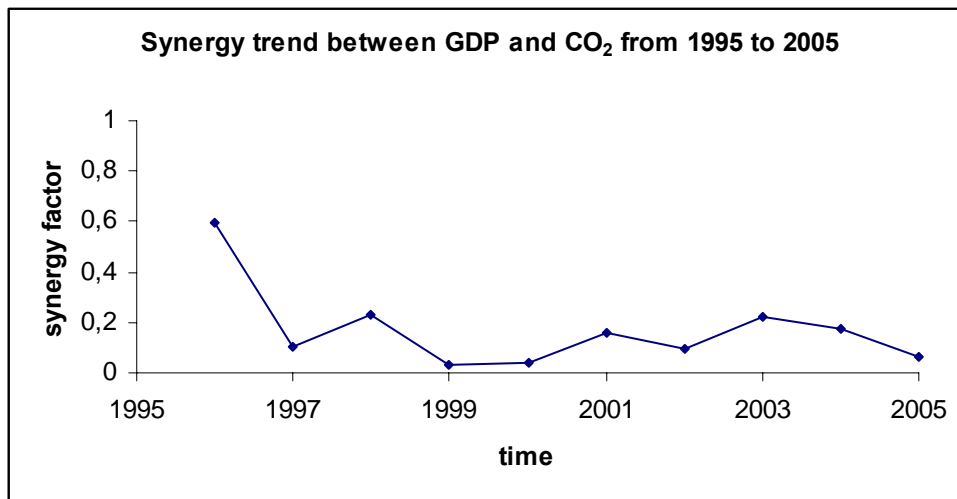


Figure 3: development of the synergy between CO<sub>2</sub> per capita and GDP per capita in EU-15

Figures 4 and 5 below present the case of UK. If we compare these to the EU-15 case, the pattern of the synergy trend is similarly close to trade-off, but the synergy factors are negative. This is due to the decrease in CO<sub>2</sub> per capita in the UK.

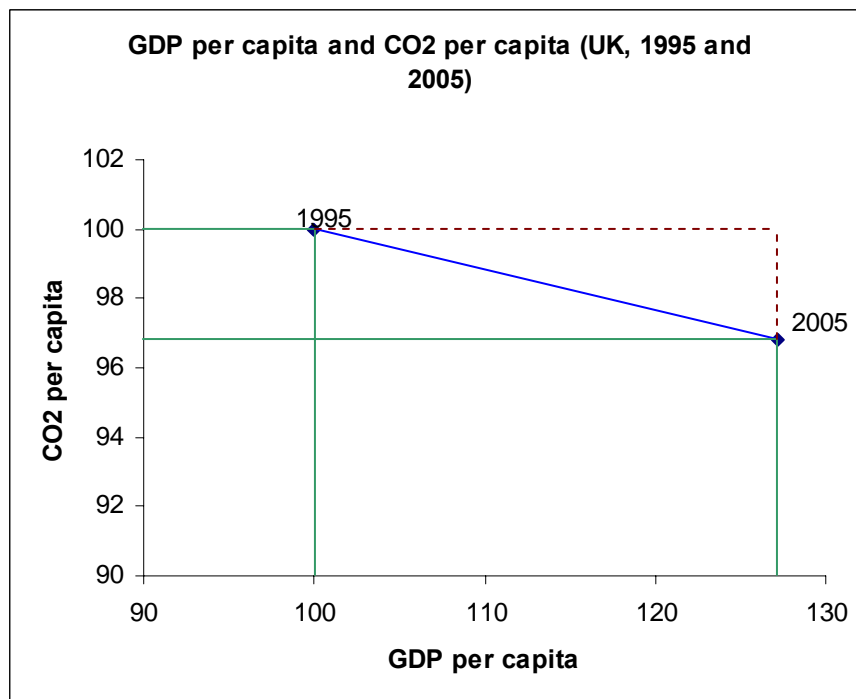


Figure 4: close-up of the synergy effect between the changes in GDP per capita and CO<sub>2</sub> per capita in UK

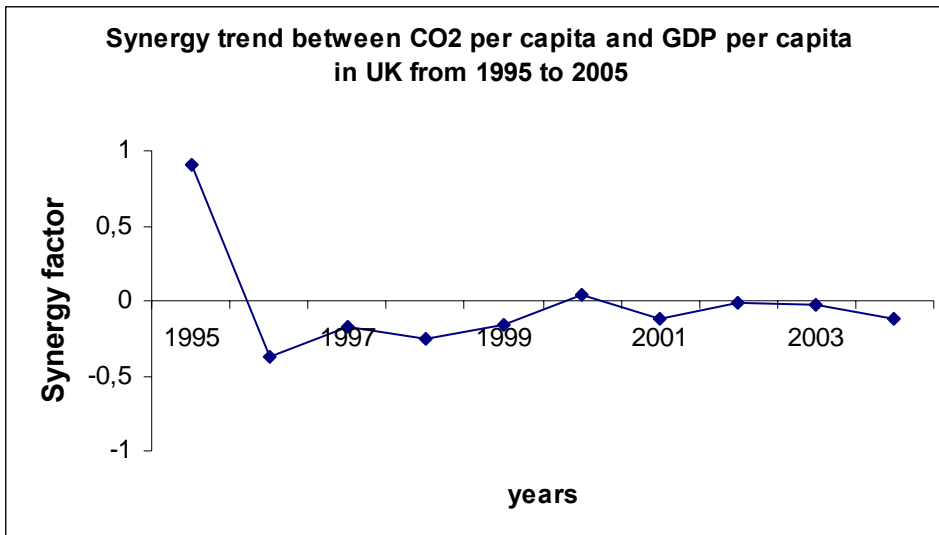


Figure 5: development of the synergy between CO<sub>2</sub> per capita and GDP per capita in UK

In contrast to the EU-15 average, Greece presents remarkably different results: the synergy factors are very close to 1 (maximum synergy) for the whole period, reaching the value of 0,99 in 1999. This clearly shows that there is a strong synergy between CO<sub>2</sub> per capita and GDP per capita in industrializing economies such as Greece.

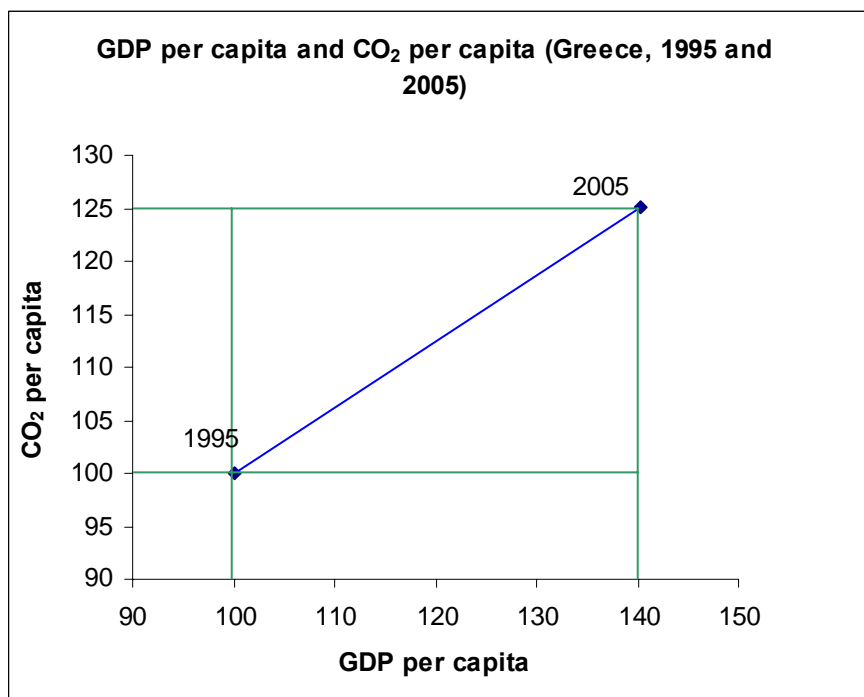


Figure 6: close-up of the synergy effect between the changes in GDP per capita and CO<sub>2</sub> per capita in Greece

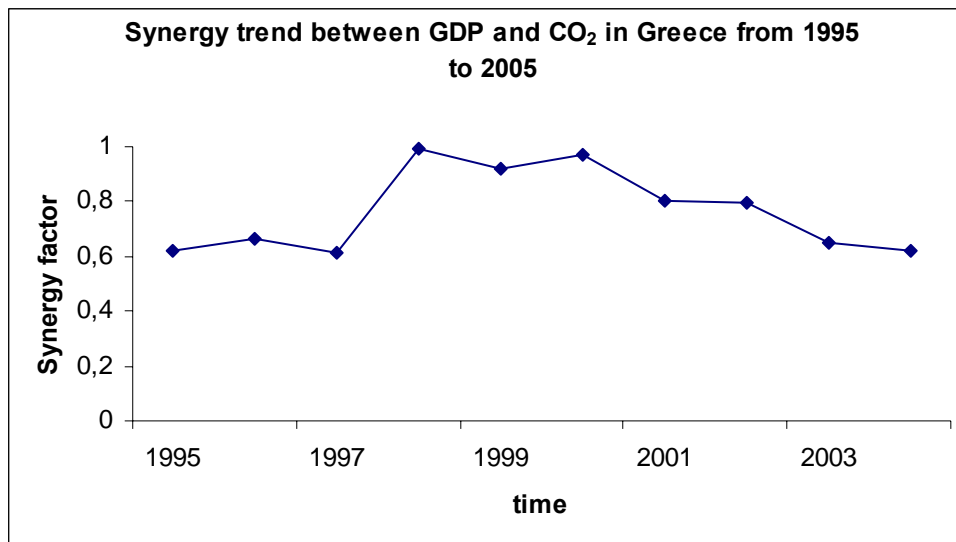


Figure 7: development of the synergy between CO<sub>2</sub> per capita and GDP per capita in Greece

## Case 2: GDP per capita and at-risk-of poverty

In Table 1 the synergy factor (ratio) for GDP per capita and poverty is negative, -0,30. The ratio is negative because at-risk-of poverty has decreased between 1995 and 2005, whilst GDP per capita has increased. Since the rate of increase of GDP has been faster than the rate of decrease of poverty (Figure 8), the synergy factor is quite small. However, Table 2 and Figure 9 show that this has not always been the case. In the beginning of the millennium the synergy factor has been considerably higher reaching its maximum in 2000, which was -0.87. These results indicate that the increase in GDP per capita can decrease the risk of poverty. In other words we can conclude that considerable synergy exists between economic growth and poverty reduction.

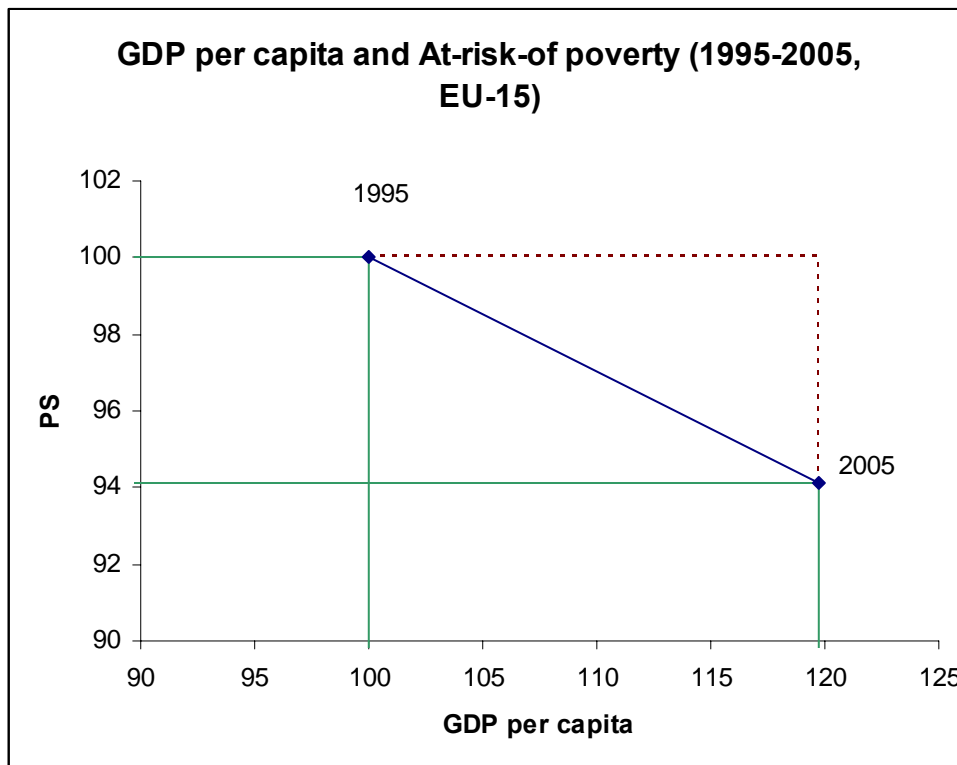


Figure 8: close-up of the synergy effect between the changes in GDP per capita and at-risk-of poverty in EU-15

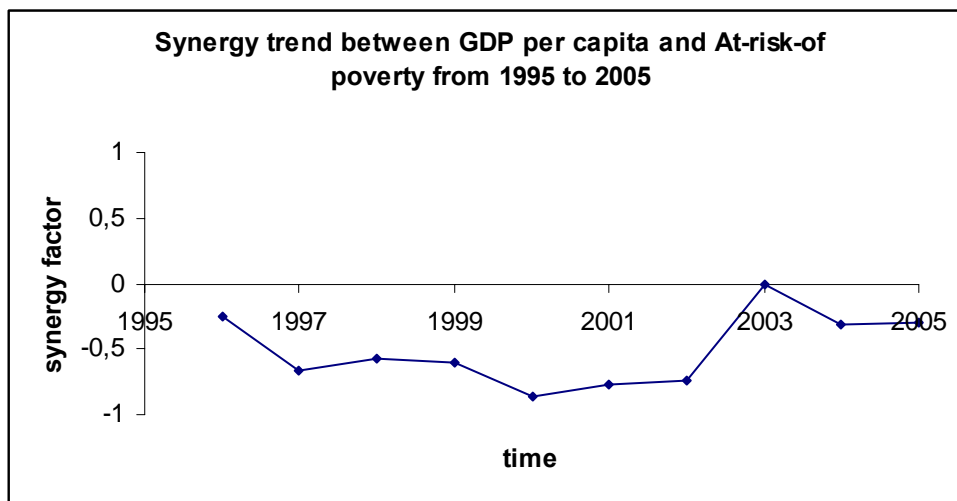


Figure 9: development of the synergy between GDP per capita and at-risk-of poverty in EU15

### Case 3: CO<sub>2</sub> per capita and at-risk-of poverty

Table 1 and Figure 10 show weak negative synergy between CO<sub>2</sub> emissions per capita and at-the-risk-of poverty. Similarly to Case 2, the negative factor is a result of the decrease in poverty between the examined years. But unlike Case 2, the synergy factor has been small throughout the examined years as is shown in Table 2 and Figure 11. In fact, the synergy trend is very close to

trade-off throughout most examined years. The only noticeable difference is the factor from 2004 which is -0,56.

