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Abstract
Using the latest available data, this brief article attempts to provide the first regional decomposition analysis of CO_2 emissions from fuel combustion. Covering eight regions of the world, determinants are estimated in relative and absolute terms for the period 1971-2010. We take the 2010 global surge in CO_2 emissions as an entry point for the analysis. Overall, results show that most regions have recently performed worse than their historical trends and lack of meaningful progress is identified. Whereas specific drivers for certain regions suggest some level of continuous improvement (e.g. reduced energy intensity in Asia), they are incapable of offsetting the effects of economic growth and energy use. With the exception of Africa, most regions appear to have missed the low-carbon economy opportunity provided by the 2008-2009 global financial crisis. Results suggest a lack of serious environmental effectiveness of regional policy portfolios aiming at reducing CO_2 emissions. Highly ambitious energy efficiency and renewable energy policies across all regions are immediately needed. Additionally, absolute reductions in CO_2 emissions and energy use from fossil fuels are urgently required in rich regions if we are to align production and consumption patterns with maintaining global warming below the 2°C threshold.

Keywords: Climate and Energy Policy; Low-carbon economy; Decomposition Analysis

1. Introduction

There is considerable cross-sectional heterogeneity in economic growth, energy use, energy mix and resulting CO_2 emissions across the regions of the world. However, a literature review indicates that there is a lack of up-to-date knowledge about historical *regional* discrepancies (in absolute and relative terms) regarding drivers of CO_2 emissions. From a global perspective, major climate and/or energy assessments have mostly undertake worldwide decomposition analyses to identify and analyse inclusive drivers of CO_2 emissions (see e.g. Johansson, Patwardhan, Nakicenovic, & Gomez-Echeverri, 2012; Metz, Davidson, Bosch, Dave, & Meyer, 2007). Although aggregate indicators of this nature are insightful in describing the energy-economy system globally, regional disparities (e.g. income levels, energy supply mix, consumption patterns, climatic conditions, technology development) are masked. The recent growth in CO_2 emissions after the 2008-2009 financial crisis provoked some decomposition analyses (see Jotzo, Burke, Wood, Macintosh, & Stern, 2012; Peters *et al.*, 2011). Again, the focus was on global trends, major economies, or distinction between developed and developing countries, or OECD vs Non-OECD countries. Although these studies provide interesting insights, the analyses overlook large disparities across multiple regional boundaries.

From a country perspective, for instance, Casler and Rose (1998) undertake a detailed analysis but limited to the U.S. economy, Wang *et al.* (2005) and Zhang *et al.* (2009) assess drivers but only for China, De Hann (2001) studies several air pollutants (including CO_2) and their drivers for the Netherlands, Liaskas *et al.* (2000) decomposes industrial CO_2 emissions for the EU, De Freitas and Kaneko (2011) evaluates CO_2-economy decoupling trends in Brazil, Luukkanen and Kaivo-oja (2002) provide an appealing study but addressed seven major developing countries (e.g. Brazil, China and India), Enevoldsen *et al.* (2007) study decoupling metrics of industrial energy consumption but for the Nordic Region exclusively, and Wilhite and Nørgård (2004) address energy use and corresponding GHG emissions for India and China. To some extent, the only exception we found is in Raupach *et al.* (2007), which analyse not only global but also regional drivers of CO_2 emissions. However, the regional analytical resolution in that study (four main countries and five regions) and time frame (1980 to 2005) are limited compared to the research at hand.

Very little attention has been given to certain regions; such as Africa, Latin America and the Middle East, and related regional drivers of accelerating CO_2 emissions. This is despite the fact that, for instance, the causes and/or impacts of climate change are mostly framed in regional (or sectoral) terms (e.g. as reflected in IPCC Assessment Reports). To a degree, this lack of regional knowledge is consistent with a very recent study acknowledging the need for much more research on geographical differences and implications of transitions to a low-carbon economy (Bridge, Bouzarovski, Bradshaw, & Eyre, 2013).

Using the most recent and longest available dataset (see International Energy Agency, 2012a), the aim of this short paper is to provide a succinct but high-resolution regional decomposition analysis of CO_2 emissions from fuel combustion for the period 1971-2010.[1] The paper at hand must be taken as a departure point for further and much deeper

[1] Note that data covering 2011 will be released by the IEA in September 2013.

analyses regarding regional low-carbon economies. [2] With the various green growth policy initiatives that were introduced in 2008-2009, our analysis also aims to cast light on whether the regions under analysis show or not signs of moving towards a low-carbon economy. This is because it has been argued that the global financial crisis provided an opportunity to move economies away from a high carbon emission path (see e.g. Barbier, 2010; Peters et al., 2011). With due limitations, we take 2010 as an entry point to briefly reveal and compare recent and historical drivers of CO_2 emissions from a regional perspective. In this regard, our paper aims to complement the results given by Peters *et al.* (2011) and Jotzo *et al.* (2012).

2. Methodology

To ensure scientific consistency with topical studies, we use the same methodological approach undertaken in the recent literature (e.g. Jotzo et al., 2012). Our paper focuses on CO_2 emissions, the dominant anthropogenic greenhouse gas flux, from fuel combustion. Emissions from cement production, gas flaring, and marine and aviation bunkers are excluded from the analysis.

We estimate the percentage change in CO_2 emissions from energy use and analyse annual changes in: (1) Gross Domestic Product (GDP), (2) energy use, (3) the ratio of energy use to GDP (energy intensity), and (4) the ratio of CO_2 to energy use (carbon intensity of energy) (for definitions see Table 1). We use the latest time series data (1971–2010) from the IEA (International Energy Agency, 2012a).[3]

Table 1: Variables, definitions and data source

Variable	**Definition**	**Data source**
CO_2 emissions	Emission from fuel combustion (in millions of tonnes of CO2), , excluding emissions from marine and aviation bunkers	IEA (2012a)
Energy	Total primary energy supply (TPES), equivalent to production + imports − exports − international marine bunkers − international aviation bunkers ± stock changes (in millions of tonnes of oil equivalent)	
Gross Domestic Product (GDP)	Total annual output valued in billion year-2005 US dollars, adjusted by purchasing power parities	

We use the following formula to estimate the percentage growth rates of CO_2 emissions, energy use, GDP, energy intensity across all regions:

$$\textit{Annual growth rate (in \%) of } X_{\textit{end year}} = ((X_{\textit{end year value}} - X_{\textit{previous year value}})/X_{\textit{previous year value}})*100$$

For the purposes of our analysis, we attempt to provide a simple but still high regional analytical resolution by dividing the world into eight regions: Africa, Asia, Latin

[2] This paper is the first of a series of manuscripts aiming at providing in-depth regional assessments of energy-economy transitions and the performance of energy and climate policy portfolios.

