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Abstract

Various policy instruments and policy reforms are being implemented to encourage Green Growth and Green Economy. However, comprehensive ex-post evaluation policy methods have yet to be developed. The emerging literature shows that there is substantial ambiguity and discrepancy about how to measure the performance of policy instruments driving a Green Economy in general and, in our case, a Green Energy Economy (GEE) in particular. Observed methodologies have tended to measure progress according to expenditure on green initiatives as a proportion of GDP. This paper aims to move beyond this by applying an approach that gives consideration to policy and economy-wide aspects that drive, or have an impact on, energy production and carbon emissions. The core methodology is based on a macro decomposition analysis using an empirical quantitative approach. It is supported by correlation and regression analyses and framed by both policy-oriented research and policy evaluation. To achieve this, time-series data from the International Energy Agency are used. The analysis is applied to three countries, Sweden, the UK and China. Then, the proposed methodology is preliminarily assessed against the following criteria: (1) policy compatibility, (2) reliability and (3) measurability. The focus is on carbon dioxide (CO_2) emissions.

Introduction

Green economic growth has become a topic of increasing policy attention. This is mostly because the traditional economic growth model has created significant losses of natural capital, produced disturbances in our climatic system, triggered social inequalities and even proven to be economically unstable (e.g. Jackson, 2009). The recent global financial and economic crisis – the worst in decades – has encouraged numerous pledges for new ways to reform the economy towards a path that is much less damaging to society, the environment and the economic system itself (OECD 2010). As a result, economic recovery packages have been implemented to stimulate green economic growth and support low-carbon economies, among several other policy objectives (Barbier 2010b). Economic stimulus packages have been portrayed as a golden opportunity and entry point into what we would call a 'Green Energy Economy' (GEE), with the energy sector playing a vital role (IEA 2009a).

Broadly speaking, a New Green Economy (NGE) can be defined as a system that pursues growth by bringing together economic, environmental, social, and technological aspects through the expansion of clean energy production, distribution and consumption. Within this dimension, a GEE is expected to increase resource efficiency, create jobs, promote successful businesses, and bring about attractive investment opportunities, while at the same time reducing GHG emissions and maintaining or improving natural capital (cf. Huberty et al. 2011). In our case, we define GEE as follows:

"Green Energy Economics (GEE) is understood as the scientific subject area that focuses on how the economic system can pursue growth by bringing together economic, environmental, social, and technological aspects through the expansion of clean energy production, distribution and consumption.

In more specific terms, and taking into account the normative aspects of NGE, a GEE covers and analyses the linkages between resource efficiency, job creation, clean energy investments, mitigation of climate change, and natural capital."

The emerging literature shows, however, that there is substantial ambiguity or discrepancy about how to measure the performance of policy instruments driving a Green Economy in general, and GEE in particular. Identified approaches cover a spectrum from narrow concerns about job creation or growth of patents on the one hand (Pew Charitable Trusts 2009), to larger aspects of sustainable development on the other (OECD 2010). The identified evaluation approaches tend to overlook policy instruments altogether, or focus at best on measuring the scale of 'supply-driven' policies based on public and private expenditures. For instance, one over-simplified metric that has been observed involves measuring progress according to expenditure on green initiatives as a proportion of GDP (Barbier 2010a). This approach measures the level of investment resulting from the 'Global Green New Deal' which, while informative in its own right, fails to address the effectiveness of such investments. Not surprisingly, the emerging literature on green economic growth is calling for the development of new accounting and evaluation frameworks (OECD 2010).

Against this brief background, the objective of our paper is to propose, apply, and assess (preliminarily) a macro decomposition ex-post policy evaluation framework to quantitatively measure progress (or lack of progress) towards a GEE. The evaluation framework is composed by the following elements: 1) correlation and regression analyses, 2) carbon and energy intensity indicators, and 3) identification and analysis of policy instruments. Details about each method are given in the next section. The scope of our research is limited to the topical aspect of CO_2 emissions, a rather critical environmental component of NGE in general (cf. Barbier 2010b; Huberty et al. 2011; IEA 2009a), and within the GEE in particular (cf. Pew Charitable Trusts 2009). The proposed framework aims at evaluating the effectiveness of energy and climate policy instruments that target low-carbon energy technologies. We assess both the results and the proposed evaluation framework. The latter is evaluated against the following criteria: (1) policy compatibility, (2) reliability, and (3) measurability.

Proposed evaluation approach

The proposed methodology is based on a top-down decomposition analysis using an empirical quantitative approach. It is framed by both policy-oriented research and policy evaluation. Policy-oriented research aims to solve societal problems through improved public policies (Fischer 1995). Its focus is on actionable factors or variables, either complementing theoretical constructs or taking preference over them (Hakim 2000). Policy evaluation is herein understood as an applied social science dealing with multiple methods of investigation that support and assist policy-making in solving public problems. Based on this selected approach, the following specific methodological steps are undertaken.

First, we apply correlation and regression analyses. Building upon the I=PAT equation (Ehrlich and Holdren 1971 - details below), correlation tests are carried out. Using the best available time series data (1971-2007), provided by the International Energy Agency (2009b), this step assesses the relative degree of association (or "closeness") between each pair of the following variables: CO_2 emissions, Gross Domestic Product (GDP), population (POP) and energy intensity (E_int). The latter is understood as the total primary energy units needed to produce one unit of GDP. E_int is often used as a measure or aggregate proxy of the energy efficiency or technology level of a country's economy (Goldemberg and Johansson 2004).