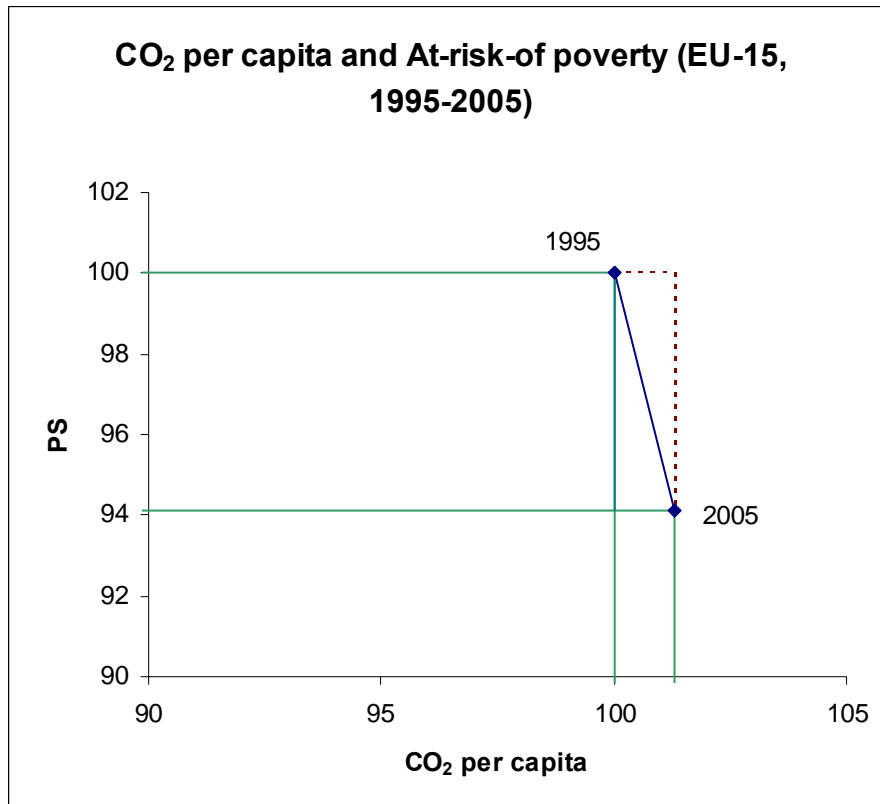


Figure 10: close-up of the synergy effect between the changes in CO<sub>2</sub> per capita and at-risk-of poverty in EU-15

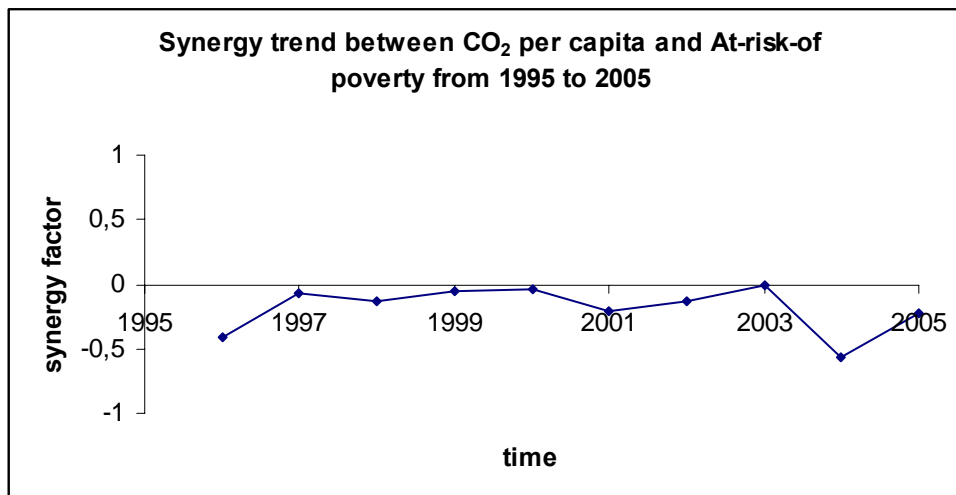


Figure 11: development of the synergy between CO<sub>2</sub> per capita and at-risk-of poverty in EU-15



## Case 4: GDP per capita and Employment

The ratio between the change in GDP per capita and employment between 1995 and 2005 are shown in the figures below. The synergy factor oscillates between negative and positive synergy, and mostly around +/- 0,5. The maximum synergy was achieved in 2002 where the synergy factor reaches -0,94. The oscillation refers to dynamic processes. This means that e.g. the increase in GDP is not immediately reflected as improvement in employment, but it may take several years to perceive the impact. A dynamic analysis would be needed.

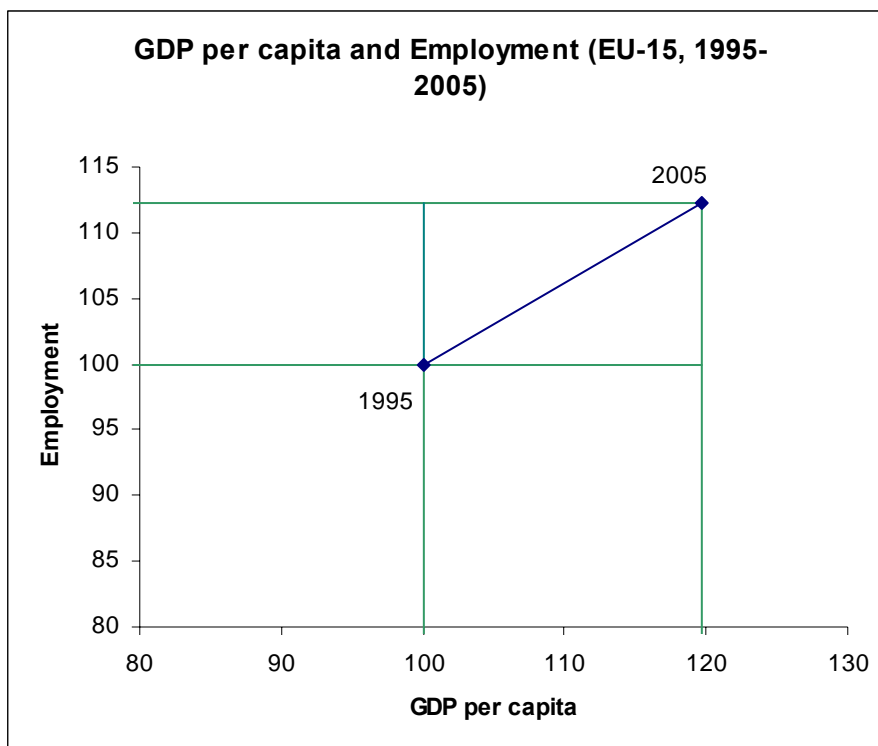


Figure 12: close-up of the synergy effect between GDP per capita and employment in EU-15

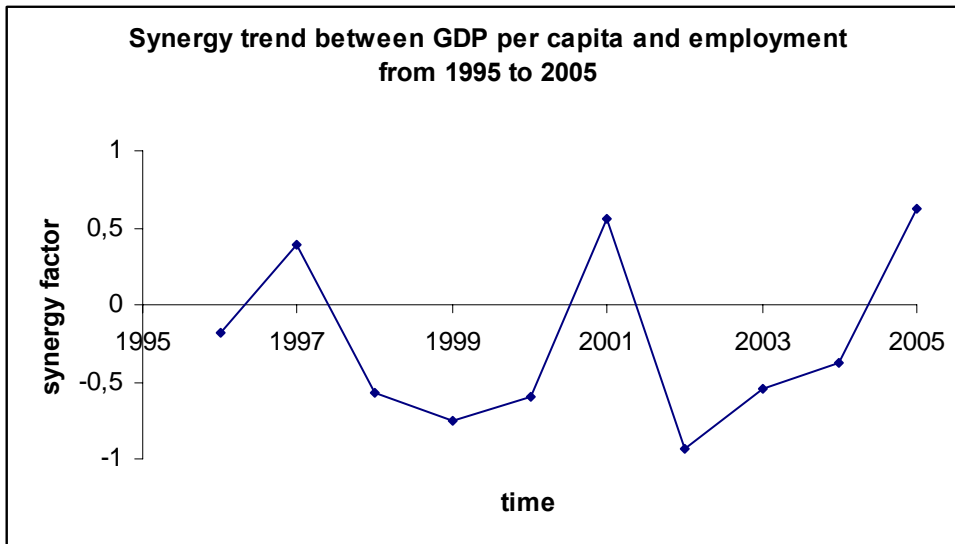


Figure 13: development of the synergy between GDP per capita and employment in EU-15

Similarly to EU-15 in UK the synergy factor between GDP per capita and employment is relatively strong, with the exception that for UK the synergy trend remains rather constant around 0,5.

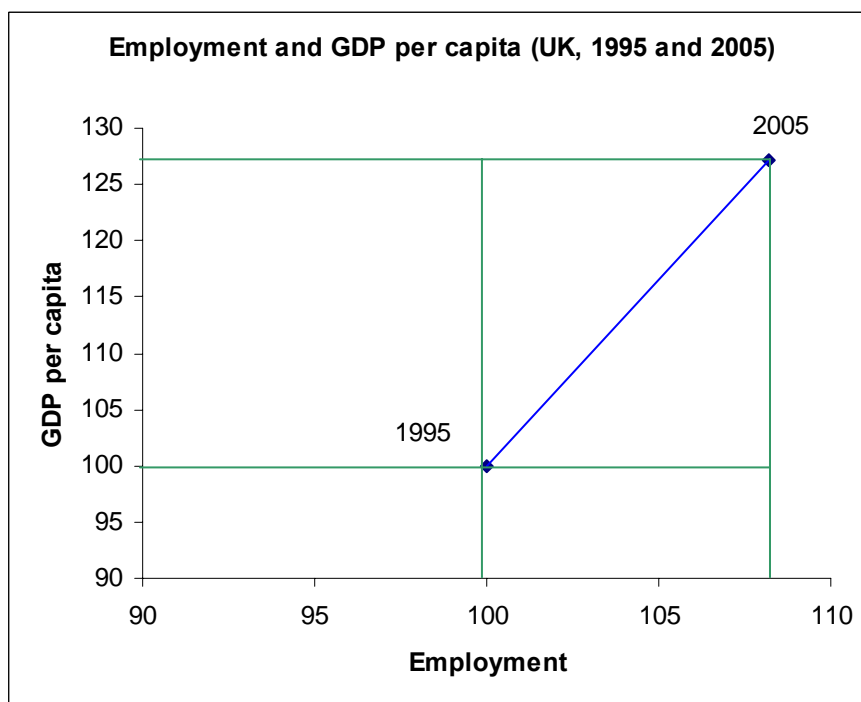


Figure 14: close-up of the synergy effect between GDP per capita and employment in UK

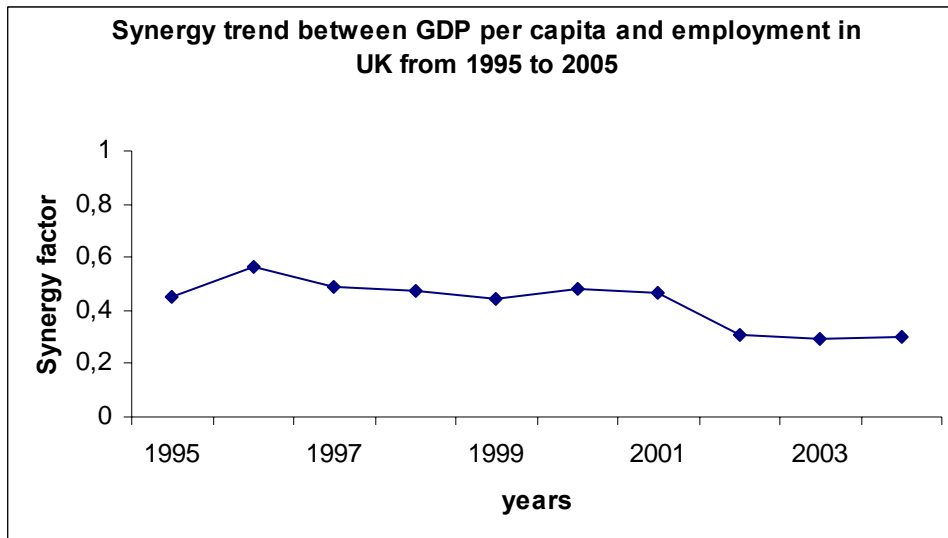


Figure 15: development of the synergy between GDP per capita and employment in UK

The synergy between GDP per capita and employment in Greece from 1995 to 2005 has decreased rather steadily from 0,79 to 0,36. This is caused by a substantial growth in GDP per capita during the analyzed time period . To compare, in Greece the normalized values of GDP per capita increase from 100 to 140, 27, whereas in EU-15 the change is equal to 19, 73 and in UK to 27,19.

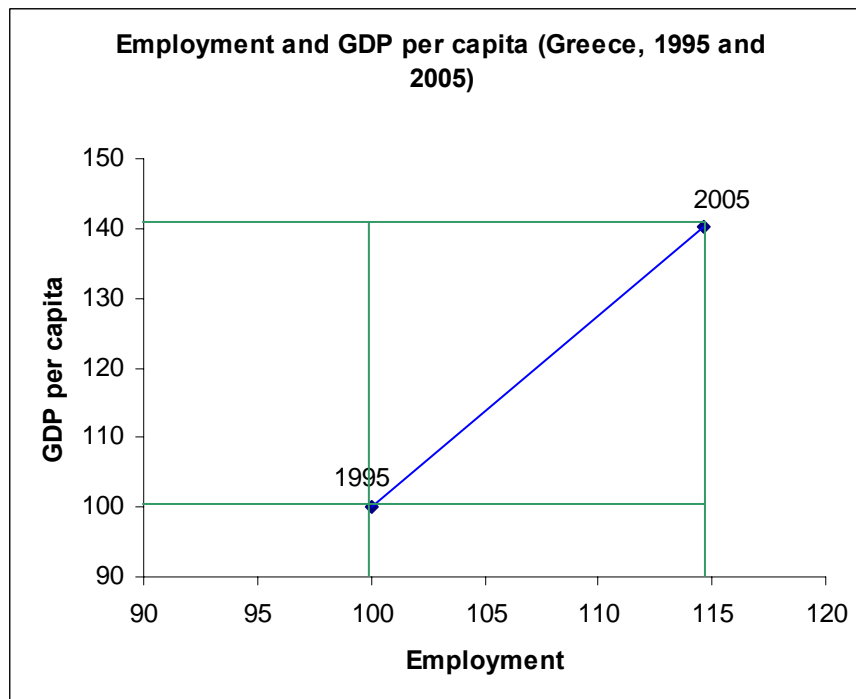


Figure 16: close-up of the synergy effect between GDP per capita and employment in Greece

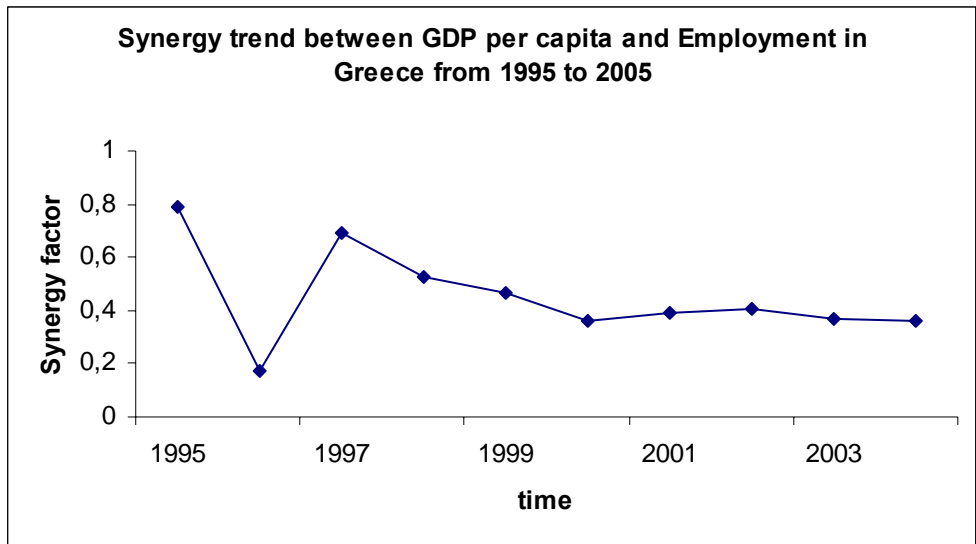


Figure 17: development of the synergy between GDP per capita and employment in Greece

### Case 5: GDP per capita and healthy life years

Since the Eurostat had data for healthy life years only from 1999 to 2003, the calculations including the health trend are between those years. Between 1999 and 2003 the synergy ratio of GDP per capita and healthy life years is 0,43 which follows constant increase of the ratio from 1999 (Figure 19 and Table 2). It seems that increase in GDP increases also healthy life years.