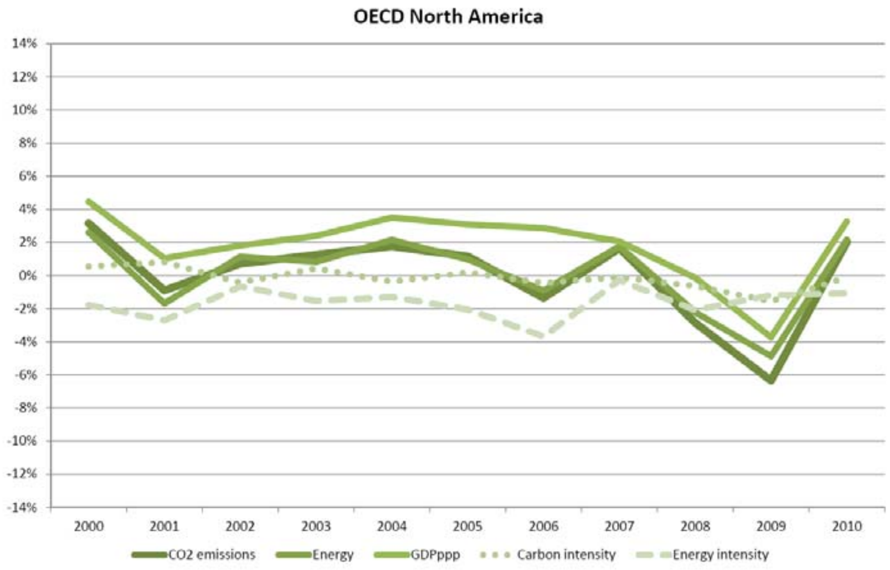
[3] Data were released in October 2012. Data are collected by the Energy Data Centre (EDC) of the IEA Secretariat and released after two years after the end of a calendar year.

America and the Caribbean (LATAM), the Middle East, Non-OECD Europe and countries from the former Soviet Union (FSU), Oceania, OECD Europe, and OECD North America (see Annex 1 for definition of regions).

3. Results

To begin with, our analysis shows that the 2010 rebound in CO_2 emissions was much more pronounced in OECD Europe, OECD North America, Non-OECD Europe and the FSU, and LATAM than in the rest of the world (Fig. 1). In these four regions, the emissions rebound correlated closely with increases in economic activity and energy use. In Europe and North America, emission growth reached a record high compared to historical averages (Table 2). In 2010 OECD Europe and OECD North America experienced an emission surge of 3% and 2% respectively, and both offset their 2009 reductions.

Figure 1: Estimated annual change (2000-2010) in CO_2 emissions, energy use, GDP, carbon intensity, and energy intensity in (**a**) OECD North America, (**b**) OECD Europe, (**c**) Non-OECD Europe and FSU, (**d**) Latin American and the Caribbean, (**e**) Oceania, (**f**) Asia, (**g**) Africa, and (**h**) the Middle East. Emissions from bunkers are not considered.


OECD North America
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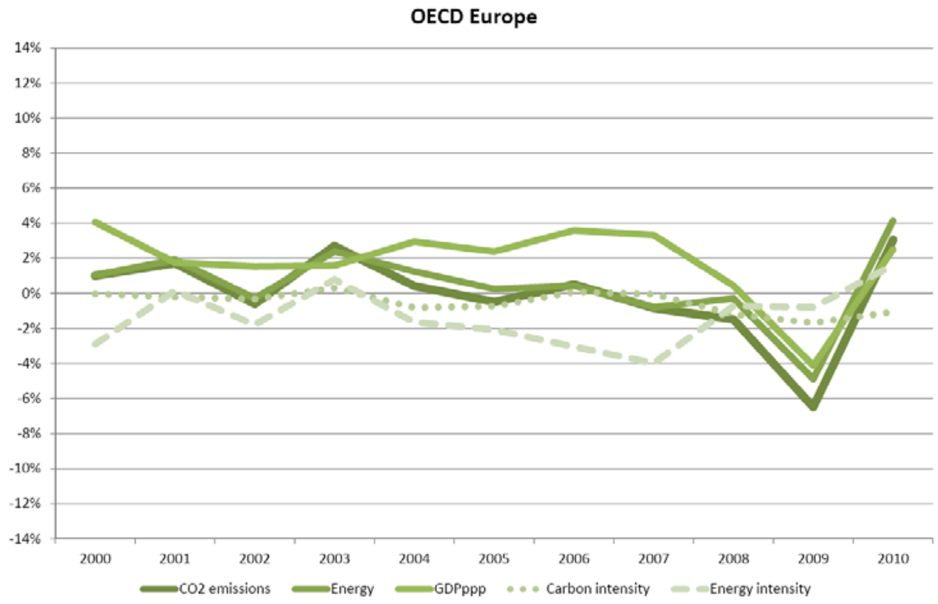
Carbon intensity
Energy intensity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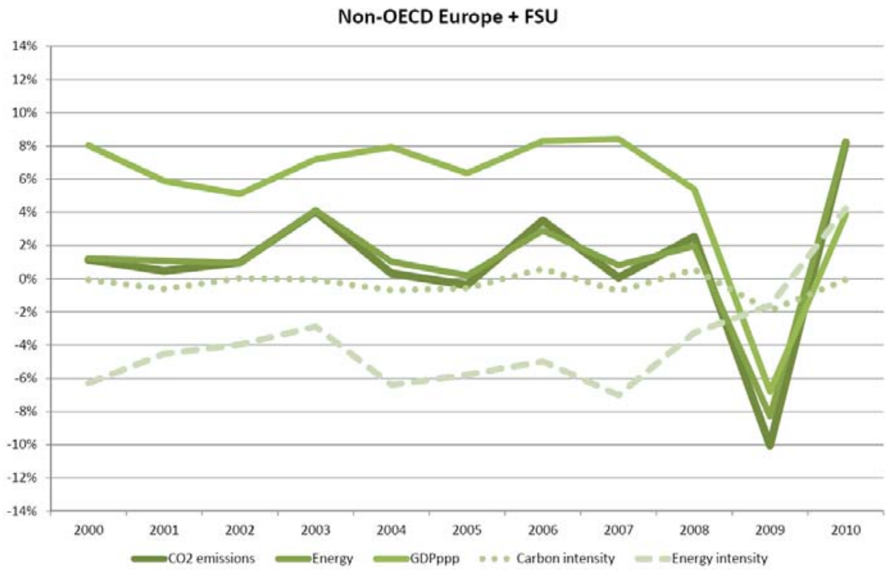
Non-OECD Europe + FSU
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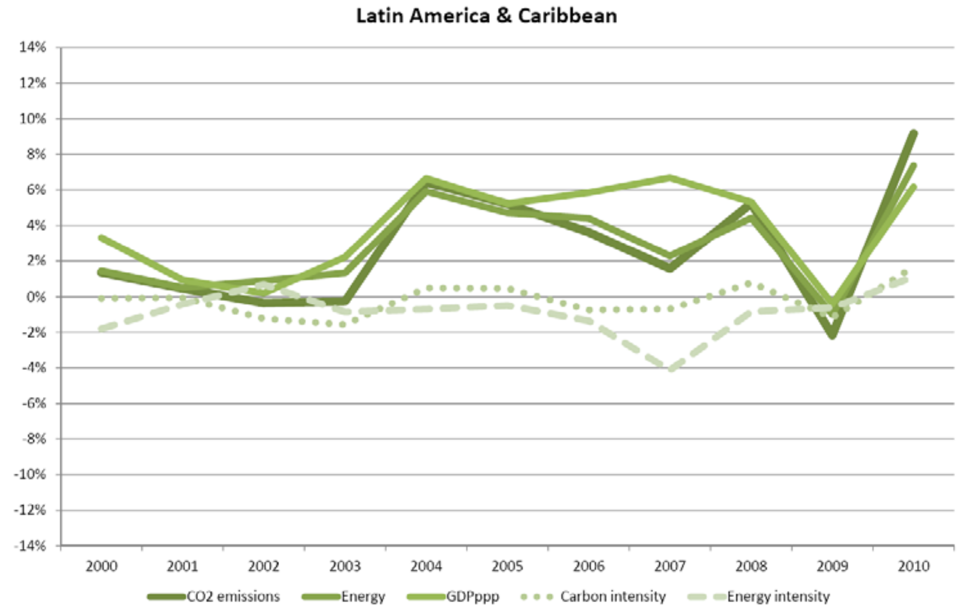
Carbon intensity
Energy intensity