Secondly, and due to the fact that independent variables can be highly correlated (i.e. signs of multicollinearity) the next step is to compute the partial correlations. This is necessary as in this situation more than one variable can convey essentially the same information, which prevents any inference from

being drawn about the relative contribution of a particular predictor or independent variable. The partial correlation tests aim at measuring the degree of association between the dependent variable (CO_2) and each of the independent variables (*POP, GDP, E_int*).

Thirdly, stepwise and multiple regression analyses are carried out in order to further investigate the statistical relationship between the above-mentioned variables. For this purpose, an initial model, which builds upon the I=PAT equation, is used and defined as:

$$CO2 = f(POP, GDP, E\_int)$$

where CO_2 emissions (dependent variable) are a function of the independent variables *POP*, *GDP* and *E_int*. The I=PAT equation is used to assess the contribution of population (P), affluence or level of consumption (A) and technology (T) to environmental impacts (I). The latter can be expressed in terms of resource depletion or other unwanted environmental impacts[1]. Here, *I* takes the form of *CO_2* emissions, affluence the form of *GDP*, and T the form of *E_int*. P remains unchanged. The objectives of the regression analyses were twofold: 1) to quantify the impact of various simultaneous influences upon *CO_2* emission levels and 2) to test the hypothesis that *GDP* has the strongest impact on *CO_2* emissions. The stepwise multiple regression analysis sequentially assesses the unique value of the independent variables on *CO_2* emissions. If adding a variable contributed to the model, then the variable is retained, while all the other variables in the model are re-tested to identify whether they are still significant contributors. In the case where the variables no longer contributed significantly to the model, they are removed. All interval estimations use a 95% confidence level ($\alpha = 5\%$)

Fourthly, various energy-economy-carbon indicators are estimated. These are taken from the 'Kaya Identity', which is a decomposition formula for energy-economy-environment policy analysis (Kaya 1990). Note that the 'Kaya Identify' builds upon the I=PAT equation and has been used by a number of studies that have addressed energy, economy and climate-related intensities at the global level (Metz et al. 2007). It has also been used to analyse major economies[2]. The formula entails a set of energy, economic, and demographic indicators that quantitatively estimate CO2 emission levels. In our case, the following indicators are estimated for the UK, Sweden and China:

- Energy intensity (*E_int*) = Total Primary Energy Supply (*TPES*) per unit of GDP
- Carbon intensity (*C_int*) = CO_2 emissions per unit of *TPES*
- Emission intensity (*Em_int*) = CO_2 emissions per unit of *GDP*

Indicators are estimated using the IEA time series data. It should be noted that the data related to CO_2 emissions used for this study only relates to fuel combustion and excludes emissions from biomass. Time series data from the IEA is used (1990-2007). Regarding the baseline, the year 1990 was taken as index – in line with the baseline year for the Kyoto Protocol.

Fifthly, we identify and analyse policy instruments (and structural aspects) explaining the behaviour of the quantitative findings. The purpose is to have a better understanding of aggregated determinants of a GEE, including related trade-offs and national/regional policy conditions. To that end, an extensive literature review is carried out to identify explicit policy instruments addressing energy and

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1 For more details see Ehrlich and Holdren (1971) and Holdren and Ehrlich (1974).
2 Wilhite and Norgard (2004) addressed decoupling and focused on India and China. Liddle (2009) analysed decoupling trends (aggregate and sectoral) but only for IEA/OECD countries. Shorrock and Utley (2006) examined intensity trends for residential energy use in Great Britain.

CO$_2$ emissions. Documentation from corresponding national energy agencies, ministries of environment, ministries of energy, peer reviewed articles and press articles are examined.

Key findings

Correlation test statistics

A priori, results from correlation analyses were consistent with the I=PAT equation.[3] This indicates that in principle all independent variables have the potential to individually explain the behaviour of CO$_2$ emissions. Correlations between *CO$_2$* and all variables are statistically significant; with all *p*-values below 0.05. For Sweden and the UK, *E_int* has the strongest correlation (97.3% and 84.5% respectively). For China, *GDP* is the variable with the strongest correlation (97.8%). However, the fact that independent variables are also highly correlated (e.g. *POP* and *GDP* in the case of SWEDEN; or *POP* and *E_int* in the case of China) indicates multicollinearity. That is, independent variables measure essentially the same variance of the dependent variable (i.e. CO$_2$ emissions). These findings strongly suggest that further analysis is needed before drawing any inference about the relative contribution of each predictor variable.

To address the correlation among independent variables, partial correlation tests were applied to measure the degree of association between *CO$_2$* and each independent variable (e.g. *GDP*), while the effect of the remaining variables (e.g. *POP* and *E_int*) was controlled. For Sweden, results confirmed the initial hypothesis that *E_int* has the most significant correlation (96.7%) with CO$_2$ emissions. When controlling *GDP* and *POP*, the correlation between *CO$_2$* and *E_int* dropped less than 1% compared to the previous correlation test. On the one hand, this suggests that the relationship between *CO$_2$* and *E_int* is marginally mediated by *POP* and/or *GDP*. On the other hand, the fact that partial correlation tests revealed a relatively substantial drop (in the proximity of 30% to 60%) for *POP* and *GDP* suggests that the relationship between *CO$_2$*, *POP* and *GDP* was largely mediated by *E_int*. Note that *GDP* is not a significant variable: p-value is 0.248; above the 0.05 threshold (5% level).