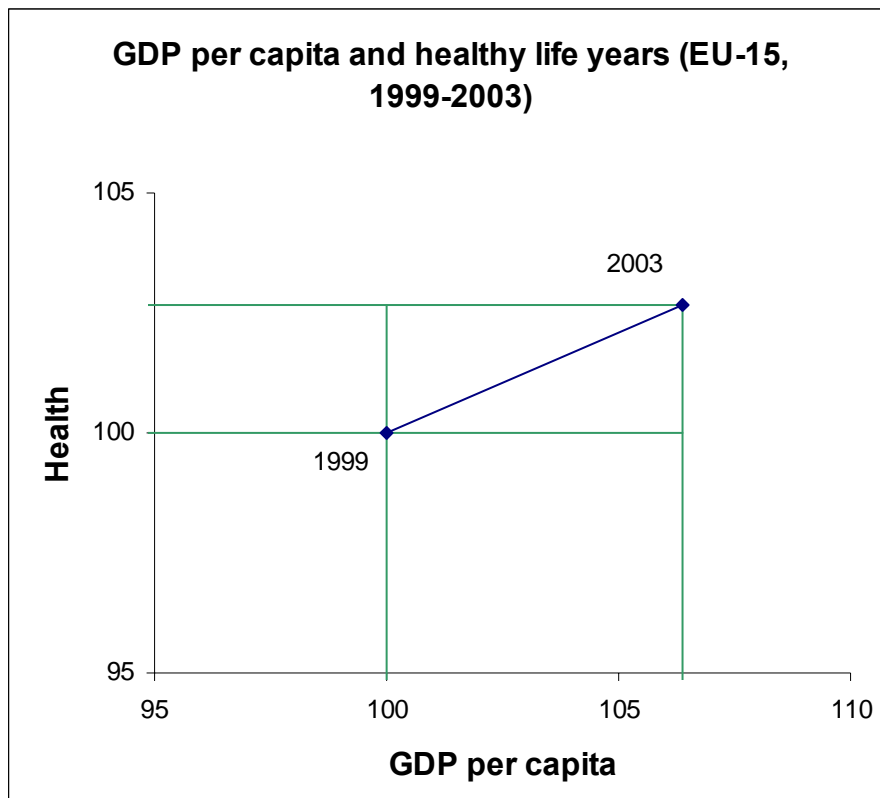


Figure 18: close-up of the synergy effect between GDP per capita and healthy life years in EU-15

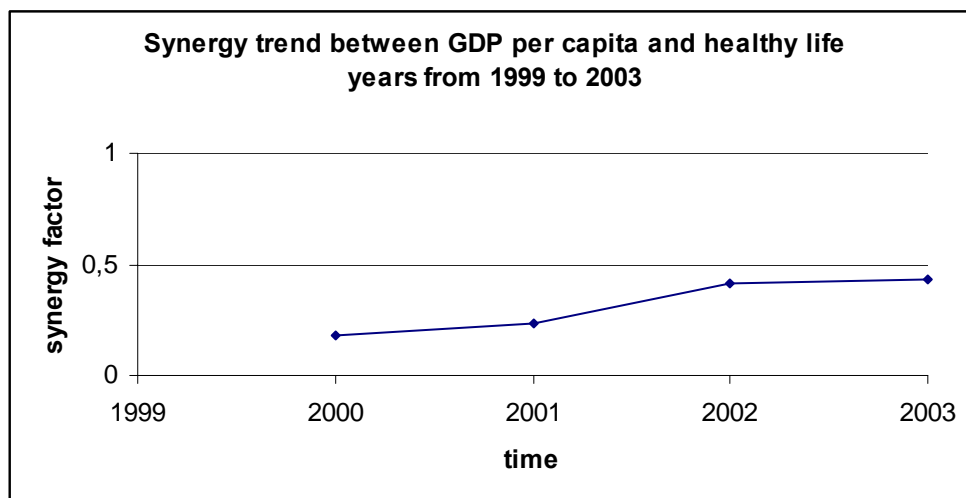


Figure 19: development of the synergy between GDP per capita and healthy life years in EU-15

### Case 6: CO<sub>2</sub> per capita and energy consumption of transport per capita

The results for CO<sub>2</sub> per capita and the final energy consumption of transport per capita show almost a trade-off between the two. After 1996 the synergy factor drops close to zero oscillates only up to

0,24. Such a small synergy, almost a trade-off between the two variables is caused by the fact that while the transport trend is increasing, the CO<sub>2</sub> trend remains rather constant.

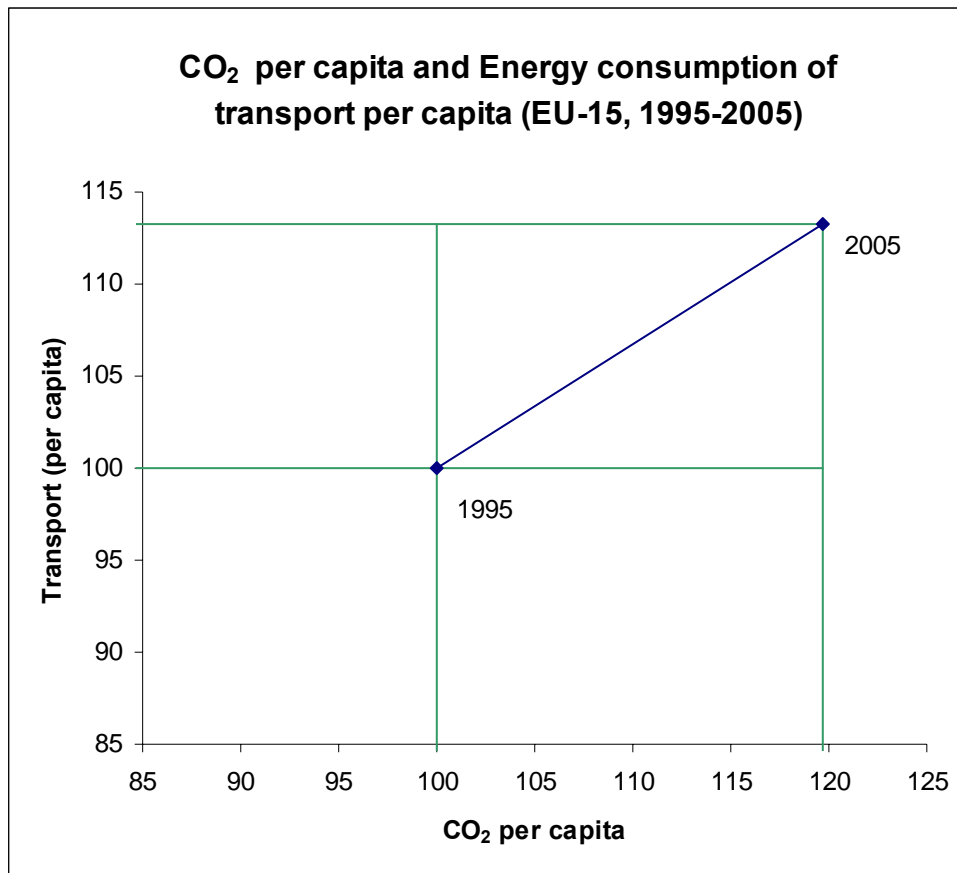


Figure 20: close-up of the synergy effect between CO<sub>2</sub> per capita and energy consumption of transport per capita in EU-15

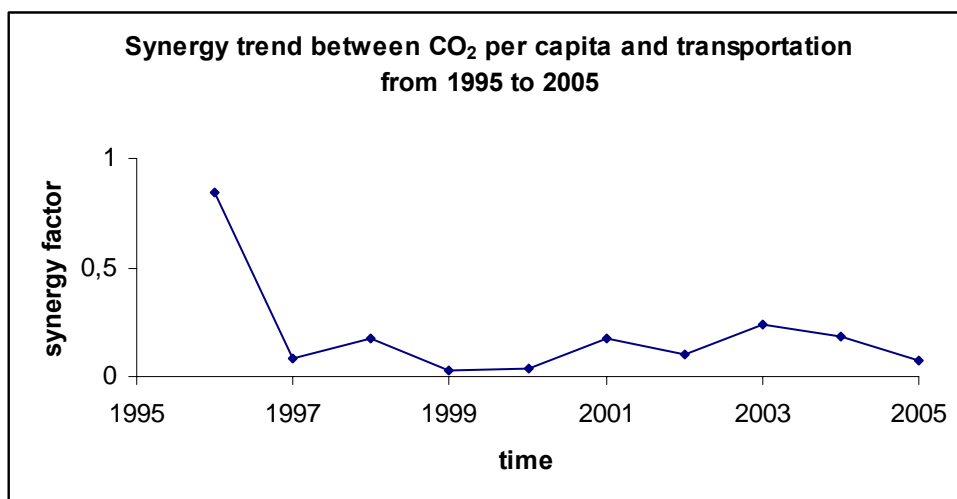


Figure 21: development of the synergy between CO<sub>2</sub> per capita and energy consumption of transport per capita in EU-15

The synergy trend between CO<sub>2</sub> per capita and energy consumption of transportation per capita in UK is also close to a trade-off. However, similarly to Case 1 due to the decrease of CO<sub>2</sub> per capita in UK the trend is negative.

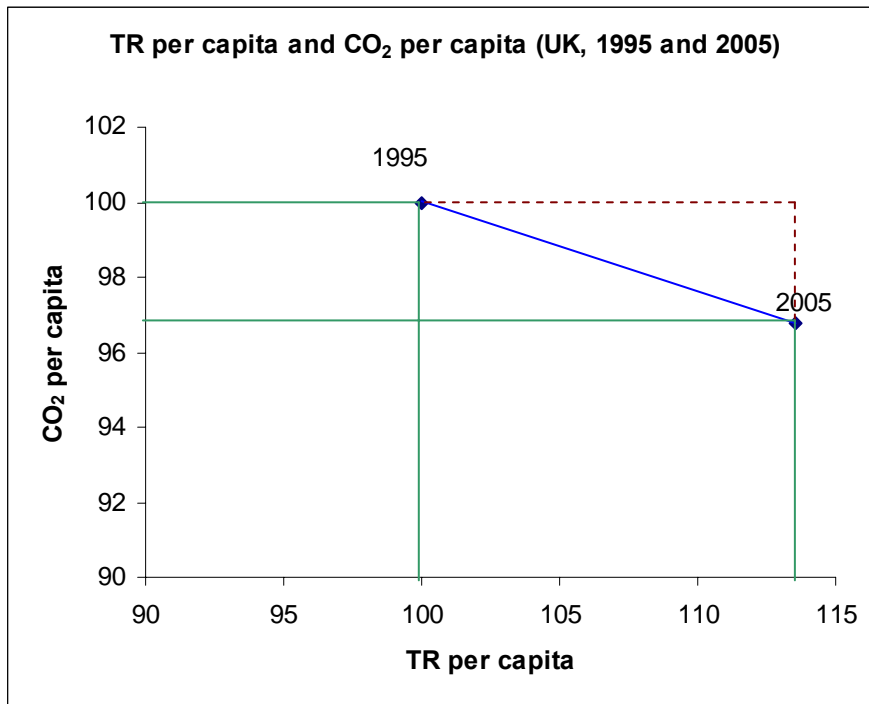


Figure 22: close-up of the synergy effect between CO<sub>2</sub> per capita and energy consumption of transport per capita in UK

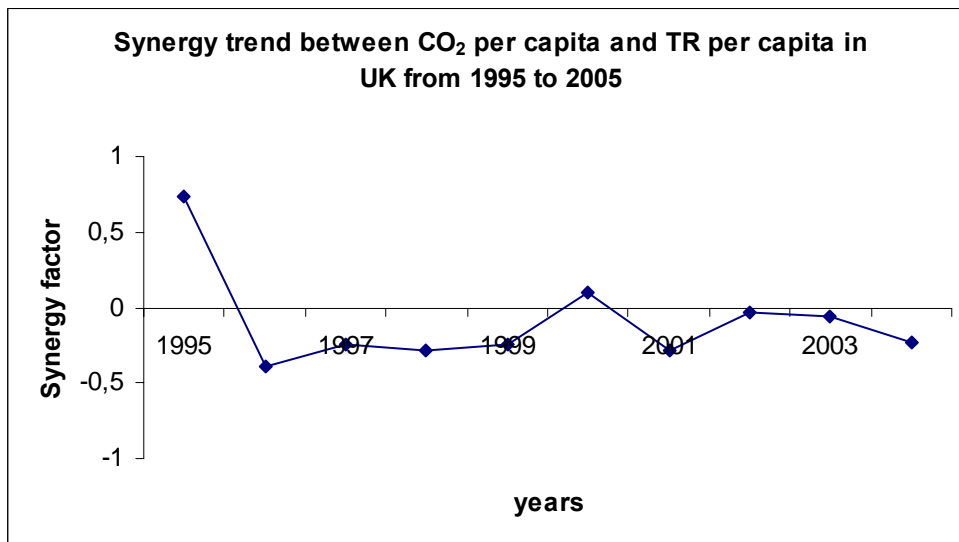


Figure 23: development of the synergy between CO<sub>2</sub> per capita and energy consumption of transport per capita in UK

There is a rather strong synergy between CO<sub>2</sub> per capita and energy consumption of transport per capita in Greece, and despite peaking at 0,92 in 1998, from 2000 on the values are increasing steadily.