Latin America & Caribbean
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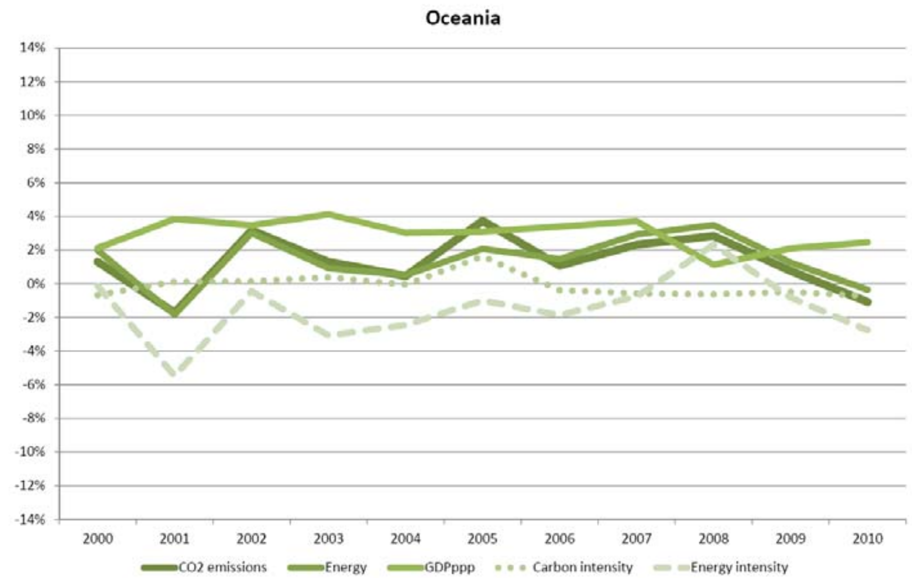
CO2 emissions
Energy
GDPppp
Carbon intensity
Energy intensity


Oceania
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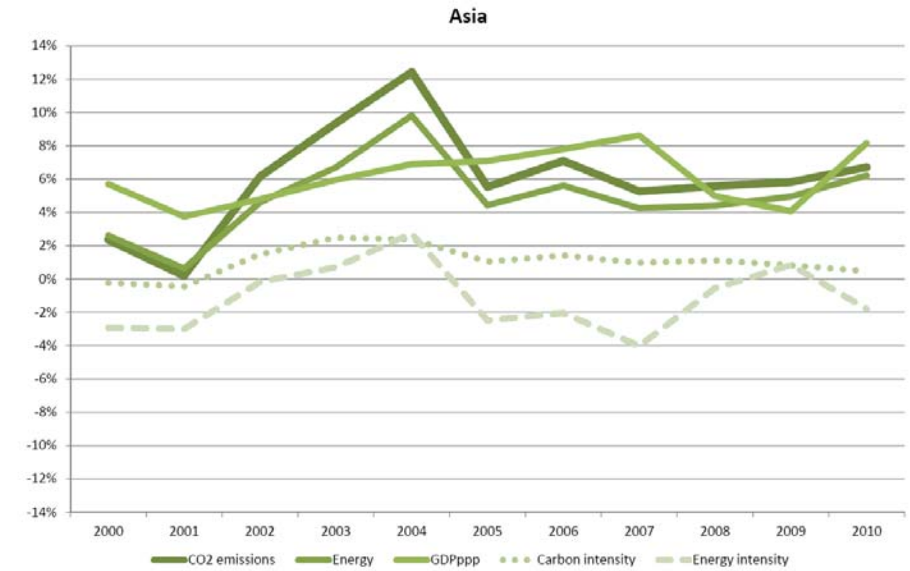
Carbon intensity
Energy intensity