Regarding the UK, results also confirmed the initial hypothesis that *E_int* has the most significant correlation (83.1%) with *CO$_2$* emissions. The correlation between *CO$_2$* and *E_int* dropped by 1.5% when controlling *GDP* and *POP*. On the one hand, this suggests that the relationship between *CO$_2$* and *E_int* is, again, marginally mediated by *POP* and/or *GDP*. On the other hand, the fact that partial correlation tests revealed an important relative drop (in the proximity of 10% to 20%) for *POP* and *GDP* suggests that the relationship between *CO$_2$*, *POP* and *GDP* has been mediated to some extent by *E_int*.

For China, results are slightly different. Results rejected the initial hypothesis that *E_int* has the most significant correlation with *CO$_2$* emissions. Part correlation tests confirmed that *GDP* has been the strongest independent variable driving *CO$_2$* emissions (87.9%) compared to *POP* and *E_int*. It accounted a 10% drop compared to the simple correlation tests. In this case, it suggests that the relationship between *CO$_2$* and *GDP* has been marginally mediated by *POP*. In fact, the correlation between *CO$_2$* and *POP* dropped substantially: from 90.9% to 36.4% when controlling the other variables. Unlike the other countries, note that *E_int* is not a significant variable: p-value is 0.188; above the 0.05 threshold ($\alpha = 5\%$ level).

Regression analyses

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[3] Note that due to length restrictions for IEPEC conference papers (max. 12 pages), we are unable to provide tables with simple and partial correlation results.

To further assess the importance of each variable in more detail, a stepwise regression analysis was undertaken for each country dataset. This sequentially assessed the unique value of the independent variables on the behaviour of CO_2 emissions. Results for the three countries are summarised in Table 1.

Table 1: Summary results from stepwise regressions

	Sweden	UK	China
n	37	37	37
Mean			
CO_2	62.473	555.122	2434.732
PoP	8.565	57.542	1113.026
GDP	198.589	1193.950	2953.225
E_int	0.341	0.187	0.485
Standardised coefficients			
PoP	0.364	-1.624	0.199
GDP	-	3.312	0.802
E_int	1.297	2.526	-
p-value			
PoP	0.000	0.008	0.006
GDP	-	0.000	0.000
E_int	0.000	0.000	-
Adjusted R^2	0.974	0.853	0.964
Std Error Estimate	1.922	12.650	253.759
Collinearity statistics			
PoP	-	0.01	0.21
GDP	0.21	0.00	0.21
E_int	0.21	0.04	-

For Sweden, results confirmed the partial correlations test. The stepwise regression analysis showed that *GDP* is not longer a significant variable and it was dismissed in the analysis altogether. In turn, *E_int* and *POP* can collectively explain up to 97.4% of the variability of CO_2 emissions in the emerging new model. *E_int* has had the strongest impact on CO_2 emissions. The coefficient of variation of the estimated regression model (*Coef_Var*$_{reg}$= Std. error estimate (1.92)/average value CO_2 emissions (62.47 $MtCO_2$)) yielded a value of 3.1% which suggests that the estimated stepwise model would be useful in predicting CO_2 emission interval values (as the ratio is lower than 10%). Collinearity statistics were estimated in order to identify correlation among independent variables, with estimated tolerance values for the independent variables equal to 0.21. This figure is higher than the defined 0.1 minimum threshold value. This means that results suggested no lack of reliability regarding individual predictors.

Regarding the UK, results showed that all variables are statistically significant. They can collectively explain up to 85.3% of the variability of CO_2 emissions in the model. In principle, as suggested by the partial correlations tests, *E_int* has had the strongest impact on CO_2 emissions. However, collinearity statistics were estimated in order to identify correlation among independent variables. In this case, statistical tests revealed signs of multicollinearity, with estimated tolerance values for the independent variables much lower than the defined 0.1 minimum threshold figure. Whereas this does not

reduce the (predictive) reliability of the model, it does suggest that the model does not give any conclusive results about any individual predictor, or about which independent variables are redundant with respect to others for the case of the UK. The coefficient of variation of the estimated regression model ($Coef\_Var_{reg}$) yielded a value of 2.3% which suggests that the estimated model resulting from the stepwise analysis would be useful in predicting CO_2 emission interval values (as ratio is lower than 10%).

When it comes to China, results confirmed to a certain extent the results from the partial correlations test. The stepwise regression analysis showed that E_int is not longer a significant variable and it was dismissed from the analysis altogether. In turn, GDP and POP can collectively explain up to 96.4% of the variability of CO_2 emissions in the emerging new model. Standardised coefficients show that GDP has the strongest impact on CO_2 emissions. The coefficient of variation of the estimated regression model yielded a value of 10.4%, which suggests that the estimated stepwise model may be useful in predicting CO_2 emission interval values (as ratio is slightly higher than the 10% threshold). Again, collinearity statistics were estimated in order to identify correlation among independent variables. Statistical tests revealed no signs of multicollinearity.