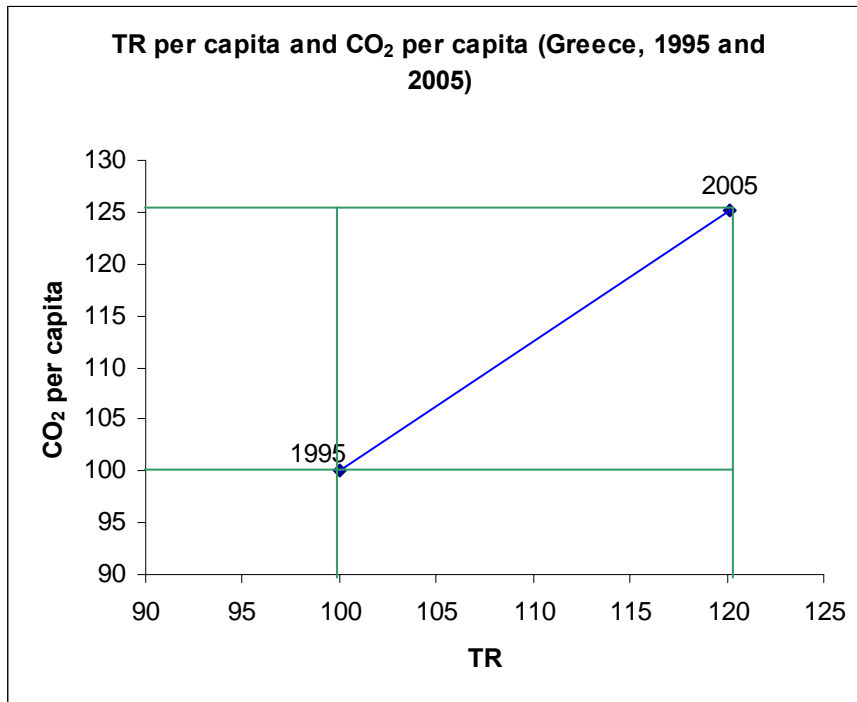


Figure 24: close-up of the synergy effect between CO<sub>2</sub> per capita and energy consumption of transport per capita in Greece

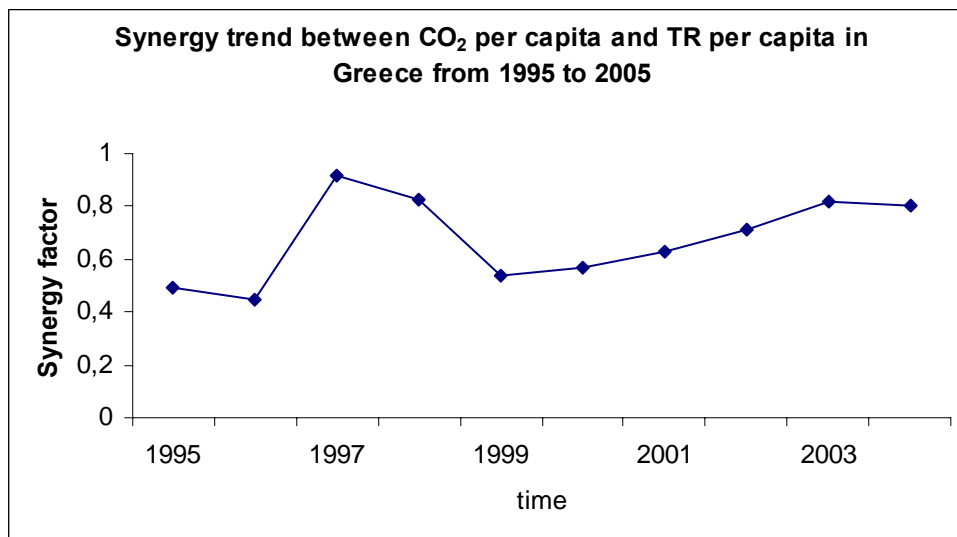


Figure 25: development of the synergy between CO<sub>2</sub> per capita and energy consumption of transport per capita in Greece



### Case 7: CO<sub>2</sub> per capita and healthy life years

Similarly to Case 5 the synergy trend for CO<sub>2</sub> per capita and healthy life years is constantly increasing. Table 1 shows small positive change in both of the trends from 1999 to 2003, resulting in strong positive synergy, 0,80. The strength of the synergy is caused by the similar rate of change between the two variables.

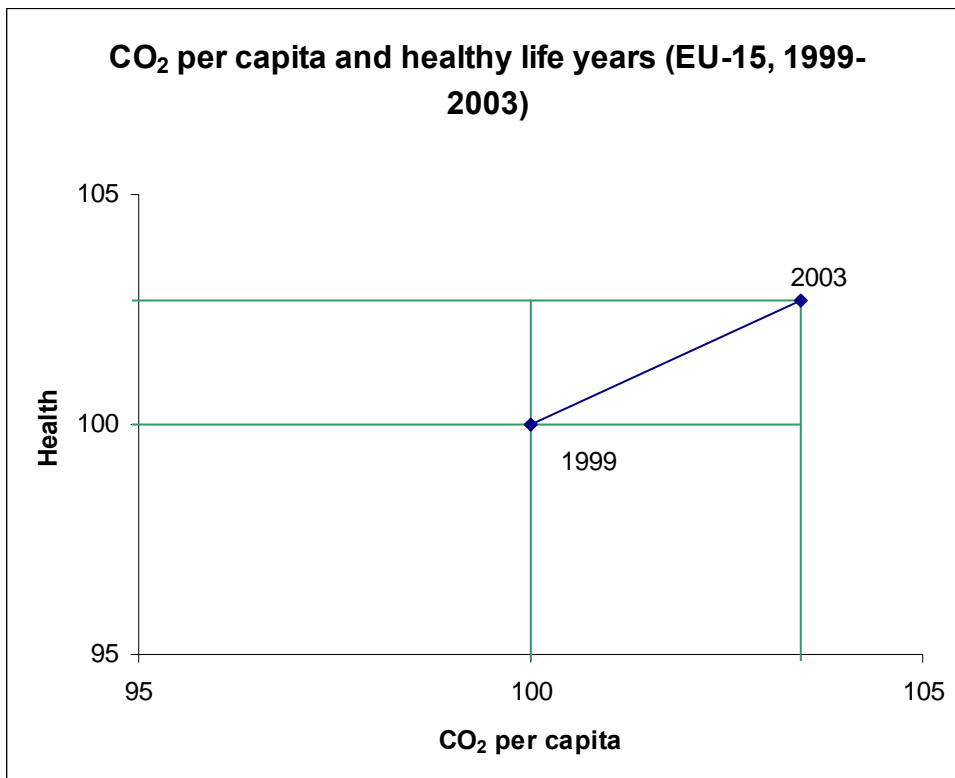


Figure 26: close-up of the synergy effect between CO<sub>2</sub> per capita and healthy life years in EU-15

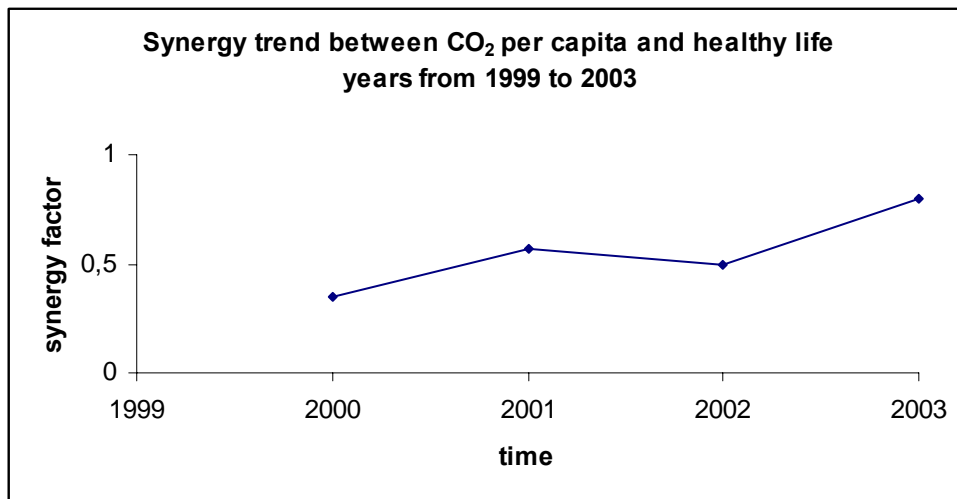


Figure 27: development of the synergy between CO<sub>2</sub> per capita and healthy life years in EU-15

### Case 8: Poverty and ageing society

Table 1 shows that there is strong negative synergy between poverty and ageing society. However, Table 2 and Figure 29 show that the synergy trend started from positive synergy from 1995 to 1996 (0,30), which then gradually decreased to strong negative synergy in 2005 (-0,94). This shows that before 1998 the ageing society was linked to increase in poverty, but after that the ageing society is linked with decreasing poverty. This may be due to the result of successful policies dealing with elderly people.

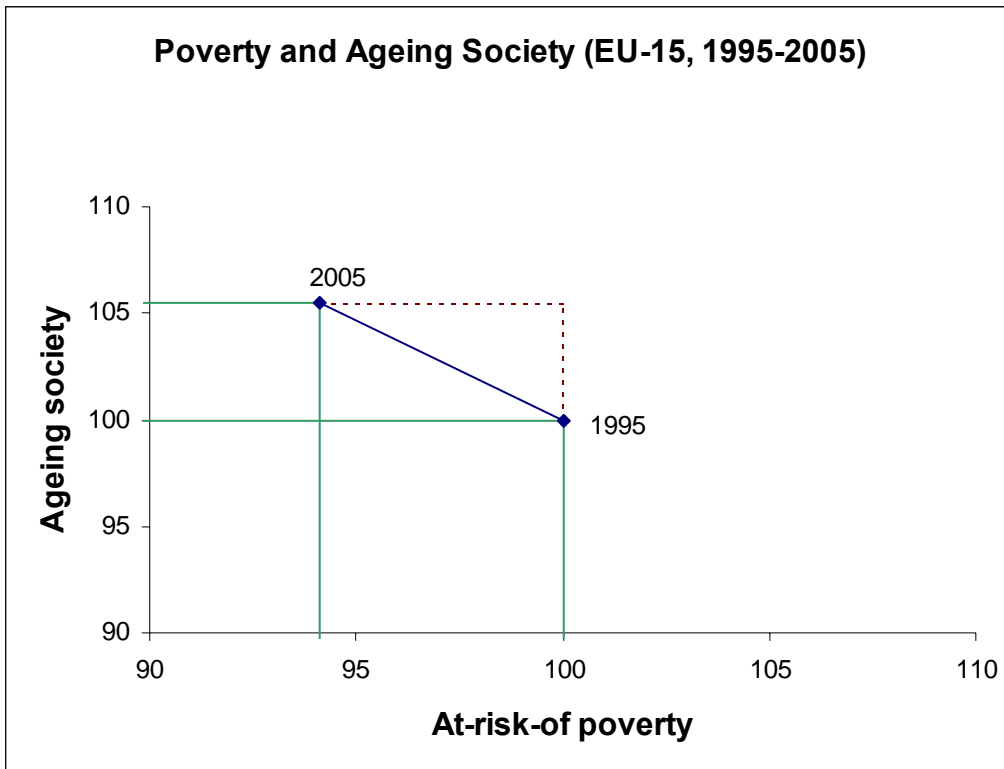


Figure 28: close-up of the synergy effect between poverty and ageing society in EU-15

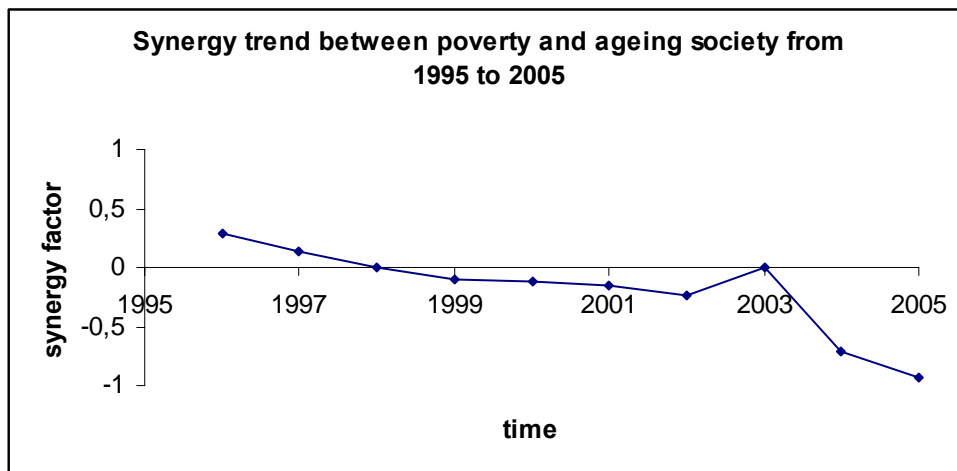


Figure 29: development of synergy between poverty and ageing society in EU-15

### **Results for 3 variable calculations**

The indicators chosen for the first 3D case were the following: CO<sub>2</sub>/capita, GDP/capita and PS (poverty and social exclusion). The original values were normalized, by setting the values reported for 1995 equal to 100. The changes occurring between 1995 and 2005 were then calculated, as shown in Table 7.

$\Delta x = \Delta PS$	-5,88
$\Delta y = \Delta GDP/capita$	19,73
$\Delta z = \Delta CO2/capita$	1,32

Table 7: changes in normalized values of PS, GDP/capita and CO<sub>2</sub>/capita between 1995 and 2005

The change relative to PS is negative because the original values decrease from 17% to 16%. This suggests a positive trend towards poverty reduction.

Since in the 2D case we assumed that, to have the maximum possible synergy, the resulting area created by  $\Delta x * \Delta y$  should be a square, in the 3D case the volume created by  $\Delta x * \Delta y * \Delta z$  should then be a cube.

In order to evaluate this and the possible presence of trade-offs among the variables chosen, the following calculations (reported in Table 8) were performed:

Actual volume (AV)= $\Delta x * \Delta y * \Delta z$	Cubic root of the actual volume	Maximum volume (MV) = $\max(\Delta x; \Delta y; \Delta z)^3$
-153,18	-5,35	$(19,73)^3 = 7675,12$
Difference between $\Delta x$ and cubic root of actual volume	Difference between $\Delta y$ and cubic root of actual volume	Difference between $\Delta z$ and cubic root of actual volume
0,53	25,08	6,67

Table 8: volume calculations for the first 3D case

By taking a look at the differences between the cubic root of the actual volume and each of the  $\Delta$  calculated, it is evident that in the case of  $\Delta y$  the difference is substantial and thus the volume created, AV, is far from being a cube. These results also point out that there's a synergy, but not very strong.

A comparison between the actual volume and the maximum possible volume (in Table 9) was carried out by calculating the share of AV in respect to MV.

$AV = \Delta x * \Delta y * \Delta z$	$MV = \max(\Delta x; \Delta y; \Delta z)^3$	% of AV
-153,18	$(19,73)^3 = 7675,12$	-2,0 %

Table 9: comparison between AV and MV

The result obtained indicates that AV is far from the hypothetical MV, so the synergy created among PS, GDP/capita and CO2/capita is really small.

The second 3D case included the following indicators: GDP/capita, CO2/capita and TR/capita, which refers to the energy consumption from transport per capita and is measured in toe/capita. Also in this case the original values were normalized and the changes between 1995 and 2005 were calculated. The results are presented in Table 10.

$\Delta x = \Delta TR/capita$	13,31
$\Delta y = \Delta GDP/capita$	19,73
$\Delta z = \Delta CO2/capita$	1,32

Table 10: changes in normalized values of TR/capita, GDP/capita and CO2/capita between 1995 and 2005

Following the same assumptions presented above, calculations were carried out so to evaluate the occurrence and strength of synergies or trade-offs. The results are shown in Table 11.

Actual volume (AV) = $\Delta x * \Delta y * \Delta z$	Cubic root of the actual volume	Maximum volume (MV) = $\max(\Delta x; \Delta y; \Delta z)^3$
346,48	7,02	$(19,73)^3 = 7675,12$
Difference between $\Delta x$ and cubic root of actual volume	Difference between $\Delta y$ and cubic root of actual volume	Difference between $\Delta z$ and cubic root of actual volume
6,28	12,70	5,70

Table 11: volume calculations for the second 3D case

As can be seen from what reported in Table 11, also in this case, the difference between  $\Delta y$  and the actual volume is relevant, thus the volume created is not a cube. The differences between AV and MV are calculated below (Table 12):

$AV = \Delta x * \Delta y * \Delta z$	$MV = \max(\Delta x; \Delta y; \Delta z)^3$	% of AV
346,48	$(19,73)^3 = 7675,12$	4,51 %

Table 12: comparison between AV and MV for the second 3D case

In this case the share of AV in comparison to MV is higher than in the first case, but still small. This means that also in the case of TR/capita, CO<sub>2</sub>/capita and GDP/capita, the synergy among the components is relatively weak.