Asia
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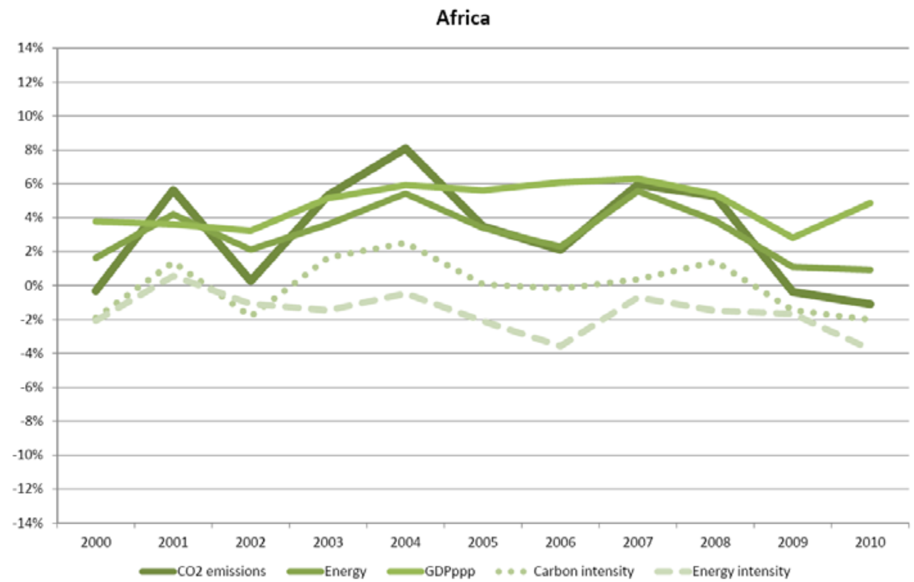
Energy
GDPppp
Carbon intensity
Energy intensity


Africa
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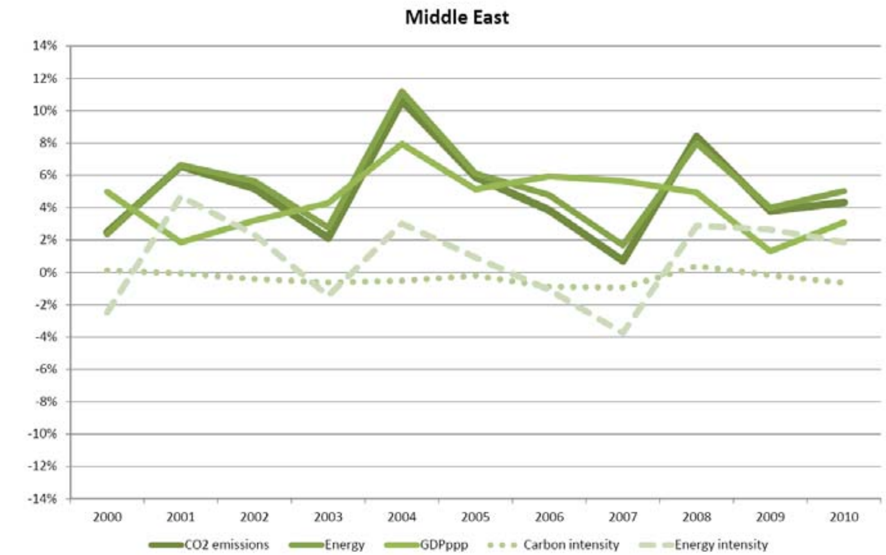
Carbon intensity
Energy intensity


Middle East
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-8%
-10%
-12%
-14%
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2004
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2006
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2008
2009
2010
CO2 emissions
Energy
GDPppp
Carbon intensity
Energy intensity

Table 2: Regional decomposition of Carbon dioxide (CO_2) emission growth (all figures are percentages). CO_2 emissions are from fuel combustion, excluding emissions from marine and aviation bunkers, and measured in millions of tonnes of CO_2. Energy is total primary energy supply measured in tonnes of oil equivalent. GDP is in constant year-2005 in US dollars, adjusted by purchasing power parities.

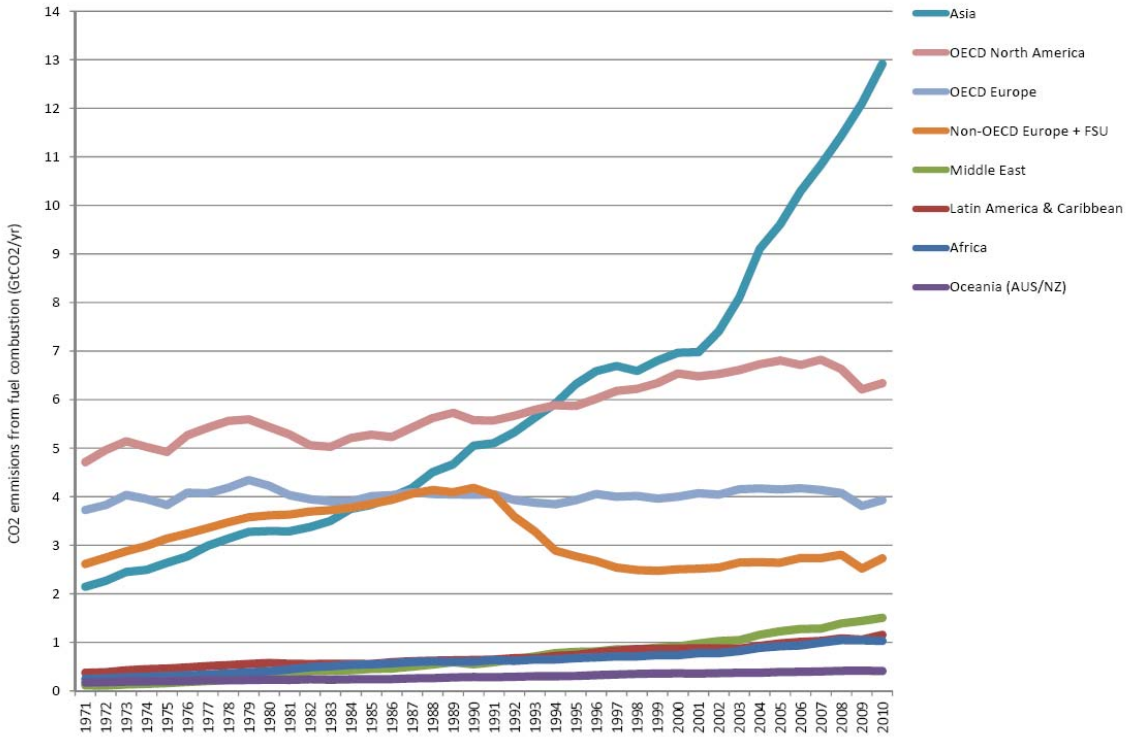
Annual % changes in	Asia	Africa	LATAM	Middle East	Non-OECD Europe & FSU	Oceania	OECD Europe	OECD North America
CO_2 emissions								
2010	6,7	-1.1	9,2	4,3	8,2	-1,1	3,0	2,0
1972-2010 average	4,7	3,8	3,0	7,2	0,2	2,3	0,2	0,8
Decadal averages								
1972-1980	4,9	5,7	5,0	12,3	3,7	3,3	1,5	1,6
1981-1990	4,4	4,1	1,0	6,1	1,5	2,2	-0,4	0,3
1991-2000	3,3	2,0	3,3	5,3	-4,9	2,5	-0,1	1,6
2001-2010	6,4	3,5	2,9	5,1	1,0	1,3	-0,2	-0,3
Energy								
2010	6,2	0,9	7,4	5,0	8,3	-0,4	4,1	2,2
1972-2010 average	4,1	3,3	2,9	7,2	0,8	2,3	1,0	1,1
Decadal averages								
1972-1980	4,3	4,0	4,2	11,5	4,2	3,4	2,1	1,9
1981-1990	3,9	3,5	1,7	6,6	2,2	2,4	0,8	0,7
1991-2000	3,1	2,5	2,8	5,5	-4,1	2,4	0,8	1,8
2001-2010	5,2	3,3	3,1	5,6	1,3	1,3	0,4	-0,1
GDP								
2010	8,2	4,9	6,2	3,1	3,9	2,5	2,5	3,3
1972-2010 averages	5,5	3,4	3,4	3,2	2,0	3,1	2,4	2,9
Decadal average								
1972-1980	5,1	4,0	5,5	7,0	5,2	2,6	3,2	3,6
1981-1990	5,8	2,1	1,3	-1,5	1,5	2,9	2,5	3,1
1991-2000	4,9	2,6	3,1	3,3	-3,7	3,6	2,3	3,4
2001-2010	6,2	4,9	3,9	4,3	5,2	3,0	1,6	1,6
CO_2/energy								
2010	0,5	-2,0	1,7	-0,7	-0,1	-0,7	-1,1	-0,1
1972-2010 average	0,6	0,5	0,1	-0,1	-0,6	0,0	-0,8	-0,3
Decadal averages								
1972-1980	0,6	1,6	0,7	0,7	-0,6	0,0	-0,7	-0,3
1981-1990	0,5	0,5	-0,7	-0,4	-0,7	-0,2	-1,2	-0,5
1991-2000	0,1	-0,5	0,5	-0,1	-0,8	0,1	-0,8	-0,1
2001-2010	1,2	0,2	-0,2	-0,4	-0,4	-0,1	-0,6	-0,2
Energy/GDP								
2010	-1,8	-3,7	1,1	1,9	4,2	-2,8	1,6	-1,1
1972-2010 average	-1,3	0,0	-0,4	4,2	-1,0	-0,7	-1,3	-1,8
Decadal averages								
1972-1980	-0,8	0,1	-1,2	4,4	-0,8	0,7	-1,0	-1,7