Estimated indicators

For each country under analysis, three intensity indicators were estimated: energy intensity (*TPES/GDP*), carbon intensity (*CO₂/TPES*) and emission intensity (*CO₂/GDP*). Key findings are summarised below.
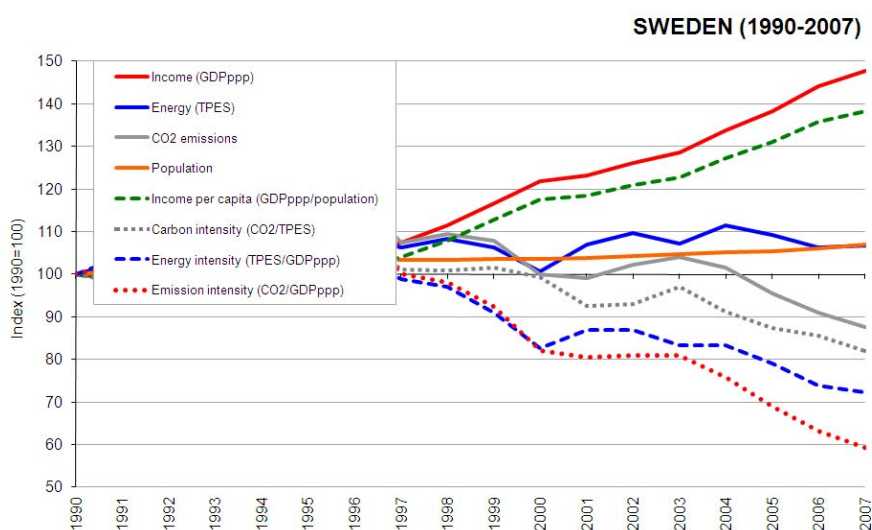

Figure 1: Estimated indicators for SWEDEN

For Sweden (Figure 1), estimated energy intensity provided a strong indication of increased industrialisation and greater efficiency of its energy-economy system against baseline values. Figures show a marked "decoupling" trend, that is, a situation in which resource or environmental impacts decline relative to economic growth. Energy intensity improvements have been driven by increased economic activity and also by a relative slow growth of energy use. That is, despite continuous economic growth relative to 1990, growth in energy use has been kept at the same level (8% in average approx.) or reduced (compared to previous years) during certain periods (e.g. 2004-2006). Major reductions in energy intensity were achieved in 2000 (18%) and late 2007 (28%). No absolute reductions in energy use can be identified. However, one can observe a relatively sustained reduction in energy intensity for the

period under analysis. Sweden's carbon intensity does not reflect a fossil fuel path dependency in the evolution of its energy-economy system. Thanks to the rapid expansion of commercial bio-energy for transport, electricity and district heating —among other aspects— one can observe a relatively sustained decarbonisation of its energy supply mix after 2000, with improvements in the proximity of 20% by the end of 2007 compared to 1990. In fact, one can also observe absolute reductions of CO_2 emissions after 2004, with an overall improvement of more than 10% by 2007 compared to 1990. In terms of emission intensity, estimated indicators show consistent improvements after the mid-1990s. A decrease in emission intensity was more due to reduced energy intensity than reduced carbon intensity though. In turn, results showed that until early 2000, improvement in emission intensity can be attributed mostly to increases in economic activity and not necessarily to the decarbonisation of the energy mix. However, after 2003, the importance of both growing economic activity and absolute reductions of CO_2 emissions greatly contributed to substantial improvements in emission intensity: 40% by the end of 2007 compared to 1990.
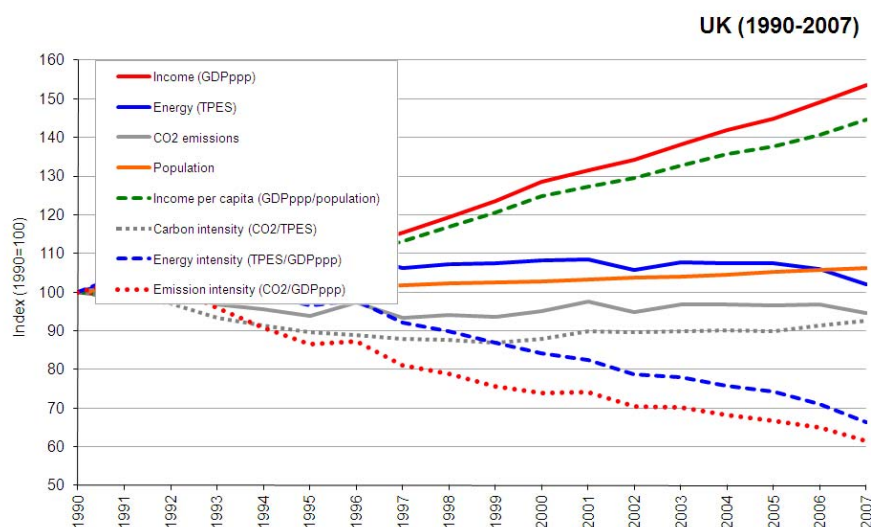