## **Conclusions**

This study has shown how ASA approach can be applied to the analysis of synergies and trade-offs between different unsustainable trends identified in the EU. We have used the ASA approach to determine whether there is synergy or trade-off between different trends by calculating the ratio between the change in the studied trends. The interpretation of the results was straightforward: the closer to 1 or -1 the ratio was the stronger the synergy between the two (or three) variables, and the closer the zero the closer to trade-off. 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; in order to interpret the results in more depth, we need to determine how we desire the trends to involve. For example, if we consider GDP per capita and CO<sub>2</sub> per capita. If there is synergy between the two, it is good only if the synergy is negative in the sense that it decreases CO<sub>2</sub> per capita, while possibly increasing the GDP per capita. A trade-off between GDP per capita and CO<sub>2</sub> per capita is actually a desirable situation when trade-off is achieved by increase of GDP without increase of CO<sub>2</sub>.

Based on the results of our study we can conclude that the determination of synergies and trade-offs between different dimensions of sustainable development and between different unsustainable trends is very case specific. At EU-level we found rather strong synergy trends between GDP per capita and poverty, and GDP per capita and employment. Whereas GDP per capita and CO<sub>2</sub> emissions per capita, CO<sub>2</sub> per capita and poverty, and CO<sub>2</sub> per capita and energy consumption of transportation were all close to trade-off. Synergy trends in UK were close to the same strength as in EU-15 countries, but with GDP per capita and CO<sub>2</sub> per capita, and CO<sub>2</sub> per capita and energy consumption of transport, the weak synergy factors were negative (the synergy factors for these variables were positive for EU-15 countries). The synergy trends in Greece were quite different from UK and EU-15 countries. In Greece, the synergy factors for GDP per capita and CO<sub>2</sub> per capita, as well as for CO<sub>2</sub> per capita and energy consumption of transportation were very strong.

## **Part 2: The application of the MuSIASEM approach for the analysis of trade-offs and synergies. Studying the effects of: (i) structural changes in the economy; (ii) demographic changes, immigration and aging**

Memo Prepared for DECOIN D3.3

*By*

*Mario Giampietro, Gonzalo Gamboa, Alevgul Sorman, Tarik Serrano*

Contribution of the ICTA/UAB group for DECOIN D3.3 “Report of the synergies and tradeoffs of selected trends”

### ***Structure of this memo***

1. The peculiarity of Multi-scale Integrated Analysis making possible the study of “synergies” and “tradeoffs” across levels
2. Applications of the MuSIASEM approach:
  - 2.1 To study the effects/trade-offs/synergies associated to Structural Changes in the economy
  - 2.2 To study the effects/trade-offs/synergies associated to aging and immigration
3. Conclusion over the application of MuSIASEM as an analytical tool for assessing “Synergies” and “Tradeoffs” within the DECOIN tool kit

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## **1. The peculiarity of Multi-scale Integrated Analysis making possible the study of “synergies” and “tradeoffs” across levels**

### **1.1 The particular choice of a scale and level for accounting Human Activity**

Conventional approaches used to generate the standard set of indicators of sustainability account for humans as an external referent used either: (i) for calculating relevant benchmarks (GDP p.c. = €/year per capita; energy consumption per capita = GJ/year p.c.); or (ii) for defining an overall size of the economy (Population = number of people). However, with this choice, all the information generated in this way will refer to an average value which is valid only for the whole socio-economic system seen as a black box. That is, these values cannot be used to understand differences among socio-economic elements and processes defined within the black box. The wage of a worker – which is expressed in €/hour – cannot be directly related to the GDP of a country, nor the added value generated by a big industrial complex (e.g. the Mercedes-Benz, expressed in €/year). On the contrary, the Multi Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) proposes to assess the pace of flows – any type of flows including economic and biophysical flows such as energy consumption – “per hour” of human activity. In this way, it becomes possible to take a different standing to explain the dynamic changes within an economic system. Changes can be explained at the local level – i.e. changes in the wages and in the pace of generation of added value – and across different levels, e.g. the individual workers and individual firms; changes in the proportion of different compartments of the economy, changes in the ratio between working and non-working population (e.g. dependency ratio), which can be due to demographic or political reasons. All these changes cannot be seen when embracing a quantitative representation of the economic performance based on a per capita approach – the black box approach typical of national economic statistics.

That is, the majority of the statistical data that have been provided up to now, regardless of the organization providing them, characterizes the total size of a society using the variable “population” and then relevant economic statistics are provided in terms of people. For instance, “employment” is characterized in terms of “number of people employed”; the “GDP per capita” is also measured per individual citizen per year. The same applies to other indicators of development such as “number of doctors per person” or “number of pupils per teacher”. The MuSIASEM approach is



based on the assumption that this system of accounting entails missing a lot of valuable information about changes taking place in socio-economic systems. In fact, the very same assessment – expressed “per capita” or in alternative “per 1,000 people” – can imply a quite different situation when coming to the internal functioning of a society. Let’s see the example of supply of hours of work per year into the economy, which depends on the demographic structure of the society and its social rules – Fig. 1.

In this example, when considering, Italy and China in the year 1999, we can compare the supply of hours of work in the economy per ‘1,000 people’ starting from differences in the structure of population over age classes and other socio-economic factors. In 1999 Italy had a supply of 950,000 hours of work in the economy per 1,000 people versus the 1,650,000 hours of work in the economy per 1,000 people in China.



Figure 1. The effect of changes in demographic structure on work supply

This example points at a standard problem associated with assessments expressed per capita or as “1,000 people” which are not able to detect relevant changes within the black box – in this case a relevant difference in the internal supply of hours of work. In this example the GDP per capita of Italy and China are generated by a different amount of hours of work per capita. The GDP of Italy has been produced using only 950 hours of work in the Paid Work per capita, whereas the GDP of China has been produced using 1,650 hours of work in the Paid Work sector per capita.

Also, in terms of evolutionary dynamics, the “per capita” approach totally ignores existing dynamics that can only be observed inside the black box. For example, when the currently active working population in China (60%) will grow older, it will become retired population, increasing dramatically the dependency ratio. On the contrary, by applying the MuSIASEM approach, when checking the ratio Working Hours in Paid Work versus the Total Hours of Human Activity, one can immediately detect the existence of a clear tradeoff associated with demographic changes. For example, in China, due to the single-child policy implemented in the last decades, China has now a clear comparative advantage over the other economies of the world: 60% of the population is in the work force, with only 40% of dependency ratio. However, this represents an advantage in the short run, which will back fire in the long run when the present wave of adults will get old simultaneously and China will start facing a shortage of labour supply at the very moment in which the cost of welfare will be skyrocketing for the wave of retired elderly in the society (Ramos-Martin et al., 2007).

Accounting for human activity in terms of hours of human activity – which is then allocated over different compartments (e.g. working versus non-working) makes it possible to study the effects of demographic changes, something impossible to do using a representation based on the conventional per capita approach.

Moving to assessment referring to hours of human activity has another important implication. It makes it possible to use the same assessment/measurement – e.g. €/hour – through non-equivalent representations of socio-economic process, such as at different scales of analysis:

(A) the level of the whole society (level  $n$ ) – we can express the GDP p.c. at the level ‘ $n$ ’ by converting it into GDP per hour (by dividing the GDP p.c. by 8,760 hours – the hours making up a year);

(B) going down to the lower levels, i.e. when referring to the Paid Work sector, and when splitting the total GDP into the various sectoral GDP $_i$  at the level  $n-1$ , we can still calculate a pace of sectoral GDP $_i$  per hours by dividing the GDP $_i$  per year by the hours of work performed in that sector in a year (this number of hours is obtained by multiplying the number of workers in the sector by the work load per year of these workers);

(C) when referring to a given sub-sector e.g. “Dairy Production” within the agricultural sector or “Banking” within the service sector, we can still express the flow of added value produced per hour at that particular level;

(D) finally even when referring to the wage of individual workers, which can be related to the income of different household types we can adopt the same variable €/hour.

That is, by using an analysis of flows “per hour of human activity”, which can be *compared* across levels and compartments, it becomes possible to study the stability of the metabolism of a society in terms of a “dynamic budget”: (i) what is **consumed** “per hour of human activity” at the whole society – the value of the flow per hour at the level n – must result congruent with (ii) the flow “per hour of human activity” in the compartment in charge of its production (at the lower level n-1, when including imports in the accounting).

As explained in previous deliverables of the DECOIN project, the MuSIASEM approach can be applied to many other types of flow, not only to flows of added value, such as energetic flows or material ones.

## **2. Applications of the MuSIASEM approach**

### **2.1 To study the effects/trade-offs/synergies associated to Structural Changes in the economy**

In relation to the analysis of effects (perceived in terms of trade-offs/synergies) of structural changes in the economy MuSIASEM has the peculiarity of making possible the opening up of the “black-box” when representing the performance of an economy (Giampietro et al. 2008). That is, it makes possible to analyze what is going on within the system within the different sub-sectors. To enable this analysis it is possible to provide a set of benchmarks characterizing the economic performance at different hierarchical levels. This is where the multi scale methodology provides a key advantage.

Within a European perspective for example, it is possible to observe that each country has its own internal structural arrangements across economic sectors when allocating: (i) a given mix of energy throughputs (over the different sectors); and (ii) a given mix of labour hours (over different sectors). A comparison based on the adoption of the MuSIASEM approach is provided in Fig. 2. The 4 sectors considered in Fig. 2 are:

(1) Agriculture; (2) Productive Sector (which includes Building and Manufacturing, Energy and Mining); (3) Service and Government; and (4) Energy Sector.

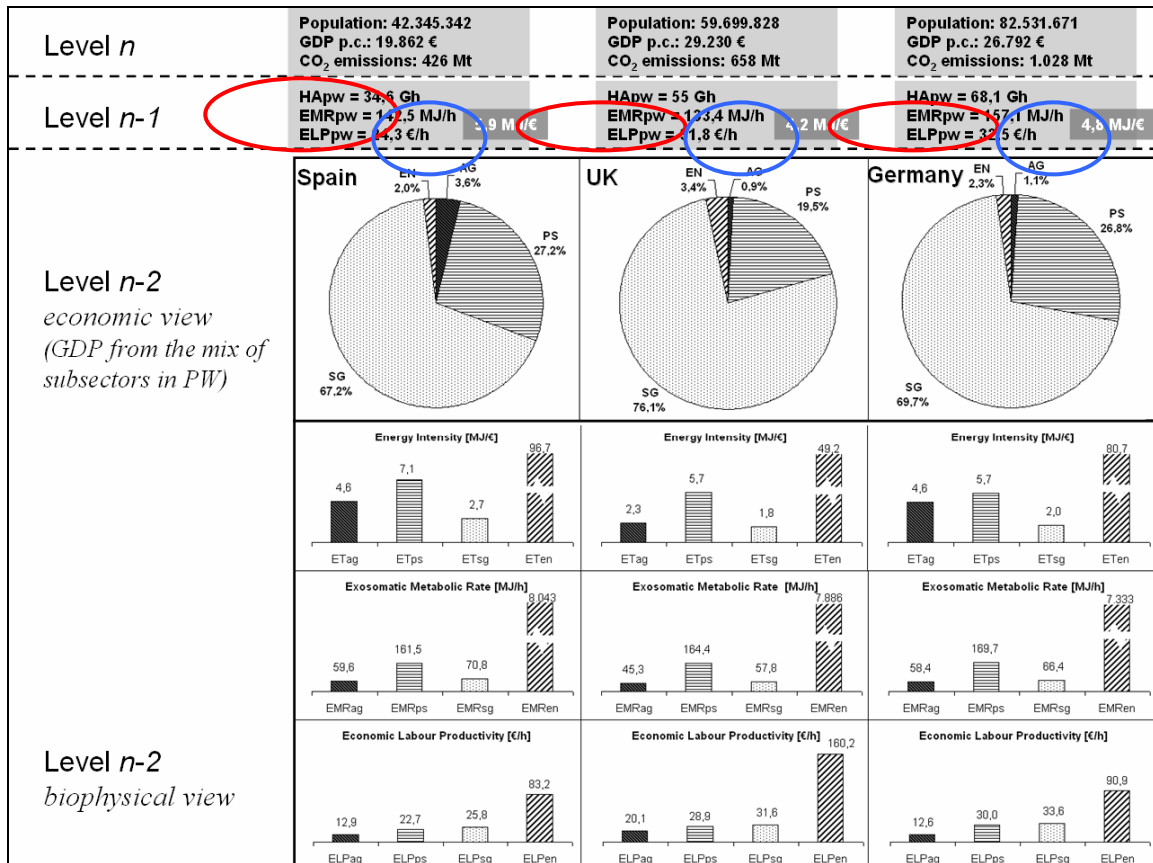


Figure 2. Illustrating the importance of structural differences across sectors within the economic systems of Spain, UK and Germany

When looking at Figure 2, the performance of the economy of the United Kingdom results better than the other countries when assessed at the level *n-1* in relation to its consumption of energy. The Exosomatic Metabolic Rate (EMR) (the amount of energy consumed per hour of work) is lower than the other two countries: Spain and Germany. In addition to that, the amount of energy consumed for every € of GDP generated in the United Kingdom is much lower than in Spain and Germany.

However, when moving the analysis at a lower hierarchical level, where the performance of economic compartments are characterized at the level *n-2*, one gets a different picture of what is actually happening within the various subsectors. At the level *n-2* it is clear how the emergent property observed at the level *n-1* is generated by two factors: (A) the characteristics of each one of these compartments; and (B) the relative size of this compartments (the share of the various compartments in the pie).

That is, when comparing analogous sectors across the three countries (Agriculture with Agriculture, PS sector with PS sector) at the level n-2, we can see that the United Kingdom shows similar values (if not worse) for each sector like Spain and Germany, in terms of energy consumption per hour of work. What comes up from this integrated analysis across levels is that the difference observed at the level 'n' is not determined by a better biophysical performance of the biophysical processes expressed at the level n-2 – e.g. due to better technology - but rather by a different mix of allocation of energy and working hours over the 4 sub-sectors of the PW sector considered in figure. The economy of UK gets the majority of its GDP (76%!) from the Service and Government sector which is a sector not as energy intensive as the other productive sectors. Because of this mix we find also that other indicators of environmental impact – such as levels of CO<sub>2</sub> – result lower in UK, than in Spain and Germany.

However, can we say that the assessment obtained at the whole country level – level n – of the amount of CO<sub>2</sub> emitted per unit of GDP in UK is reflecting a lower impact on the global environment and a lower consumption of energy of the different economic processes, in relation to Spain and Germany? After having gone deeper into the differences in the structure of these three economies and having seen the different "mix" of the economic structure from within the black box the answer to the previous question is NO. By analyzing the metabolism of UK, Spain and Germany across different hierarchical levels we can explain the differences found at the level n of the black box in a different way. The UK has shifted to a service based economy. But when looking at the production of goods within the Productive sector, the UK performance is similar to that of the two countries. Since the pattern of consumption in UK is not that different from the one found in other European countries we can infer the UK is a net importer of energy intensive products (produced by the productive sector of other countries).

This type of analysis focuses on the existence of a clear tradeoff between the local (national scale) and the large scale (international scale). The reduction of energy intensity in UK (and in general in developed countries, especially in Europe) is obtained through a continuous externalization of the production of energy intensive goods to developing countries (especially to China). There is a series of tradeoffs that should be considered here: the reduction of the consumption of energy for the production of goods within European economies is paid for by an increase in the consumption of energy for the production of goods in developing countries – e.g. China and India. The biophysical cost of this trade-off is aggravated by the addition of the energy consumption for transporting the imported goods. This is to say, that the lowering of the pressure on the ecosystems in Europe,

associated with the process of post-industrialization translates into increases of the pressure on ecosystems in those countries producing the imported goods.