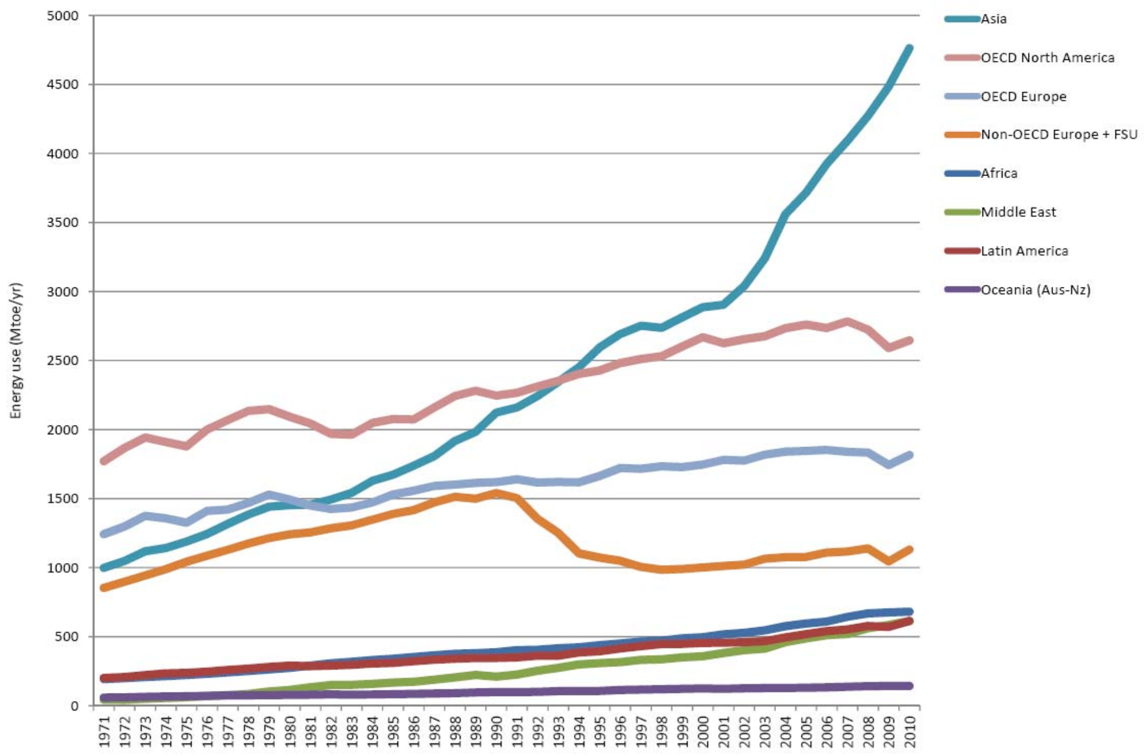
1981-1990	-1,8	1,4	0,5	8,8	0,8	-0,5	-1,6	-2,3
1991-2000	-1,6	0,0	-0,2	2,2	-0,3	-1,1	-1,5	-1,6
2001-2010	-1,0	-1,6	-0,8	1,2	-3,6	-1,6	1,2	-1,7

In OECD Europe the growth rate in energy intensity in 2010 was 1.6%, the highest since 1976. While OECD North America recorded a decrease in carbon and energy intensities in 2010, the recent rates show a slight weakening of relatively strong historical declining trends. In both OECD Europe and OECD North America, the 2010 upward trends in energy intensity as compared to the long term energy trends were likely due to lower fossil-fuel costs (oil prices in 2010 were 75–90 US dollars per barrel, similar to 2007 prices) (International Monetary Found, 2012) and to the extraordinary growth in the construction sector (an energy- and labour-intensive sector targeted by economic recovery packages) (cf. Jotzo *et al.*, 2012). Nevertheless, in both regions, absolute energy intensity values were equal to, or lower than, any year prior to 2007 (Fig.2e). OECD Europe appears to be the single region making consistent progress to decarbonise its energy mix (Fig.2d).