Figure 2: Estimated indicators for the UK

Regarding the UK (see Figure 2), estimated energy intensity showed a more marked downward pattern than Sweden. As suggested by (partial) correlation analyses, strong signs of "decoupling" can be observed. Whereas energy use increased by 8% (average) throughout the entire period of analysis, economic activity increased by 150%. Therefore, energy use declined relative to economic growth, leading to energy intensity improvements of more than 30% in by the end of 2007. As far as carbon intensity is concerned, it is first important to note that absolute reductions in CO_2 emissions (ca. 5% decrease in average) are observed for most of the period under analysis. However, estimated carbon intensity suggests structural issues behind the decarbonisation of the energy mix. Whereas carbon intensity fell during the 1990s (13%), it levelled off soon after and started approaching baseline values by the end of 2007. In fact, and contrary to the case of Sweden, CO_2 emissions levels are much more dependent on energy use and followed a similar pattern. In terms of emission intensity, estimated indicators show consistent improvements for the entire period. Before 1999, interestingly, improvements in emission intensity (20% approx.) can be mostly attributed to a reduction in carbon intensity rather than energy intensity. After 1999, and like in the case of Sweden, a decrease in emission intensity (38% approx. by the end of 2007) can be mostly attributed to reduced energy intensity and not to reduce carbon intensity. At all events, overall improvements in emission intensity can be mostly related to increases in economic activity and not to the decarbonisation of the energy mix or absolute reductions in energy use.
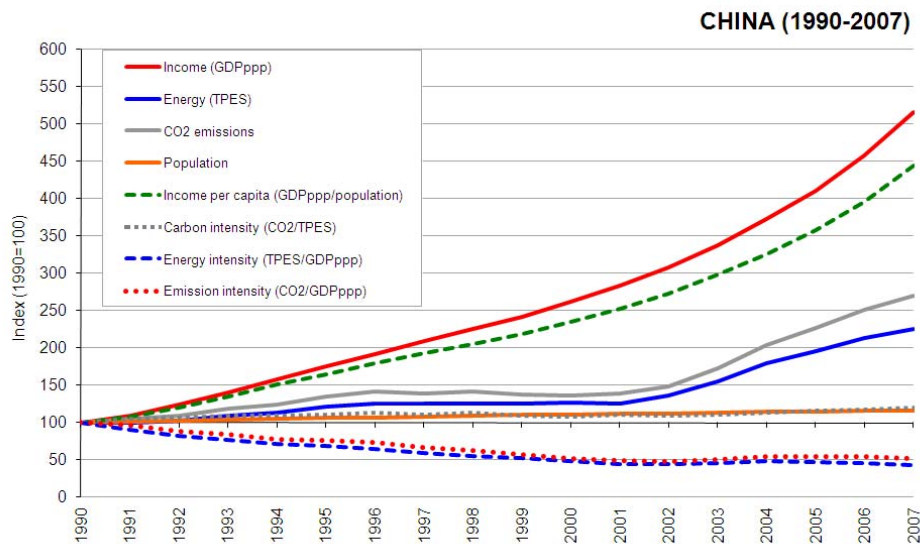
Figure 3: Estimated indicators for CHINA

When it comes to China, (see Figure 3), estimated indicators confirmed the very strong influence of high economic activity during the last decades. Estimated energy intensity showed a much stronger downward pattern than Sweden and the UK. As strongly suggested by (partial) correlation analyses, very strong signs of "decoupling" can be attributed to very high economic growth, which increased by a factor of 5 by 2007 compared to 1990. During the same period energy use grew at a slower rate: by less than a factor of 2 during the same period. Thus, and despite very high growth of energy use, energy intensity improvements reached a 50% level by 2007. Unlike Sweden and the UK, however, carbon intensity showed no sign of improvements. The growth of CO_2 emissions was higher than energy use throughout the entire period (and even higher after 2002). Thus, the estimated indicator strongly suggested no sign of decarbonisation of the energy mix. In fact, results showed a higher degree of fossil fuel dependence in the energy supply mix compared to baseline values (25% approx.). Regarding emission intensity, results stressed the importance of economic growth to the resulting improvements. The data showed a regular trend and results clearly revealed that the decrease in emission intensity was more due to reduced energy intensity than reduced carbon intensity. In other words, empirical results show that relative improvements in emission intensity can be attributed mostly to increases in economic activity and not to the decarbonisation of the energy mix.

Identified policy packages

Sweden introduced its Green Electricity certificate scheme in 2003 and it is intended to run until 2035. The scheme appears to have been successful so far in achieving its targets, so much so that the programme was revised in 2007 and again in 2010 with the setting of more ambitious targets (Ministry of Sustainable Development, 2006; Swedish Energy Agency, 2011a). In the period 2002-2010 there was an increase of 11.6 TWh in electricity from renewable sources eligible for certification (Swedish Energy Agency, 2012). This policy specifically targets carbon intensity, in that it seeks to reduce the emissions associated with a production input (in this case electricity), without adversely affecting output. Thus, a successful project would have delivered less units of CO_2 per unit of production (that is, carbon intensity). Moreover, the certificate scheme is designed to be technology neutral so it attempts to employ the most cost-effective means of renewable energy production – the idea is that income will continue to rise, but a decoupling effect will occur and CO_2 emissions will decline relative to economic growth (Plumb and Zamfir 2009). The indicators have matched the aims of this goal– since 2003 (when the scheme was announced) CO_2 emission intensity has continuously fallen while income has risen.