A second clear tradeoffs is that the post-industrialization of European economies has the effect of transferring the European industrial capability (the technical capital required for generating actual production processes) to developing countries. These countries, at the moment, are exporting the goods we need at very convenient prices. But what will happen when their internal demand will grow, and their internal demand will enter in competition with the demand of Europeans?

By adopting the MuSIASEM methodology one can perform analysis shifting across scales and levels of analysis. In this way one can see how the actual structural differences among countries and structural changes within a given country can generate the tradeoffs discussed so far.

## **2.2 To study the effects/trade-offs/synergies associated to aging and immigration**

As discussed in the introduction the multi-scale perspective of MuSIASEM also allows to approach (from an analytical perspective) some of the issues associated with aging and immigration in relation to sustainability.

In fact, at the individual level it is possible to characterize the demographic structure as a profile of distribution of the individuals over different age groups (Fig. 1). Then we can use the resulting set of categories (males and females of different age classes) to estimate the profile of distribution of human time on different activities. For instance, children (age below 14) and elderly (age above 65) usually do not take part in the paid work sectors. In general we can say that the demographic pyramid (age structure of the population) does affect the profile of distribution of human activity over different compartments of society, and the MuSIASEM can study it. For example the graphs presented in Figure 3, show the difference in the ratio Working Hours and Total Hours of human activity in El Salvador and Finland. The difference depends on several factors in different countries: (i) the difference in the dependency ratio (due to life expectancy); (ii) level of education (non-working students); (iii) levels of unemployment (non-working adults) and (iv) the work load (e.g. hours of work per year).

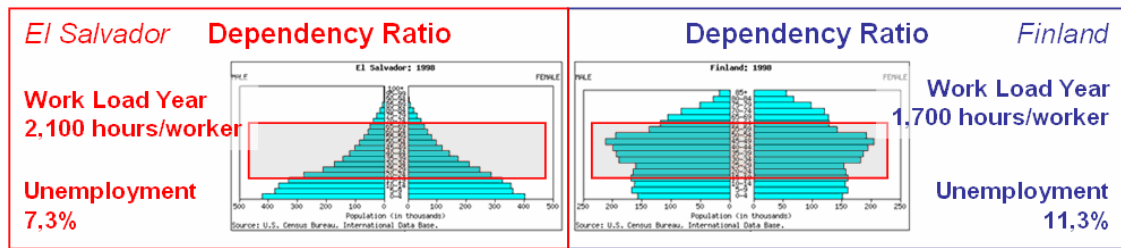


Figure 3. Illustration of the Population Pyramid of El Salvador and Finland and other factors relevant for determining the ratio Working hours/Non-working hours

Two variables and their ratio can be used to characterize this difference:

- (i) hours of human activity invested in the paid work sector “Human Activity in Paid Work” ( $HA_{PW}$ );
- (ii) the total hours of human activity “Total Human Activity” (THA); and
- (iii) the fraction of working hours related to Total Human Activity ( $HA_{PW}/THA$ ).

By using this characterization we can describe the side effect of demographic changes. For example, an aging society entails a decreased availability of working hours (due to the higher dependency ratio) at the very same moment in which the requirement of services is dramatically increased. This implies a Paid Work sector with a smaller workforce, within which an increasing fraction of labor has to be allocated to provide the services for the non working population. This predicament can be avoided for a while by: (i) increasing the productivity of labor (the output per hour) of the shrinking work force (by increasing the level of capital per worker); and (ii) by importing goods which are labor intensive. This makes it possible to utilize the scarce local work supply more and more on services. Services get priority since they have to be locally delivered, so they require local labor. Another solution is to import “human activity” from a “population” having a much lower dependency ratio (e.g. a population of immigrants).

However, also in this case several tradeoffs can be studied in relation to immigration. Immigrants provide a much needed work supply for the hosting economy, since they accept to work on low paid jobs. This is something which helps substantially aging economies. On the other hand, when considering a larger scale, the supply of working time injected in the hosting economy is subtracted from the economy in which the immigrants were born.

Another problem is represented by the fact that the reduction in the dependency ratio in the hosting country is only temporary. In fact, after a while (a decade or two), the population of immigrants, composed at the beginning only by adults, will change, when these immigrants start their own



family. This implies that after a certain lag time, the advantages provided by immigrants will be compensated by an increase in the demand of services and by an increasing demand in investments for their integration in the structure of the society.

By using the MuSIASEM approach this type of tradeoff can be studied by moving beyond the classic demographic analysis, which is based on the hierarchical level of individuals: individuals are categorized as belonging to different age-classes. In fact, the same analysis of the relation of demographic structure and allocation of human activity over a set of possible activities can also be performed at the household level. That is, it is possible to develop a system of accounting of profiles of allocation of human activity, which is based on the identification of a relevant types of households in the analyzed society. Then it becomes possible to study how demographic changes will affect the profile of distribution of the population over this set of households. For instance, a household of a nuclear family of five members with only a working adult – the husband – a housewife and three children will perform really differently in their consumption and production than a household containing four working adults (e.g. four immigrants sharing an apartment) or a “two-elderly-household” needing continuous assistance. After establishing a system of accounting based on the simultaneous characterization of demographic changes across different levels (in terms of profile of distribution of individuals over age class and in terms of profile of distribution of population over a chosen set of household types) it becomes possible to study the effects that changes in the demographic structure imply (either because of aging or because of emigration/immigration), both in terms of tradeoffs or synergies.

In particular with the MuSIASEM approach – when applying the tool-kit developed in the DECOIN project to the cases study selected in the SMILE project, we will assess synergies and tradeoffs across countries (Catalunya and Romania) and within countries (Catalunya).

One of the cases study deals with the effect on the Spanish economy of the flow of immigrants coming from Romania and the effect on Romanian economy of the flow of emigrants going to Spain. The accounting of flows in “per hour of human activity” rather than “per capita” makes it possible to assess the effects of the shifting of hours from the compartment of production (Paid Work) and the compartment of consumption in time, both within and across countries. An example of this analysis is provided in Fig. 4. It describes the situation of Romania, a country which has been exporting workers to other European Countries in the past ten years. The population pyramid shown below represents the age structure of only the emigrating population. Obviously the vast

majority of the emigrants are adults providing the labour hours and work force in a population (upper part of the figure). Due to such a trend, Romania has lost more than 20% of the potential working hours within its own economy, beside having changed its original profile of distribution of the work force over the different sectors. In fact, with emigration there is a selection on the most skilful workers. This type of change, very relevant for the performance of the economy, is described in the lower part of Figure 4.

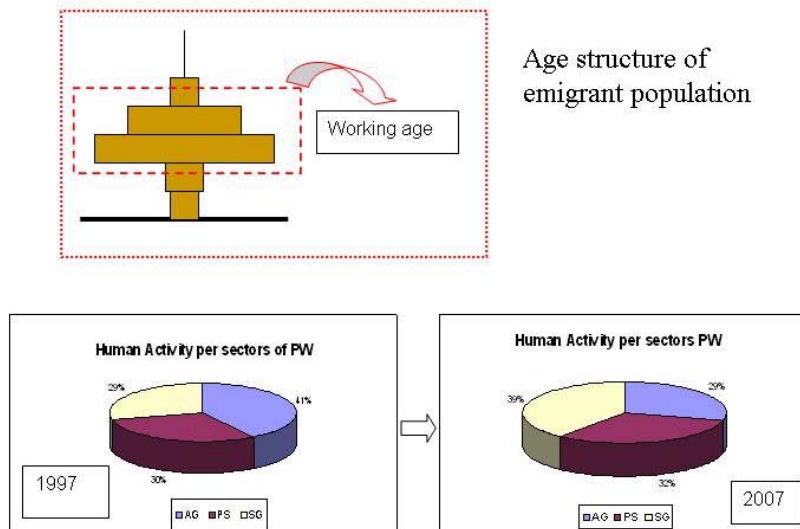


Figure 4. Illustration of change in the Paid Work Sector with emigration

As discussed earlier, demographic changes within a society can be expected to have both short term and long term effects. For the country receiving immigrant population, it can be regarded as a very valuable injection of work force into the aging population on the short run. The reduction in the social overhead on labour (hours of work required in services per hour of work delivered to the Paid Work sector) obtained with the immigrants does change productivity patterns and increases that available work supply to the society. On the contrary, the country that faces emigration will face severe shortage of labour activity due to a loss of its population of working age.

However, in the long term, with the second generations of the immigrant families, the economy will experience a boost in patterns of consumption which are energy and resource intensive, due to a larger fraction of families of immigrants (getting into the household type of large nuclear family) that requires both products and services.



### **3. Conclusion over the application of MuSIASEM as an analytical tool for assessing “Synergies” and “Tradeoffs” within the DECOIN tool kit**

Overall, the method of Human Activity accounting employed in the MuSIASEM provides the necessary analytical tool capable of establishing a link between changes in the structure of the population and changes in the metabolic performance, by adopting the multi-scaling properties previously explained. This makes it possible to look at changes associated to: (i) changes in the terms of trade across countries – outside the black box level; and (ii) changes of technical coefficients and relative size over subsectors described inside the black box. All these changes imply tradeoffs, since they imply winners and losers – e.g. more jobs or less jobs in various sectors, more or less consumption of resources, better or worse quality of life, more or less resilience of the economy to perturbations. However, a holistic assessment of the integrated effect of these changes can only be obtained by looking simultaneously at different levels and across different economic elements defined at different levels and scales.

Any society has a dynamic budget of Total Human Activity, affected by the demographic structure of ages and the migratory flows of people. These factors combined with other socio-economic factors such as level of education, retirement age, work load, determine the fraction of disposable working time and the use of land for establishing viable and desirable patterns of production and consumption of goods and services. In turn, any pattern of production and consumption of goods and services established in a society can be characterized in terms of monetary flows, coupled to energy and material flows. Using the MuSIASEM approach all these flows can be described in relation to different classifications of Human Activity (both in production and in consumption) across the various compartments of an economy. This makes it possible to calculate intensive variables (e.g. benchmarks describing the intensity of the flows – total GDP per hour at the national level; flows of €/hour in different sectors, subsectors, household types, wages for job type, etc.). In this way it becomes possible to: (a) compare different countries looking at all these characteristics expressed across levels in a synchronic way (at a given point in time); (b) track the historical evolution of the various variables within individual countries in a diachronic way (using historic series), looking at the internal shifting of labour, capital and circulating resources across the different compartments of the economy.

By combining these two ways of studying societal metabolism one can better understand the picture emerging from an analysis of trends of societies (the historic series – e.g. done by using ASA) by looking at the particular set of constraints coming from either higher or lower level (when looking at the synchronic comparison) that at any particular point in space and time are operating within a given economy.

After having developed the tool-kit in the DECOIN project we will apply it to study the relative “tradeoffs” and “synergies” that European societies experience when: changing production patterns; their demographic characteristics; affected by large migration flows (either in or out). This will be done using the set of cases study chosen in the SMILE project. The ability to develop such an analysis is a prior topic because of the expansion and change of borders within the European Union.

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## **Part 3: Matter, Energy and Emergy Assessment in the agricultural sectors of the Campania region. Constrains, bottlenecks and perspectives.**

### ***1. Introduction***

Agriculture is not only the activity that provides food to society. It always had, and still has, a multifunctional role by providing society with construction materials, fibres, chemicals, energy, environmental services and landscape protection. In times of increasing population and decreasing availability of cheap energy sources, the multifunctional role of agriculture becomes much more important and cannot be disregarded. Even if GDP, labor and energy expenditure associated to agriculture never represent the largest fraction of total performance of a national developed economy, yet the role of such a sector goes much beyond the actual food production and calls for higher attention by concerned policy makers. The performance of agricultural activity needs to be assessed, monitored and improved – if needed, in order to keep it at the highest possible level. This is not only in the interest of the farmer, but also and mainly in the interest of a country's population and economic wealth. Agricultural activity is also required to become the source of energy (from biomass conversion) to replace the declining oil availability. One of the main objectives of our study is to understand if this is possible and to what extent.

The dynamics and performance of agriculture – as for all other productive sectors of an economy – can be evaluated in many ways by means of economic, energetic, social and environmental parameters. In general, the economic performance is the most investigated aspect, due to its links to the employment and social parameters (economic and social sustainability). However, a comprehensive evaluation cannot disregard the resource use and other environmental aspects, that shed light on the environmental sustainability of the sector by focusing on crucial parameters such as energy consumption, material resource use and environmental integrity.

In this study we focus on the performance of the agricultural sector at the regional level, in order to highlight the characteristics and perspectives of such an activity on a relatively local scale, where environmental, social and technical parameters can be considered very similar, or at least not too different, in each part of the investigated system.

Evaluating a productive system is always an interesting exercise because it helps understanding what are the main driving forces of its performance and what is its dynamical interaction with surrounding environment and main economy in which it is embedded. For this to happen, the system must be carefully investigated from different points of view (energy, economic, material, environmental) as well as on a significantly long time scale, in order to also point out how the system and its main driving forces evolve over time. The final goal is to understand what are the steps of the activity that are characterized by the lowest performance as well as how can the system be made more robust and more stable in spite of the existing problems (increasing prices, decreasing productivity, increasing demand for resources). The improvement of agricultural activity requires as a prerequisite the identification and optimization of crucial steps, with special focus on energy and resource use flows.

## **2. Materials and methods**

The agricultural sector of Campania region was investigated by means of joint application of energy, material flow, and environmental analysis methods, in order to better understand the variations of the system's performance over time, and provide reliable data for agricultural and environmental policy making at regional level, also in order to assess internal and external constraints to system's development as well as to draw scenarios of future trends. Data were provided by ISTAT (National Italian Statistical yearbooks, several years, referred to in the Tables) as well as by local and regional agencies and statistical surveys.

### **2.1 The method used**

A comprehensive evaluation method (SUMMA – Sustainability Multimethod Multiscale Assessment, [1]) is used in the study in support to decision-making. In SUMMA the different (upstream and downstream) perspectives are not forced to combine, but retain their full wealth of information, on the basis of which wise decisions can be made, also taking into account important external factors such as social and economic welfare. SUMMA is based on a selection of upstream and downstream methods, which offer complementary points of view on the complex issue of environmental impact and performance assessment.

The upstream methods used in SUMMA are *Material Flow Accounting*, *Embodied Energy Analysis*, *Exergy Analysis* and *Emergy Accounting*, while the downstream method (assessment of downstream impact categories) used in SUMMA approach is *CML2 baseline 2000* (Figure 1).