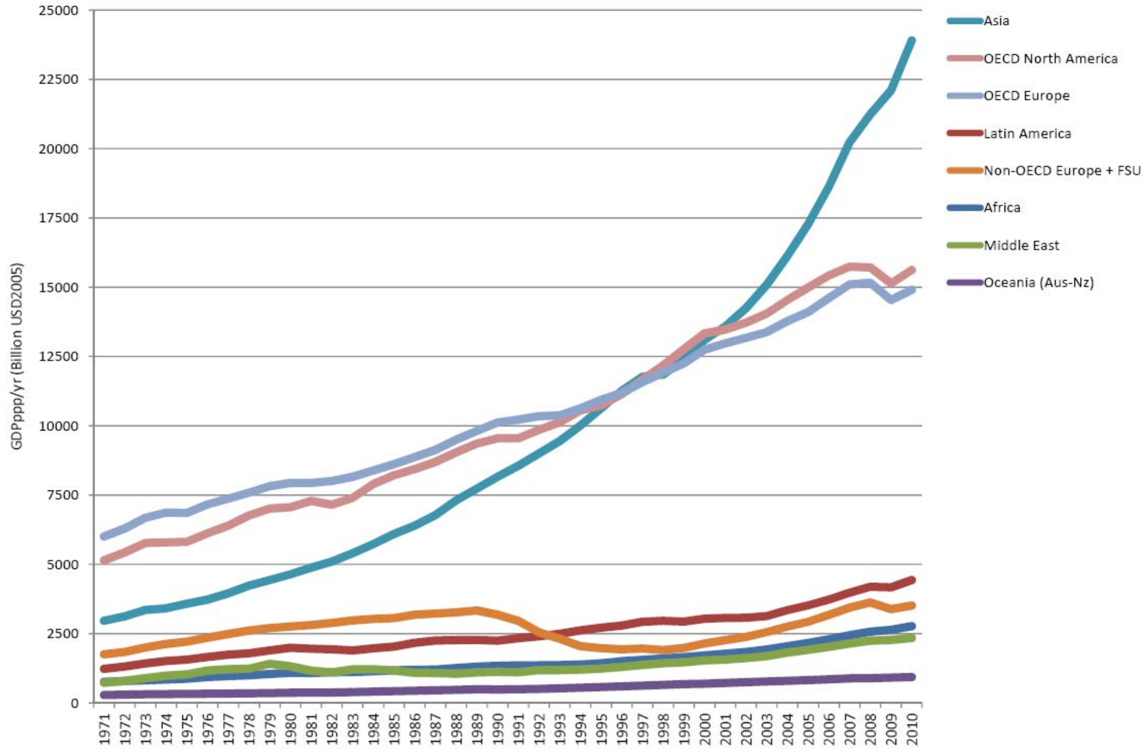
Among the emerging economies, LATAM experienced the highest rebound in emissions in 2010, namely 9.2%. Emissions grew faster than both GDP and energy use, which grew at nearly twice their average historical rates. The consequent increase in carbon and energy intensity confirms the historical lack of progress in energy efficiency and decarbonisation across LATAM (Mundaca, 2013). The CO_2 content of the energy supply mix increased by 1.7%, and was the highest growth rate across all regions. In fact, the estimated absolute value for 2010 is comparable to figures from the early-1970s (Fig.2d).

Figure 2: Historic estimated absolute values per region from 1971 to 2010: (**a**) CO_2 emissions, (**b**) energy use, (**c**) GDP, (**d**) carbon intensity, and **e**) energy intensity. Bunker fuels and emissions are not considered.