The Swedish Programme for Energy Efficiency Improvements (PFE) was launched in 2004. This is an energy efficiency policy directed to "energy intensive industries", whereby they are encouraged to bring in energy efficiency measures in return for exemption from certain energy taxes (these measures include auditing and analysis of energy use, investment in profitable efficiency improvements and so on). PFE is widely regarded as being a successful scheme to date – estimates of the energy savings vary from 689GWh and 1450GWh annually, depending on the methodology applied (Stenqvist & Nilsson, 2011; Swedish Energy Agency, 2011b). Whereas the green certificate scheme was aimed at carbon intensity, PFE is more relevant to the energy intensity indicator. Its success depends on significant energy users reducing their energy use in such a way that their productivity is not significantly affected, thus decreasing their energy use per unit of production (that is, energy intensity). As with the green certificate scheme, the trends we have observed in our estimated indicators closely match the aims of the programme – energy intensity has decreased continuously since the programme's launch in 2004.

A third programme of interest is the BELOK scheme, introduced in 2001. This programme is aimed at bringing energy efficiency innovations to market through public procurement, demonstrations, evaluations and so on (Nilsson, 2006). As, ultimately, an energy efficiency scheme, the success of BELOK would be indicated by a decrease in energy intensity. Energy intensity has fallen overall since 2001, although this decline did not start until 2002. Logically, one would expect this trend from a successful programme of this nature - as an exercise in bringing products to market, it would not be expected to bring in efficiency savings immediately, since there would be a delay before such products would be available and utilized.

When it comes to the UK, the Energy Efficiency Commitment (EEC) was a tradable white certificate scheme targeted at gas and electricity suppliers in Great Britain. It operated from 2002 until 2008, when it was replaced with the Carbon Emissions Reductions Target (CERT) which widened the scope of the project beyond energy efficiency to include renewable energy projects (International Energy Agency, 2011). Both policies obliged providers to achieve certain energy saving targets in the residential sector, or else purchase certificates to make up the shortfall (Lees, 2006). The first EEC programme, for instance, delivered 98% of its targeted energy savings, however, the level of ambition of the target (0.6% of annual household energy consumption, raises the question of whether high energy-saving effectiveness was met at the expense of soft targets (Mundaca & Neij, 2009). In addition, one has to consider that there was already a pattern of decreasing energy efficiency prior to 2002, so EEC and CERT are likely not the sole significant contributors to this trend. It may be that the reduced energy intensity is due more too structural and economic factors rather than environmental policies. From the late 1970s through to the early 1990s, Great Britain underwent a deindustrialization process (Baddeley, 2008). The shift from energy intense heavy industries to computerized and financial activities in the tertiary sector could partially explain the decline in energy intensity throughout 1990s.

The Renewable Energy Certificate (ROC) scheme was also implemented in 2002. It is a tradable green certificate scheme and is the primary domestic policy instrument for promoting large scale renewable energy in the UK (Energy - Department of Climate Change 2012). The literature indicates that this scheme has brought about increase in renewable energy production but that more effective methods may be available (Held, Ragwitz, & Haas, 2006; Toke, 2005). Nevertheless, the ROC scheme has been supported by successive governments and has been extended until 2037 (Energy - Department of Climate Change 2012).

Prior to the introduction of the ROC scheme, the government incentive programme for renewables was called the Non-Fossil Fuel Obligation (NFFO). This policy was largely seen as ineffective in creating renewable energy sources (Mitchell & Connor, 2004; Smith & Watson, 2002). The perceived ineffectiveness of NFFO in comparison to ROC is not reflected in our energy indicators – carbon intensity decreased overall when NFFO was in place (1990-2002) and increased when ECC came

into operation (2002-2007).

Regarding China, the energy intensity indicator shows an overall improvement throughout the observed period. However, despite the huge rises in GDP and energy use, the decrease in energy intensity has been less than in the two European countries we have looked at, relative to their baselines. In absolute terms, a 2011 study estimated Chinese energy intensity to be 2.4 times the global average (Zhao, Zuo, Fan, & Zillante, 2011). The most interesting aspect of the energy intensity trend is perhaps that it remained constant from 2001 onwards. Zhou et al. (2010) attribute this pattern to the ineffectiveness of energy efficiency policies from 2000 onwards. Their thesis is that energy efficiency was tightly monitored from 1980 to around 2000, but at that time policies expired or were ignored, and thus the increase in energy demand was not tempered by adequate policy measures (Zhou, Levine, & Price, 2010). This hypothesis fits with the energy intensity indicator, which shows a decrease from 1990 until 2001, with a levelling off thereafter.

Throughout the 1990s and early 2000s there were many individual policies tackling efficiency and productivity in numerous industries, but there was not a comprehensive, integrated policy that tackled energy efficiency across the entire economy (Price, Worrell, Sinton, & Yun, 2001). This piecemeal approach included command and control measures enacted through the 1997 Energy Conservation Law and the phasing out of outdated and inefficient processes and technologies through the forced closure of many energy intensive operations across eleven industrial sectors in 1999 (Price et al. 2001). Since 2005, energy efficiency has become a far more high-profile issue, with a large number of centrally issued policies. These include voluntary agreements with organizations with the greatest energy use, fiscal policies, standards and subsidies. A decrease in energy intensity in 2008 has been observed, but this falls outside the time-scale of this study. Analysis of these policies, however, may be worthwhile once more recent data becomes available.