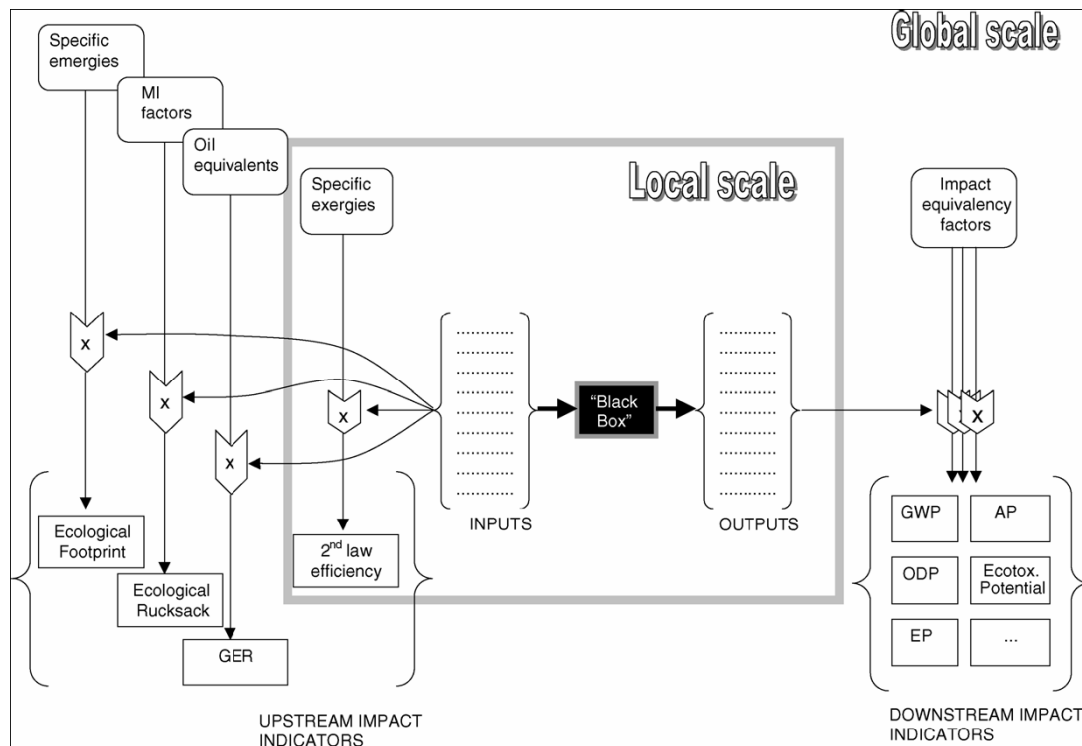


Figure 1. SUMMA – Sustainability Multimethod Multiscale Assessment [1].

The analysed system or process is treated as a “Black Box”, and a thorough inventory of all the input and output flows is firstly performed on its local scale. It is important to underline that this inventory forms the unavoidable common basis for all subsequent impact assessments, which are carried out in parallel, thus ensuring the maximum consistency of the input data and inherent assumptions as well as comparability of results. Each individual assessment method is applied according to its own set of rules. The “upstream” methods are concerned with the inputs, and account for the depletion of environmental resources, while the “downstream” methods are applied to the outputs, and look at the environmental consequences of the emissions. The calculated impact indicators are then interpreted within a comparative framework, in which the results of each method are set up against each other and contribute to providing a comprehensive picture on which conclusions can be drawn. The following paragraphs briefly describe the theoretical basis of the methods used in the assessment. In the present evaluation the exergy analysis method [2], also included in Figure 1, was not applied.

The *Material Flow Accounting* method [3, 4, 5] aims at evaluating the environmental disturbance associated with the withdrawal or diversion of material flows from their natural ecosystemic pathways. In this method, appropriate Material Intensity factors (g/unit) are multiplied by each input, respectively accounting for the total amount of abiotic matter, water, air and biotic matter that is directly or indirectly required in order to provide that very same input to the system. The resulting



Material Intensities (MIs) of the individual inputs are then separately summed together for each environmental compartment (again: abiotic matter, water, air and biotic matter), and assigned to the system's output as a quantitative measure of its cumulative environmental burden from that compartment (often referred to as "Ecological Rucksack").

The *Embodied Energy Analysis* method [6, 7] deals with the gross (direct and indirect) energy requirement of the analysed system, and offers useful insight on the first-law energy efficiency of the analysed system on the global scale, taking into consideration all the employed commercial energy supplies. In this method, all the material and energy inputs to the analysed system are multiplied by appropriate Oil Equivalent factors (g/unit), and the cumulative embodied energy requirement of the system's output is then computed as the sum of the individual Oil Equivalents of the inputs. Oil Equivalents can be converted to energy units by multiplying by the standard calorific value of 1 g of raw oil (41,860 J/g).

The *Emergy Accounting* method [8, 9] also looks at the environmental performance of the system on the global scale, but this time also taking into account all the free environmental inputs such as sunlight, wind, rain, as well as the indirect environmental support embodied in human labour and services, which are not usually included in traditional embodied energy analyses. Moreover, the accounting is extended back in time to include the environmental work needed for resource formation. All inputs are accounted for in terms of their solar emergy, defined as the total amount of solar *available energy* that was directly or indirectly required to make a given product or to support a given flow, and measured in solar equivalent Joules (seJ). The amount of emergy required per unit product is referred to as its specific emergy (seJ/unit) or transformity (seJ/J), and can be considered a "quality" factor which functions as a measure of the intensity of the support provided by the biosphere to the input under study. The total emergy thus calculated can be interpreted as an indicator of the environmental support required by the analysed human activity.

Finally, the downstream method, such as *CML2 baseline 2000* [10], provides an evaluation of the potential impact of airborne, liquid and solid emissions by means of appropriate equivalence factors to selected reference compounds for each impact category. The impact potential of the analysed system for each category is calculated by multiplying all emissions by their respective impact equivalence factors, and then summing the results. The CML2 method was selected among other similar methods for its versatility and completeness. In this study, however, only two downstream impact categories are investigated:

- *Global Warming Potential*, expressed in gram CO<sub>2</sub> equivalent per gram of product;

- *Acidification Potential*, expressed in gram SO<sub>2</sub> equivalent per gram of product.

Indicators, obtained through the joint application of the above methods, allow an estimate of the environmental performance of investigated system. SUMMA is an innovative integrated approach to environmental impact assessment. Its main objective is to overcome the inherent shortcomings of all single-criterion approaches, which constitute the vast majority of the Life Cycle Assessments performed to date in the scientific literature, and which invariably lead to partial and often misleading results. Instead, in SUMMA the main idea is the separation of indicators that provides a much more comprehensive environmental profile.

For each method used, calculation is performed according to the following equation:

$$F_J = \sum F_{J,i} = \sum f_i \times c_{J,i} \quad i= 1, \dots, n \quad \text{Equation (1)}$$

where:

J stands for MFA (Material Flow Accounting), EE (Embodied Energy), ES (Emergy Synthesis), AE (Airborne Emissions);

F<sub>J</sub> in turn indicates the total material, energy, emergy input to, or total emission of each chemical species from, the process;

f<sub>i</sub> = i-th input or output flow of matter or energy;

c<sub>i</sub> = conversion coefficient of the i-th flow (i.e. material, embodied energy, emergy or emission intensity factors, from literature or calculated in this work).

Application of Equation (1) to the flow inventory of the investigated system translates into Tables of Total Material Requirement, Embodied Energy, Emergy and Emissions, based on the same set of input and output data. Such values, F<sub>J</sub>, are finally divided by the total economic value, total energy content, and total mass (dry weight) of the product. As a consequence of the procedure, results of calculation are consistent and comparable, and jointly provide a reliable and comprehensive picture of the whole system performance.

## 2.2. The system

The investigated regional agricultural system includes all the land cropped in the Campania region (8.49 x 10<sup>5</sup> Ha in 1985 and 6.03 x 10<sup>5</sup> Ha in 2006, with important oscillations in the two decades investigated, Table 1). Out of the total surface, forage production accounted for about 35% in 1985, up to 44% in 2002 and a slightly smaller fraction of 43% in 2006. Cereals (mainly wheat and corn) account for an average, slightly declining fraction of 22% of total cropped land. Olive production accounted for about 9% of total agricultural land in 1985 with an increasing trend up to 11.6% in

2006. All kind of fruit, citrus and nut trees globally accounted for about 12.2% in 1985, stabilizing at about 11% in the following years. Other non-negligible sub-sectors are grape production (5% average in the investigated period), tobacco (declining from 3.5% in 1985 to 1.6 % in 2006), potatoes (also declining from 3% in 1985 to 1.7 % in 2006), tomatoes (declining from 3% in 1985 to 0.9 % in 2006). Forage provides support to the livestock sector, which is an important economic activity at the regional level and also imports feedstock from outside the region. Livestock sector is not included in the present study, since the assessment is still in progress, but will be included in the final evaluation.

Work force in agriculture in the year 1981 was 4.9% of a total regional population of 5.46 million people (Table 2) and 17.7% of total work force. Work force accounting did not include: population below 14 years, students, people working at home (mainly women), and retired people. Out of this agricultural work force, 46.7% were men and 53.3% women, while the largest age class were workers in the range 30-54 years (66.4%), followed by a 17.4% of workers in the age class 20-29 years and then by a 12.6% of workers 55 years old or more. Only 3.5% of these workers were in the range 14-19 years. The fraction of work force in agriculture compared to total regional population decreased to 2.9% after 10 years (1991) and then to 1.9% in the year 2001, to finally drop to 0.8 in the year 2006. In the investigated period, the fraction of feminine work force increased to 48.6% (2001) to decrease again to 47.7% (2006). Age classes also changed in the investigated period reaching a final state with 69.4% of total agricultural work force falling within the age range 30-54 years, 19.4% in the upper age class (55 years or more), 10.6% in the range 19-29 years, and a negligible 0.7% in the range 14-19, due to the increased school attendance. In summary, regional agriculture is increasingly based on aged people, and such a trend is not expected to change in the near future.

### **3. Results**

Total land area cropped and the percentage that main crops are of the total agricultural surface in the investigated period are shown in Table 1, where forage crops, cereals, olive and vineyard appear to be the most important production processes in the region. A declining amount of work force in the agricultural sector is shown in Table 2, where the ageing of agricultural population is also pointed out. Table 3 shows the total product of regional agriculture as a whole, quantified as dry mass, energy and economic value, over time. The total mass (d.w.) decreased by about 57%, from  $1.2 \times 10^7$  tons/yr (1981) to  $5.1 \times 10^6$  tons/yr (2006), amounting to about 8.4 tons/ha (d.w.). Instead, the economic value of the product increased by 53.2%, reaching an average value of 3880 €/ha/yr.

Such a trend was affected (and very likely generated) by the price increase of all agricultural input flows (fuels, machinery, fertilizers, labor, etc), as shown in Table 4. In fact, it clearly appears that prices of commodities and energy increased by a factor 1.5-3.0 over the investigated period, and labor increased up to a factor 5.0.

Production indicators do not change monotonically, but oscillate following the amount of land cropped, the mix of crops installed as well as changes in climatic conditions.

Table 5 lists the main input flows to the regional agricultural system, as a whole, in the investigated years. As already pointed out, input data were converted into embodied matter, energy and emergy flows, to be used for the evaluation of the system's performance over time. In so doing, input data can be used to assess extensive and intensive variations of production tools (fertilizers, machinery, etc.) as well as of performance indicators. Extensive data refer to the whole agricultural sectors of Campania Region, while instead intensive indicators split into six categories: input per euro of product generated (g/€; J/€; sej/€); input per ha (g/ha; J/ha; sej/ha); input per g of dry matter (g/g dry matter; J/g dry matter; sej/g dry matter); input per J of energy content (g/J; unit/J; sej/J); input per hour of labor (g/hour; unit/hour; sej/hour); and finally, actual efficiency and performance indicators.

Table 6 lists extensive and intensive indicators of Material Requirement. Tables 7, 8 and 9a,b show similar calculations respectively for Airborne Emissions, Embodied Energy, and Emergy Synthesis (with and without accounting for the emergy supporting Labor and Services). Extensive indicators account for the total flow (abiotic matter, water, embodied energy and emergy) supporting the system at the regional level. In a way, they provide a measure of the "size" of the system itself, i.e. of how much of a given flow is required to support the systems dynamics, also including hidden flows occurring at larger spatial and time scales. Of course, extensive indicators depend directly on the physical size of the system (total hectares cropped) and may follow the oscillations of such a size over time. Physical size is not, however the only important factor. In fact, total supporting flows also depend on the mix of crops adopted in each investigated year, as well as on a variety of factors such as technological improvement or price, that may affect the use modality of some input flows. On the other hand, intensive indicators are more independent on the physical size, and provide a measure of efficiency or performance compared to the final product (e.g., more or less material or energy used per unit of product or per unit of time). Therefore, it is possible to create performance indicators in terms of amount of input (matter, energy, emergy) per gram or joule or € of product as well as amount of input per unit time applied or per unit surface of system. When these extensive and intensive indicators are analysed and discussed, the performance of our system

can be assessed in depth, and improvement strategies can be designed. This is because the construction of historical series of data offers a powerful tool to assess the role of each input over time (e.g. increased use of nitrogen fertilizer, decreased use of direct labor, etc) as well as the changes of system's performance over time, as a more global picture of trends, efficiency, sustainability. Finally, Tables 6 to 8 also show the ratios of global to local flows, so that it is possible to ascertain: (a) the real global scale impact of our local use of a given resource; (b) the opportunities for improvement at global scale, driven by optimization of resource use at local scale, (c) the advantages of technological improvements that affect material, energy and emergy intensities, and finally (d) the advantages of a better mix of input resources capable of generating lower global scale impacts.

**Table 1.** Land area devoted to main agricultural crops in Campania region from 1985 to 2006.

Crop	1985	1993	2002	2006
Total area cropped (Ha)	8.49E+05	6.34E+05	6.85E+05	6.03E+05
Forage crops	34.60 %	37.50 %	44.10 %	42.30%
Cereals	21.60 %	22.60 %	21.30 %	20.20 %
Fruit, citrus and nuts trees	12.20 %	10.83 %	11.20 %	10.90 %
Olives	9.55 %	9.30 %	11.10 %	11.60 %
Vineyard	5.02 %	5.80%	5.30 %	4.40 %
Tabacco	3.50 %	3.40 %	2.40 %	1.60 %
Potatoes	3.20 %	2.20 %	1.70 %	1.70 %
Tomatoes	2.93 %	1.65 %	1.20 %	1.10 %
Others	7.40 %	6.70 %	1.70 %	6.20 %

Source of data: [11].

**Table 2.** Evolution of work force in the agricultural sector of Campania region.

	1981	1991	2001	2006
Regional population	5.46E+06	5.63E+06	5.70E+06	5.79E+06
Agric work force as % of regional population	4.90%	2.90%	1.90%	0.80%
Agric work force as % of total work force	17.70%	10.20%	7.40%	3.50%
Female work force as % of agric work force	53.30%	52.50%	48.60%	47.70%
% of work force in the age range 14-19 years	3.50%	2.10%	0.70%	n.a.
% of work force in the age range 20-29 years	17.40%	18.80%	10.60%	n.a.

% of work force in the age range 30-54 years	66.40%	60.00%	69.40%	n.a.
% of work force aged 55 and more	12.60%	19.10%	19.40%	n.a.

Source of data: [12-15].

**Table 3.** Global agricultural production of Campania region.

	Unit	1985	1993	2002	2006
Land cropped	ha/yr	8.49E+05	6.34E+05	6.85E+05	6.03E+05
Mass of products (d.w.)	g /yr	1.19E+13	1.30E+13	5.27E+12	5.09E+12
Energy of products	J/yr	1.98E+17	2.16E+17	8.54E+16	7.99E+16
Economic value	€/yr	1.53E+09	1.72E+09	2.46E+09	2.34E+09

Source of data: [11, 16-18].

**Table 4:** Prices of main input flows.

Price	Unit	1985	1993	2002	2006
Gasoline	€/L	0.73	0.79	1.05	1.29
Diesel	€/L	0.33	0.42	0.60	0.86
Electricity	€/kWh	0.09	0.11	0.16	0.23
Water for irrigation	€/m <sup>3</sup>	0.12	0.15	0.17	0.18
Nitrogen (N)	€/q	12.97	13.37	17.73	32.10
Phosphate (PO <sub>4</sub> )	€/q	9.86	10.17	13.48	24.41
Potassium (K <sub>2</sub> O)	€/q	13.17	13.58	18.01	32.60
Fungicide	€/kg	3.03	4.48	4.77	7.61
Insecticides	€/kg	2.04	3.01	3.21	5.11
Acaricides	€/kg	5.85	8.64	9.20	14.67
Labor	€/yr	2.10	4.15	8.60	10.58

Source of data: [11, 16-23].