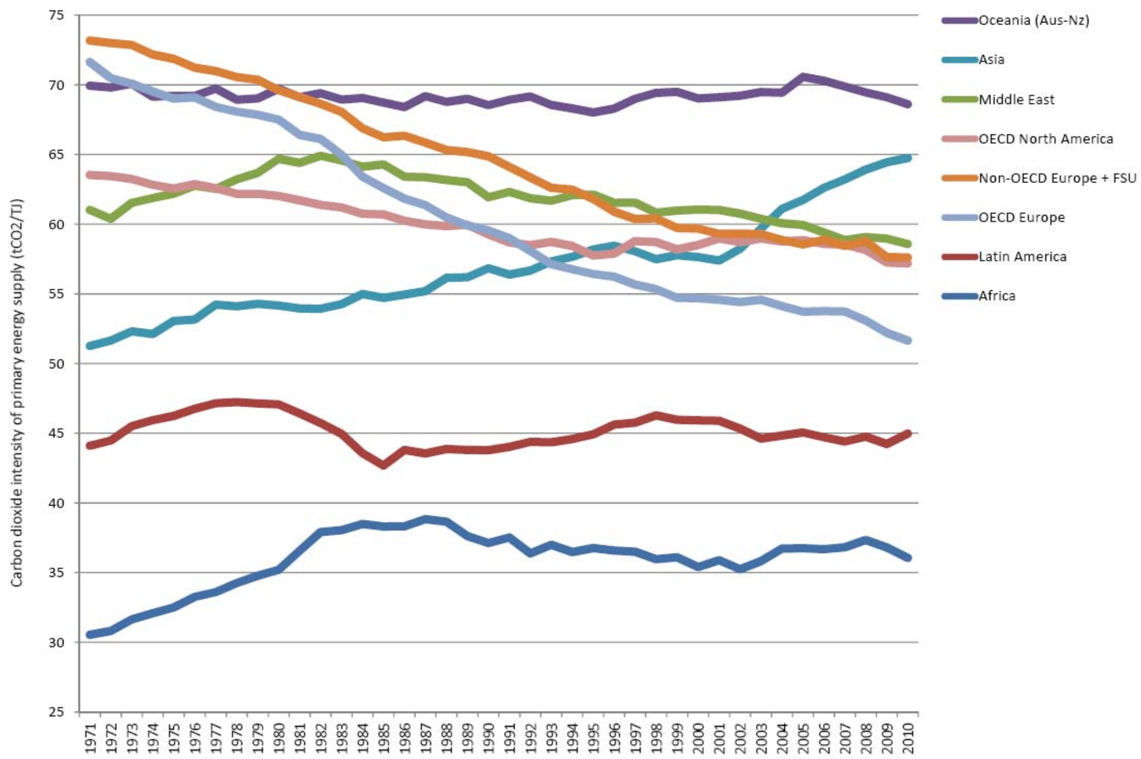


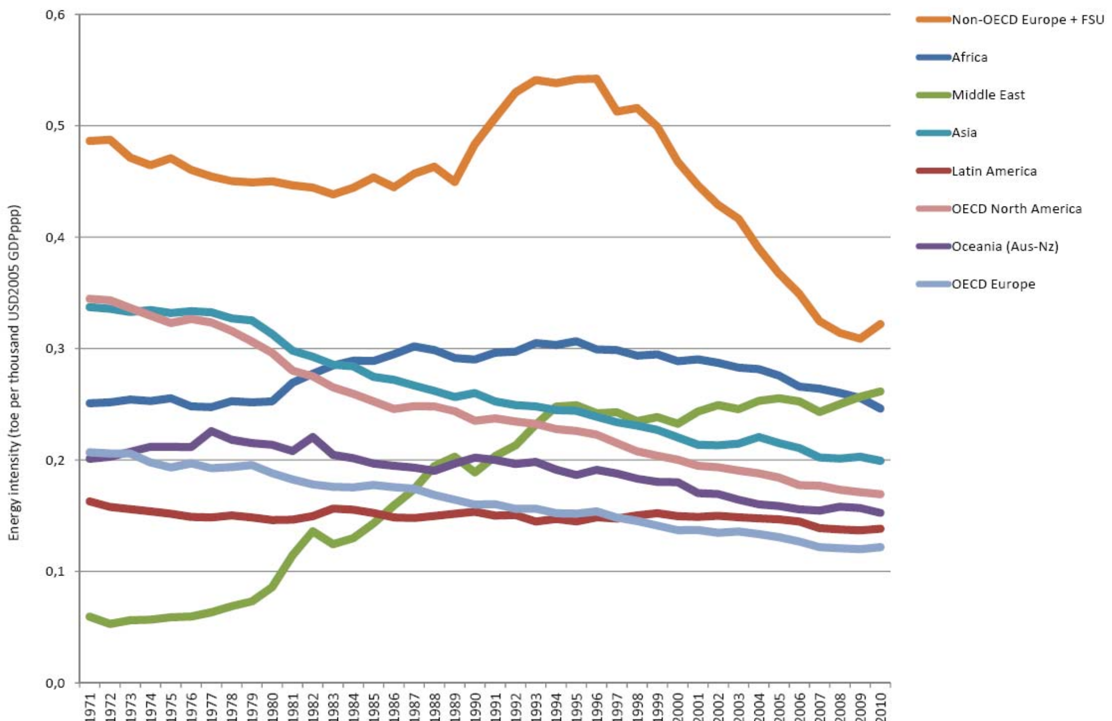


Energy use (Mtoe/yr)
Asia
OECD North America
OECD Europe
Non-OECD Europe + FSU
Africa
Middle East
Latin America
Oceania (Aus-Nz)



GDPppp/yr (Billion USD2005)
Asia
OECD North America
OECD Europe
Latin America
Non-OECD Europe + FSU
Africa
Middle East
Oceania (Aus-Nz)

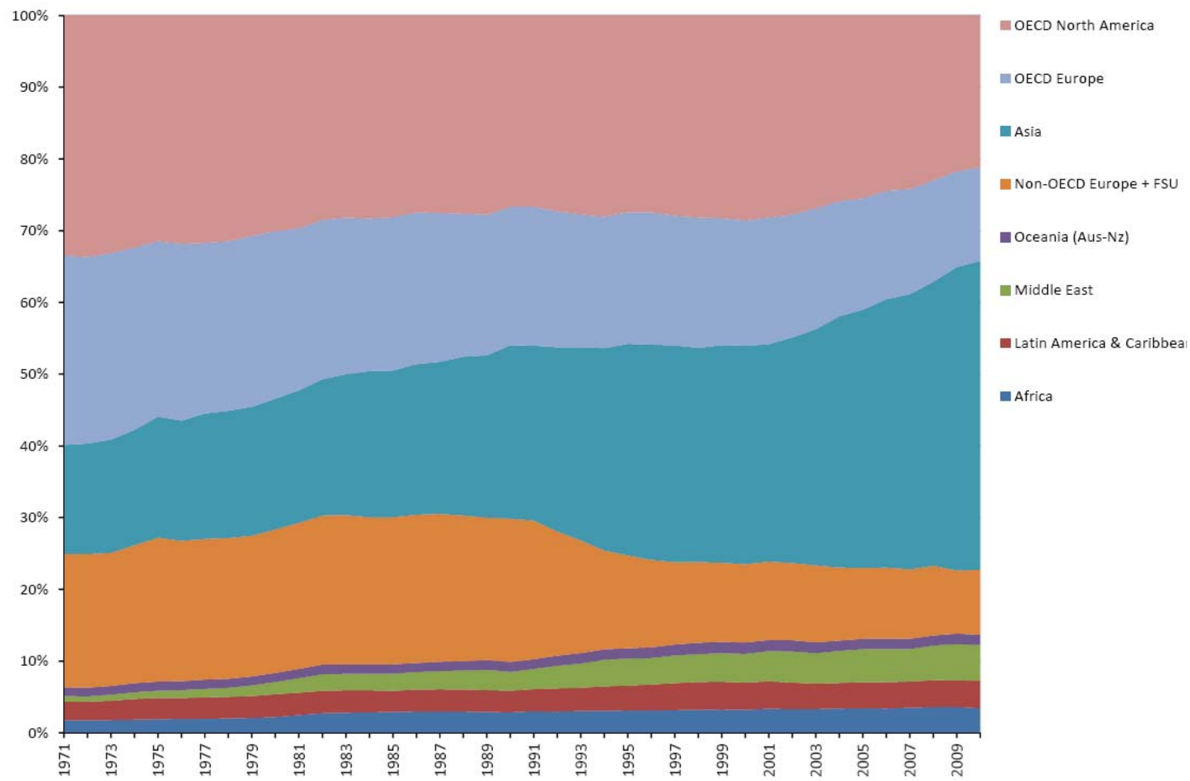




In the non-OECD Europe and FSU region, both the decline and increase in emissions were sharper than in any other region, with a decrease of 10% in 2009, followed by an increase of 8.2% in 2010. This growth in emissions was about twice as high as that of GDP and correlates closely with growth in energy use. Progress for decarbonising the energy mix in the non-OECD Europe and FSU region has slowed down since the mid 1990s. Across the whole of Europe (both OECD and non-OECD countries) a historical decline in energy intensity has not only stopped, but the trend has reversed.