The gradual, continual increase in carbon intensity throughout the observed period is indicative of the lack of renewable energy policies prior to the 21st century. From around 2005 onwards, there has been a profusion of renewable energy policies and standards. This has resulted in a sudden leap in China's renewable energy capacity, which would possibly be reflected in a fall in the carbon intensity indicator post-2007 (Martinot, 2010). As with energy efficiency, the impact of these policies is unlikely to fall within the scope of this study.

Preliminary assessment of the proposed evaluation framework

Policy compatibility

One can safely argue that this method has a limited scope as far as the GEE is concerned: it aims to cover the aggregated dynamics of energy and CO_2 emissions, or collective impacts of policy portfolios, at the economy-wide level. Therefore, the scope of the "policy compatibility" was placed within this specific subject. By no means has it been suggested that this focus is the most important of a GEE. However, it is worth acknowledging that in the economic recovery packages implemented to stimulate green economic growth, the support towards low-carbon economic growth is of prime importance. In line with Greening et al. (1997), we found that indicators combined with correlation and regression analyses offer the potential to capture key structural aspects driving over CO_2 emissions over time. From the policy perspective, this approach is likely to stress efforts to promote technology change and innovation, while putting less pressure on the controversial issue of population control (cf. Chertow 2000).

Regardless of the estimated patterns or trends, one part of the decomposition approach is heavily focused on intensity values. Here, many aspects can be discussed however we focus our attention on the significant and core aspect of "decoupling". As mentioned before, decoupling refers to a situation in which resource impacts decline relative to economic growth. The term decoupling has often been used as a key transitional element to bridge the contentious debate on continuous economic growth and its negative environmental implications. *Relative* decoupling can be broadly understood as the capability of an economic system to grow with smaller corresponding increases in ecosystem pressure or damage - for example, GHG emissions can still rise but at a lower pace than GDP. Largely confined to the technology paradigm, the main argument in favour of relative decoupling is that technological efficiency improvements alone can be sufficient to satisfy an ever-growing demand for energy services while permitting significant reductions in energy use and resulting levels of GHG emissions.[4] However, one can argue that policy efforts addressing "absolute" reductions in energy consumption and resulting carbon emissions need to be realised to move towards a GEE. This arguments states that technology optimism and incremental improvements that intensity targets may promote, or measure, are not enough to drive a genuinely sustainable future (Jackson 2009). This may have important implications for the policy compatibility of the approach. In turn, this takes us to the issue of targets.

A critical policy evaluation to assess target compliance relates to "environmental effectiveness". Intensity targets may be an attractive tool for framing progress of GEE policies, but they also run the risks of being misleading –as stated above. The "intensity targets" component of our approach can accommodate the need for economic growth, especially in the developing nations. The method can help assessing that "efficient" component of economic growth (Baumert, Herzog, and Pershing 2005; Herzog, Baumert, and Pershing 2006). A focus on target setting and absolute reductions (including due enforcement) can lead to more meaningful policy evaluation and discussions. The results of the utilised approach should be greatly complemented with policy targets are defined. This is not a deficiency of the approach as such, but a condition to better assess real policy compatibility. In line with some critics in the context of a cap-and-trade scheme for greenhouse gases (Greenspan Bell 2005), we agree with the position that progress of GEE policies can be better measured if quantitative targets (e.g. absolute and legally-bidding) are set. Therefore, from the analytical point of view, this leads us to think that much more attention should be focused on absolute changes in CO_2 emission levels and less on intensity ratios or indicators.

When it comes to the identified packages of policy instruments, the approach helped to cast light on their relative environmental effectiveness in reducing CO_2 emissions. In policy evaluation, "value criteria" are advocated as a basis for normative judgements about any significant effect of public policy. Again, a fundamental pre-condition for a policy instrument to be effective is the establishment of mandatory target, which stresses the point made above. Thus, the effectiveness of the instrument can then be assessed in terms of the degree to which it contributes to the achievement of the policy target (cf. Blok 2006; EEA 2001). To better fine-tune the methodology, it is critical to understand the ambition level, the non-compliance rules (e.g. financial sanctions) and the enforcement efforts central to the policy instruments.

Reliability

Our approach is intended to convey, in a simple manner, a wide range of complex economy-wide aspects that drive, or have an impact on, energy production and CO2 emissions. The indicators we propose can help to measure and illustrate progress, or lack of progress, toward a GEE with regards to (green) energy production and carbon emissions. Historical trends and changes associated with energy

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4 The term *energy service* refers to the delivered benefits of useful energy consumption, such as heating, refrigeration, lighting, cooking, transportation, etc., as opposed to the simple provision of units of energy as such (kWh).

production and carbon emissions can support a better understanding of the aggregated determinants of a GEE, including related trade-offs and national/regional policy conditions. To some extent, it also allows international comparison. The proposed indicators revealed, for instance, the carbon performance associated with the energy supply mix and aggregated technology level. However, there is still the challenge associated with decoupling (relative vs. absolute).

In line with Baumert et al. (2005), we argue that intensity indicators may be helpful for establishing emission targets, but also involve some challenges, such as the incorporation of non-CO2 greenhouse gasses. In addition, the extent to which the proposed evaluation framework captures the impacts of existing (energy) investment capital, and the need for new investments (e.g. in renewable energy technologies) requires further analysis (cf. Kemp-Benedict 2011).