**Table 5:** Input flows to the agricultural sector of Campania region.

	Unit	1985	1993	2002	2006
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Rainfall	grain/yr	8.74E+15	3.78E+15	5.76E+15	4.88E+15
Fertilizers (N+ PO4 +K2O)	g/yr	9.37E+10	7.80E+10	8.95E+10	1.06E+11
Nitrogen (N)	g/yr	5.95E+10	4.41E+10	5.25E+10	9.37E+10
Phosphate (PO4)	g/yr	2.53E+10	2.38E+10	2.54E+10	1.18E+10
Potassium (K2O)	g/yr	8.83E+09	1.01E+10	1.17E+10	8.87E+08
Electricity	J/yr	4.62E+14	7.47E+14	8.01E+14	8.87E+14
Water for irrigation	g/yr	4.42E+14	2.30E+14	1.53E+14	1.04E+14
Liquid fuels	J/yr	4.10E+15	3.37E+15	4.00E+15	4.23E+15
Machinery	g/yr	3.76E+11	4.03E+11	6.70E+11	7.06E+11
Direct Labor	hours/yr	5.47E+08	3.21E+08	1.92E+08	9.38E+07
Direct Labor	€/yr	1.15E+09	1.33E+09	1.65E+09	9.92E+08
Indirect labor (services)	€/yr	2.77E+08	2.23E+08	7.96E+08	1.76E+09

Source of data: [16-30].

**Table 6:** Material Requirement Indicators.

	Unit	1985	1993	2002	2006
<b><i>Intensive Indicators</i></b>					
Abiotic Material Intensity per € of product	g/€	2.10E+03	1.56E+03	1.23E+03	1.58E+03
Abiotic Material Intensity per ha	g/ha	3.77E+06	4.22E+06	4.42E+06	6.11E+06
Abiotic Material Intensity per g of dry matter	g/g	0.27	0.21	0.57	0.72
Abiotic Material Intensity per J of energy	g/J	1.62E-05	1.24E-05	3.55E-05	4.61E-05
Abiotic Material Intensity per hour of labor	g/hour	5.85E+03	8.33E+03	1.58E+04	3.93E+04
Global to local ratio of abiotic material		2.11	2.34	2.43	3.23
Water Material Intensity per € of product	g/€	3.01E+05	1.46E+05	7.18E+04	5.69E+04
Water Material Intensity per ha	g/ha	5.42E+08	3.96E+08	2.58E+08	2.21E+08
Water Material Intensity per g of dry matter	g/g	38.69	19.33	33.49	26.16
Water Material Intensity per J of energy	g/J	2.33E-03	1.16E-03	2.07E-03	1.67E-03
Water Material Intensity per hour of labor	g/hour	8.41E+05	7.82E+05	9.18E+05	1.42E+06
Global to local ratio of water requirement		1.04	1.09	1.15	1.28

Total Material Intensity per € of product (abiotic + water)	g/€	3.04E+05	1.48E+05	7.30E+04	5.85E+04
Total Material Intensity per ha (abiotic+ water)	g/ha	5.46E+08	4.00E+08	2.62E+08	2.27E+08
Total Material Intensity per g of dry matter (abiotic+ water)	g/g	38.96	19.53	34.06	26.89
Total Material Intensity per J of energy (abiotic+ water)	g/J	2.34E-03	1.18E-03	2.10E-03	1.71E-03
Total Material Intensity per hour of labor (abiotic+ water)	g/hour	8.47E+05	7.90E+05	9.34E+05	1.46E+06
<b><i>Extensive Indicators</i></b>					
Total abiotic material requirement	g/yr	3.20E+12	2.68E+12	3.03E+12	3.69E+12
Total water material requirement	g/yr	4.60E+14	2.51E+14	1.76E+14	1.33E+14

**Table 7:** Airborne Emissions Indicators.

	Unit	1985	1993	2002	2006
CO <sub>2</sub> released	g <sub>CO2</sub> /yr	1.03E+12	8.21E+11	8.89E+11	1.12E+12
CO <sub>2</sub> per € of product	g <sub>CO2</sub> /€	6.75E+02	4.78E+02	3.62E+02	4.80E+02
CO <sub>2</sub> per ha	g <sub>CO2</sub> /ha	1.21E+06	1.29E+06	1.30E+06	1.86E+06
CO <sub>2</sub> per g of dry matter	g <sub>CO2</sub> /g	0.09	0.06	0.17	0.22
CO <sub>2</sub> per J of energy	g <sub>CO2</sub> /J	5.21E-06	3.80E-06	1.04E-05	1.41E-05
Global to local CO <sub>2</sub> ratio		3.23	3.15	2.88	3.47
CO released	g <sub>CO</sub> /yr	2.73E+09	2.28E+09	2.69E+09	2.88E+09
Global to local CO ratio		1.25	1.27	1.26	1.27
NO <sub>x</sub> released	g <sub>NOx</sub> /yr	4.46E+09	3.67E+09	4.30E+09	4.67E+09
Global to local NO <sub>x</sub> ratio		1.32	1.33	1.31	1.34
SO <sub>2</sub> released	g <sub>SO2</sub> /yr	1.76E+09	1.39E+09	1.49E+09	1.92E+09
Global to local SO <sub>2</sub> ratio		4.78	4.59	4.13	5.06
Unburnt hydrocarbons	g <sub>part</sub> /yr	5.98E+08	4.94E+08	5.82E+08	6.24E+08
Global to local unburnt hydrocarbon ratio		1.27	1.28	1.26	1.28
NO <sub>2</sub> released	g <sub>NO2</sub> /yr	1.31E+07	1.14E+07	1.30E+07	1.46E+07
Global to local NO <sub>2</sub> ratio		1.68	1.78	1.70	1.81



CH <sub>4</sub> released	g <sub>CH4</sub> /yr	8.37E+07	6.99E+07	7.91E+07	9.11E+07
Global to local CH <sub>4</sub> ratio		1.78	1.81	1.73	1.89

**Table 8:** Embodied Energy Indicators.

	Unit	1985	1993	2002	2006
<b><i>Intensive Indicators</i></b>					
Oil equivalent intensity per € of product	g <sub>oil</sub> /€	1.38E+02	9.90E+01	7.09E+01	1.03E+02
Oil equivalent intensity per ha	g <sub>oil</sub> /ha	2.49E+05	2.68E+05	2.55E+05	3.99E+05
Oil equivalent intensity per g of dry matter	g <sub>oil</sub> /g	1.77E-02	1.31E-02	3.31E-02	4.73E-02
Oil equivalent intensity per J of energy	g <sub>oil</sub> /J	1.07E-06	7.86E-07	2.04E-06	3.01E-06
Oil equivalent intensity per hour of labor	g <sub>oil</sub> /hour	3.86E+02	5.29E+02	9.07E+02	2.57E+03
Energy Intensity per € of product	J/€	8.96E+06	6.46E+06	4.89E+06	6.44E+06
Energy Intensity per ha	J/ha	1.61E+10	1.75E+10	1.76E+10	2.50E+10
Energy Intensity per g of dry matter	J/g	1.15E+03	8.53E+02	2.28E+03	2.96E+03
Energy Intensity per J of product	J/J	6.91E-02	5.13E-02	1.41E-01	1.89E-01
Energy Intensity per hour of labor	J/hour	2.50E+07	3.45E+07	6.26E+07	1.61E+08
Global to local Energy ratio		3.00	2.69	2.50	2.95
<b><i>Extensive Indicators</i></b>					
Total embodied energy applied	J/yr	1.37E+16	1.11E+16	1.20E+16	1.51E+16
Total oil equivalent applied	g <sub>oil</sub> /yr	2.11E+11	1.70E+11	1.74E+11	2.41E+11

**Table 9a:** Energy Synthesis Indicators (including the energy supporting labor and services).

	Unit	1985	1993	2002	2006
<b><i>Intensive Indicators</i></b>					
Specific Energy of monetary value	sej/€	5.44E+12	4.80E+12	4.82E+12	5.63E+12
Specific Energy of ha	sej/ha	3.33E+15	3.57E+15	3.55E+15	4.31E+15
Specific Energy of unit of dry matter	sej/g	6.96E+08	6.32E+08	2.24E+09	2.58E+09
Transformity	sej/J	4.20E+04	3.82E+04	1.39E+05	1.65E+05
Emergy Yield Ratio = U/(F+L+S)		1.24	1.17	1.12	1.09
EIR = 1/(EYR-1)		4.19	5.90	8.17	10.59

Environmental Loading Ratio = (N+F+S)/(R)		1.48	1.66	3.33	7.40
%REN= 1/(1+ELR)		0.40	0.38	0.23	0.12
EYR/ELR		0.84	0.70	0.34	0.15
<b><i>Extensive Indicators</i></b>					
Locally renewable input, R (without double counting)	sej/yr	1.57E+21	1.17E+21	1.27E+21	1.11E+21
Locally nonrenewable input, N	sej/yr	3.07E+19	2.30E+19	2.48E+19	2.18E+19
Purchased inputs to agricultural phase, F (without L&S)	sej/yr	1.23E+21	1.07E+21	1.14E+21	1.46E+21
Direct Labor (L)	sej/yr	4.42E+21	5.12E+21	6.35E+21	3.81E+21
Indirect labor (services, S)	sej/yr	1.06E+21	8.56E+20	3.06E+21	6.76E+21
Total energy inputs to agricultural phase, U= (R+N+F+L+S)	sej/yr	8.31E+21	8.24E+21	1.18E+22	1.32E+22

**Table 9b: Energy Synthesis Indicators (without accounting for energy supporting labor and services).**

	Unit	1985	1993	2002	2006
<b><i>Intensive Indicators</i></b>					
Specific Energy of monetary value (without L&S)	sej/€	1.85E+12	1.32E+12	9.89E+11	1.11E+12
Specific Energy of ha (without L&S)	sej/ha	3.33E+15	3.57E+15	3.55E+15	4.31E+15
Specific Energy of unit of dry matter (without L&S)	sej/g	2.35E+08	1.72E+08	4.57E+08	5.06E+08
Transformity (without L&S)	sej/J	1.43E+04	1.05E+04	2.85E+04	3.25E+04
Energy Yield Ratio (without L&S) = U*/F		2.30	2.12	2.13	1.78
EIR (without L&S) = 1/(EYR-1)		0.77	0.89	0.88	1.29
Environmental Loading Ratio (without L&S) = (N+F)/(R)		0.80	0.93	0.92	1.33
%REN (without L&S) = 1/(1+ELR)		0.55	0.52	0.52	0.43
EYR/ELR (without L&S)		2.87	2.27	2.32	1.33
<b><i>Extensive Indicators</i></b>					

Locally renewable inputs, R (without double counting)	sej/yr	1.57E+21	1.17E+21	1.27E+21	1.11E+21
Locally nonrenewable inputs, N	sej/yr	3.07E+19	2.30E+19	2.48E+19	2.18E+19
Purchased inputs to agricultural phase, F (without L&S)	sej/yr	1.23E+21	1.07E+21	1.14E+21	1.46E+21
Total energy inputs to agricultural phase, U*=(R+N+F)	sej/yr	2.83E+21	2.27E+21	2.43E+21	2.60E+21

Total energy embodied per unit of product (g, J, €) or per functional unit (ha) or per unit time (hr) oscillates over the investigated period due to the joint effect of crop mix and market price of commodities and labor (Table 8). A similar behaviour is shown by material requirement and energy with some differences that are specific of the method used. A careful reading of these performance indicators and global-to-local ratios sheds light on different aspects of the regional production process and calls for comparison at smaller (farm) and national scales.

First of all, nitrogen, liquid fuels and electricity (mainly for irrigation water) respectively accounted for 32%, 30% and 26% of total energy used in 1985. After 20 years (2006) nitrogen increased its importance in terms of embodied energy expenditure (46%), while liquid fuels accounted for 28% and electricity dropped to a low 19%. The total embodied energy investment was  $1.37 \times 10^{16}$  J/yr in 1985, steadily increasing to  $1.51 \times 10^{16}$  J/yr in 2006. The energy content of the harvested products (Table 3) was 14.4 times the energy investment in the year 1985, decreasing to 5.3 times in the year 2006, as a joint effect of the changed mix of crops and a more intensive agriculture (more machinery, more fuel, less labour). The agricultural production in the Campania region is mainly addressed to the food sector, not to the bioenergy sector. However, assuming a main product/residues ratio equal to 1, and assuming that at least 50% of these lignocellulosic residues must be left in the field in order to keep its structure and fertility unchanged, we may calculate an availability of about 2.5 million ton/yr of agricultural residues (d.w.). Such an amount translates into a potential bioenergy source of  $8.5 \times 10^5$  ton of oil equivalent, equal to about three times the amount invested into the regional agricultural system. Considering the expenses for residues harvest as well as additional expenses for drying and conversion, it is very likely that the agricultural system could become energy self-sufficient by converting these residues into energy locally by means of appropriate thermal and biochemical technologies. The available amount of residues is not, however, likely to support any centralized bioenergy conversion process, due to the fact that

this would imply transportation expenses to a centralized conversion plant as well as additional energy expenses for storage and thermochemical treatment of lignocellulosic substrate.

Tables 9a,b show energy synthesis indicators for the whole system of regional agriculture, respectively calculated with and without accounting for the energy that supports labour and services provided to the system. Due to the large role that labour and services have in the agricultural sector, as well as due to the large fraction of non-renewable energy that these typology of energy flows have in the Italian economy, the two tables differ significantly in both total amount of energy flows and energy-based performance indicators. We will only point out here that the Energy Yield Ratio declined from 1.24 to 1.09, indicating that the agricultural system is no longer a system based on local resources but strongly relies on imports. Values of EYR lower than 2 are alarming, because they indicate that the process is not exploiting local resources but instead is only a conversion process of resources imported from outside. Since EYR is linked to EIR (Energy Investment Ratio) by the relation  $EIR = F/(R-N) = 1/(EYR-1)$ , the EIR diagram decreases confirming the large investments are needed to exploit one unit of local resource. From an economic point of view this makes the local process hardly able to compete with other regions. As a consequence of the fact that energy imports are mainly non renewable, the Environmental Loading Ratio increased by 4.19 in the year 1985 to more than twice (10.6) in the year 2006, indicating that the renewable fraction of agricultural products declined from 40% (1985) to 12% (2006). If labor and services are not included in the accounting, figures are different and show a better performance (renewability at about 43% in 2006). The aggregate environmental Energy Sustainability Index ( $ESI = EYR/ELR$ ) decreases steadily by more than 50% in the investigated period.

## **Conclusion**

Evaluating historical series of regional agriculture provided a deep insight into its energy and material basis, social structure, demand for environmental support and sustainability. Our data show that the regional agriculture is increasingly becoming a less sustainable, fossil fuel based, process and that this is affecting its ability to serve as a source of renewable materials, food, energy and services.

Indicators of performance as well as Intensity Factors were calculated by means of a variety of approaches within the SUMMA framework. Figures allow an understanding of how the system is changing over time and provide an alarming signal of its dynamics under market pressure, competition for land use, work force aging and decrease, increased demand for energy and

environmental support. Moreover, since several of the calculated indicators are composite indicators, a further disaggregation of their components would be highly illuminating about the driving forces of the investigated trends.

Finally, oscillations or changes of embodied quantities (Total Material Requirement, Embodied Energy, Energy) as well as of global-to-local ratios suggest variations of the relation between processes that occur locally and processes that occur globally and provide input to the local system. This means that changes in the way goods and energy are used locally affects the global scale according to the value of these indicators and ratios and deserves further exploration.

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