Asia did not experience a significant rebound, but its emissions grew much faster than the historical annual average. The region, which has been the world's dominant CO_2 emitter since the mid-1990s (see Fig 3.), experienced an increase in emissions of 6.7% in 2010, a higher figure than both its historical average of 4.7% yr^{-1} and the growth during the financial crisis, which ranged from 5.6% to 5.8%. In 2010 emissions also grew faster than energy use (6.2% yr^{-1}). Despite the deceleration in economic activity in Asia – from 8.6% GDP growth in 2007 to 4.1% in 2009 – annual growth in energy use remained unchanged, approximately 5% in the period 2008–2009. Thus, whereas energy intensity in 2010 decreased by 1.8%, the improvement was more due to an increase in economic activity (8.2%) than actual reductions in energy use. In addition, Asia did not show any progress in the decarbonisation of its energy supply mix; CO_2 intensity increased by 0.5% in 2010 – a figure comparable to its historical average annual growth rate (0.6% yr^{-1}) (Fig. 2). Absolute figures show a worrying marked upward historical trend (Fig. 2d).

Figure 3: Relative contributions of regions to CO_2 emissions from fuel combustion for the period 1971-2010.



The Middle East showed a much less pronounced carbon rebound in 2010 than other region. However, emissions continued to grow faster than GDP. Although the rebound did not offset 2008–2009 reductions, on average, emissions have grown at 7.1% yr^{-1} since 1972, the highest rate across all regions (Table 2). A similar trend is found for energy use, which correlates closely with emissions growth, indicating essentially no change in the energy supply mix. Additionally, even if energy intensity in 2010 increased more slowly (1.9%) than the historical annual average (4.2%), absolute values show a very disturbing upward trend. In fact, the Middle East region shows the most dramatic increase in energy intensity (by a factor of 5) than any other region in the world historically (approx. 0.5 toe/USGDP in 1971 compared to 2.6 0.5 toe/USGDP in 2010). Possible explanations for these trends include an unchanged oil path dependency (cf. Grubler *et al.*, 2012), promoted by the highest subsidies in the world for fossil fuels (50–80%) (International Energy Agency, 2012b).

In Oceania and Africa, there was a decrease in CO_2 emissions of 1.1% in 2010. This is despite the fact that both regions experienced economic growth, 2.5% and 4.9% respectively. Only these two regions experienced reductions in energy and carbon intensities at the same time. Africa shows consistent reductions in energy intensity since the mid 1990s and is still a relative marginal contributor to CO_2 emissions globally (Fig.3). Although a slight relative decrease in carbon intensity of 0.7% is estimated for Oceania in 2010, the region has not shown any significant progress historically, and its absolute value has been the highest in the world for the past three decades.

4. Concluding remarks

Keeping in mind substantial differences across regions, our estimates show that by the end of 2010 most regions do not seem to show any substantial progress in reducing CO_2 emissions. Whereas specific drivers for certain regions suggest some level of continuous improvement (e.g. decarbonisation of energy mix in OECD Europe; reduced energy intensity in Asia), they are incapable of offsetting the effects of economic growth and increased energy use. Looking at several drivers, most regions reveal a worsening trend lately (e.g. increased energy intensity) or lack of improvement compared to historical rates. Estimates show that economic growth and/or increased energy use were the dominant drivers behind the unparalleled CO_2 emission surge in 2010. Increased energy intensity also played a critical role.

In most regions results appear to confirm that it is a delusion to continue talking about 'decoupling'. That is, a situation in which environmental impacts decline relative to GDP growth. If dangerous climate change is to be avoided, global CO_2 emissions must be reduced and cannot continue to rise forever, even if at a slower rate than GDP. The consequence of decoupling, whether termed relative or absolute, is no coupling at all, which makes no sense. To counteract the environmental impacts of the GDP growth, we can (1) reduce the environmental intensities of our economies, as discussed here, through lowering energy and carbon intensities, and/or (2) reconsider the policies of endlessly promoting economic growth (Nørgård, 2006), even in regions where demand for more production in recent decades have fallen back, and environmental costs are rising. This could leave more 'environmental space' for economic growth in regions where the needs are evident.

With due limitations, results suggest limited (if any) environmental effectiveness regional policy portfolios to encourage a low-carbon economy. Whereas it is too early to judge, and contrary to initial expectations, Africa (and Oceania to a lesser extent) appears to be the only region that showed signs of grabbing the low-carbon economy opportunity. Trends in other parts of the world seem to support earlier concerns about the effectiveness of economic recovery packages (particularly in the United States, the European Union and Asia) to stimulate a green economy and support low-carbon technologies (Barbier, 2010).

At the risk of stating the obvious, our results clearly suggest that highly ambitious policies are needed now, more than ever, if significant progress in reducing CO_2 emissions is to be made. If we are to align production and consumption patterns with maintaining global warming below the 2°C threshold, meaningful progress in increasing energy efficiency and decarbonising energy systems is still very much needed across all regions (cf. Luderer et al., 2012; Ürge-Vorsatz & Metz, 2009). However, radical absolute reductions in fossil fuel-based energy use and CO_2 emissions are particularly urgently required in rich regions. This is critical if there is to be economic growth in the less-developed regions of a world where carbon constraints and other ecological limitations pose a serious challenge. Unfortunately historical trends, policy commitments, and current carbon reduction pledges show that there is still a 20% probability of going beyond a 4°C rise by 2100 (The World Bank, 2012).

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Annex 1: Definition of regions

Region	Geographical coverage
Africa	Algeria, Angola, Benin, Botswana, Cameroon, Congo, Dem. Rep. of Congo, Côte d'Ivoire, Egypt, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Libya, Morocco, Mozambique, Namibia, Nigeria, Senegal, South Africa, Sudan, United Rep. of Tanzania, Togo, Tunisia, Zambia, Zimbabwe, other Africa
Asia	Bangladesh, Brunei, Cambodia, Hong Kong (China), India, Indonesia, Israel, Japan, DPR of Korea, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, People's Rep. of China, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, Vietnam, other Asia
Latin America and the Caribbean	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela, other Americas
Middle East	Bahrain, Islamic Rep. of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen
Non-OECD Europe and FSU	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Georgia, Gibraltar, Kazakhstan, Kosovo, Kyrgyzstan, Latvia, Lithuania, FYR of Macedonia, Malta, Republic of Moldova, Montenegro, Romania, Russian Federation, Serbia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, USSR (former), Yugoslavia (former)
Oceania	Australia, New Zealand
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
OECD North America	Canada, Mexico, United States