Building upon the IPAT equation and Kaya identity, the use of correlation and regression analysis also requires attention. First, the approach may be criticised because of difficulties in model specification. As mentioned before, IPAT was initially used to put emphasis on the contribution of a rising global population on environmental impacts. It was thus not conceived for the analysis of CO_2 emissions as such. Second, given the aggregate nature of the econometric model, the approach runs the risk of being criticised for offering an overly simplistic macro-economy relationship between economy-wide aspects that drive, or have an impact on, energy production and carbon emissions. Third, one can also argue that economic structures and behaviours are constantly subject to change, and that observed relationships in the past might not be an indication of future developments. However, we need to stress that the approach has not been proposed for prediction purposes, but for ex-post evaluation.

Finally, one must bear in mind that policy instruments do no work in isolation, so it is necessary to stress that the methodology aims to assess the overall or aggregate performance of a given policy package. Due to its nature, the methodology is not suitable to assess single policy instruments.

Measurability

On the whole, the approach is time and information-intensive. There is a need for available, reliable, timely and useful data... In particular, the reliability of its findings depends on the accessibility of estimates and their level of uncertainty. However, this should be considered as part of the evaluation challenge and not a deficiency in the approach as such. Processes to ensure adequate data should be devised and implemented to support the methodology. Relevant and high-quality data is critical to support an evaluation exercise of this kind and thus support policy-making while facilitating the continued development of policy instruments driving a GEE.

The literature points out particular data uncertainties with our approach (e.g. Baumert, Herzog, and Pershing 2005). For the particular case of GHG emissions, non-CO_2 emissions (e.g. CH4 and N_2O) are often not taken into account. In addition, input data for CO_2 emissions often relate to fuel combustion, and excludes emissions from biomass (see IEA 2009b). Uncertainties for developing countries are also likely to be higher (Baumert, Herzog, and Pershing 2005).

The results from this approach (e.g. partial correlations or intensity indicators) are not especially complex to calculate. Assuming that the data are reliable, for instance, both intensity and absolute indicators are easy to process. However, we must bear in mind that intensity targets may offer a challenging prospect with respect to how they are communicated to or perceived by policymakers and relevant stakeholders. In turn, these extra complexities may bring further implications for the application and usefulness of the proposed method (Herzog, Baumert, and Pershing 2006).

Concluding remarks

The decomposition analytical approach has shown that the behaviour of CO_2 emissions is very case and country-specific. Although the model specification runs the risk of being criticised for offering aggregated economy-wide relationships, regression analyses for the three countries under study show that the variability of CO_2 emissions can be largely explained (>85%) by the independent variables. In addition, it was possible to identify significant predictors of CO_2 emissions for Sweden (energy intensity) and China (GDP). The presence of multicollinearity in the case of UK prevented any inference about the relative contribution of a particular predictor.

In terms of policies as such, for Sweden, both the green certificate scheme and PFE are likely to make good subjects for policy evaluation. They are compatible, in that they address issues central to the Green Energy Economy (environmental, economic, technical and so on). They are also of such a scale that they are likely to be major determinants of the measurable outputs (e.g. economic growth, national energy demand, and CO_2 emissions). This is likely to increase the reliability of results, since the impact of other variables is less likely to significantly obscure the policies' impact. For the UK, the strong influence of the tertiary sector make evaluation of identified policies complex, methodologically, because their impact will have to be separated from other contributory factors. On a more positive note, the identified policies should meet the measurability criteria well, since they have been evaluated in the past and the authors are aware of the availability of relevant data for detailed bottom-up analyses. Regarding China, the identification of aggregated impacts of various specific policies addressing energy efficiency and productivity requires specific de-limited analyses, as the performance is likely to be very context-specific and difficult to capture at aggregate levels.

The preliminary evaluation of the proposed evaluation framework suggests some methodological advantages and disadvantages. The compatibility (and usefulness) in policy terms of intensity indicators in particular can be questioned (e.g. when absolute reductions in CO_2 emissions are considered). The results of our study suggest the need to complement our approach with other policy evaluation techniques (e.g. target setting, multi-criteria policy evaluation). This is necessary to allow us to better understand the broad effects, attributes and complexities of policy instruments. A mix of evaluation methods can provide a larger foundation for judging the merit of policy instruments. In addition, complementary evaluation methods can provide decision makers with more specific and comprehensive information on the performance of policy instruments encouraging a GEE. Furthermore, complementary methods are likely to increase the analytical strength for verifying policy outcomes, identifying inefficient policies, or providing more specific assertions to improve the performance of policy instruments.

Some other points to consider are that bottom-up models do not allow for rapid exploration of key drivers behind CO_2 emissions, which is the appeal of the proposed method. Also, one has to be aware that using a greater variety of evaluation methods has the potential to yield conflicting results, which may add complexity to the overall analysis. Therefore, trade-offs when applying several evaluation approaches are likely to arise (e.g. analytical richness vs. resource and data intensiveness). To perform comparative ex-post evaluations, a key challenge for evaluators is the so-called 'de-linking' of the effects of different policy instruments. Finally, we need to further scrutinize the capability of the proposed decomposition framework in relation to specific policy evaluation questions.

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