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Towards a Green Energy Economy? A macroeconomic-climate evaluation of Sweden's CO_2 emissions

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HIGHLIGHTS

- The assessment is based on E-3 indicators, econometrics and MRIO analysis.
- Energy intensity decreasing mostly attributed to increases in economic activity.
- Sweden's CO_2 emissions embodied in imports are higher than in exports.
- Mitigation policies needed in sectors with high embodied emissions in imports.
- Bioenergy policies will become crucial for reducing Sweden's CO_2 intensity.

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ABSTRACT

This paper provides a production and consumption-based empirical macroeconomic-climate assessment of Sweden's CO_2 emissions. The core methodology is based on three complementary quantitative methods, namely energy-economy-environment indicators, econometric analyses, and a multi-regional input-output (MRIO) sectoral model. Based on the latest available data (1971–2011), indicators show a sharp decarbonisation of Sweden's energy supply mix pre-1990, and reductions or reversals in energy intensity, CO_2 intensity and energy use post-1990. Reductions in energy intensity are mostly attributed to substantial increases in economic activity rather than reductions in energy use. Econometric results show that variability of CO_2 emissions is best explained by CO_2 intensity than any other tested variable. The MRIO model shows that the Swedish emissions trading balance is negative with both the European Union and the rest of the world (i.e. embodied CO_2 emissions in imports are higher than embodied emissions in exports). Sweden's low-carbon intensity is a critical and horizontal explanatory factor in our results.

1. Introduction

There is growing consensus that traditional economic models have had significant negative effects. It has been argued that they have led to loss of natural capital, unsustainable energy production and consumption, climate instability, social inequalities, and even proven to be economically unsound [1–5]. Consequently, since the 2008–2009 global financial crisis, 'Green Growth', 'New Green Economy' and 'Green Energy Economy' have received increasing attention, and several OECD countries have implemented so-called 'green' economic recovery packages (e.g. [6,7]. With a strong focus on green energy technologies, these recovery packages have been implemented to stimulate green growth and support low-carbon economies, among several policy objectives. Here, a 'Green Energy Economy' refers to an energy-economic system that pursues growth through the expansion of low-carbon energy production, distribution and consumption. As it aims to reduce CO_2 emissions [8], it has important impacts on climate change mitigation.

In this context, several claims have been made about Sweden's success. For example, it has been argued that Sweden has combined welfare development with climate protection to build a green economy [9]. Sweden has been ranked among the world's top green economies [10], created through increased wealth and

Abbreviations: E-3 indicators, Energy-Economy-Environment indicators; ETB, Emissions Trading Balance; EE, Embodied Emissions; IOA, Input–Output analysis; GTAP database, Global Trade Analysis Project database; MRIO model, multiregional input–output model; TPES, Total Primary Energy Supply; VIF, Variance Inflation Factors; WIOD, World Input Output Database.

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jobs, and reduced carbon emissions [11]. While such assertions may hold true for certain sectors (e.g. bioenergy as the literature has pointed [12–14]) there is a lack of sound, peer-reviewed analyses and empirical macroeconomic data. Not only is there a lack of consensus on the definition of a 'green economy', but most of the current scientific literature focuses on empirical evaluations of specific policy instruments, such as a Carbon Tax [15], Tradable Green Certificates [16] and the Programme for Energy Efficiency Improvements [17].

The lack of ex-post studies of macroeconomic-climate aspects of green economies may be explained by the fact that theoretical frameworks and assessment methods are still being developed. Current approaches address specific concerns about job creation or technology patents [18] or the broader issues of sustainable development [7]. At the same time efforts are being made by the Swedish Environmental Protection Agency to support prospective research on production and consumption in a low-carbon economy [19].

Against this background, this paper provides a quantitative macroeconomic-climate assessment of Swedish progress towards a green energy economy. It provides a detailed empirical analysis of production and consumption patterns underlying CO_2 emissions -a rather critical focal point in the green economy policy discourse [7,20,21] and is based on three quantitative approaches, namely: (a) energy-economy-environment (E-3) indicators, (b) an econometric assessment, and (c) a multi-region input–output (MRIO) model. In recent decades concern has grown that reductions in CO_2 emissions in industrialized countries are being cancelled out by imports [22–27]. Therefore our MRIO model examines the role of trade in reducing Swedish CO_2 emissions.

To the best of our knowledge, this is the first empirical analysis of Sweden's CO_2 emissions from an integrated macroeconomic-climate perspective. Using the best available and longest time series data, the three methods are complementary, as they address both the production and consumption side of the Swedish energy-economic system. The two first ones, the indicator and econometric analyses, decompose the production side in different macro-economic indicators, which are heavily used to measure progress towards a green economy [7]. The novelty of the MRIO analysis is the provision of not only CO_2 emissions caused by the Sweden's production side (complementing the modelling and figures obtained by the first set of methods) but also generates estimates resulting from Sweden's consumption side. This approach stresses the systemic view of our analysis and also the role of trading and (potential) carbon leakage of 'national' economic systems, which may favour the outsourcing of production to countries with less costs related to labour and climate policies. For this reason, the aim of this paper is to understand if the path of Sweden to a green economy is coherent not only from a production perspective (that seems to be the case), but also from a consumption point of view. The paper is structured as follows. Section 2 describes the methodology. Section 3 presents the main outcomes. Results are divided into findings coming from E-3 indicators, econometric analyses, and the MRIO analysis. Finally, Section 4 draws some conclusions.

2. Methodology and data sources

Our methodology is based on a quantitative empirical approach. It deploys three complementary analytical tools, namely (a) energy-economy-environment (E-3) indicators; (b) an econometric assessment and (c) a multi-region input–output (MRIO) sectoral model. Details are given below.

Table 1
Data for Sweden for years 1971, 1990 and 2011.

Indicator	1971	1990	2011
CO_2 emissions (Mt)	82.4	52.8	44.9
Population (millions)	8.1	8.6	9.5
TPES (Mtoe)	36.0	47.2	49.0
GDP_{ppp} per capita (2005 USD)	17 374	24 567	35 121
Energy intensity (toe per thousand 2005 USD GDP_{ppp})	0.26	0.22	0.15
Carbon intensity (tCO_2/Tj)	54.6	26.7	21.9

Data source: IEA [30].

2.1. E-3 Indicators

We start with the 'I = PAT' equation[1] [28] and the 'Kaya Identity' [29] to define and estimate indicators. The analysis is based on International Energy Agency (IEA) time series data for the period 1971–2011 [30]. The 'Kaya Identity' builds upon the I = PAT equation; it is a macro decomposition of the energy, economic and demographic indicators used to quantitatively estimate CO_2 emission levels. In this study, the following indicators were estimated or used: Population, per capita Gross Domestic Product (GDP), Total Primary Energy Supply (TPES), Energy Intensity and Carbon Intensity (see Table 1 for definitions and Table 2 for Swedish data). The year 1990 was taken as a baseline and all absolute values were indexed to 100 in that year. We also benchmarked estimated values for Sweden against estimates for the OECD region, OECD Europe, the non-OECD region and the rest of the world.

2.2. Econometric assessment

We used various econometric tests to assess the contribution of different variables to Swedish CO_2 emissions. As the Swedish energy supply has a low carbon content, our initial hypothesis was that CO_2 intensity was most closely correlated with CO_2 emissions. Therefore we carried out bivariate correlation tests of causality among variables. These tests evaluated the relative degree of 'closeness' (or association) between each pair of the following indicators: CO_2 emissions (CO_2), Population (*Pop*), GDP_{ppp} per capita (*g*), energy intensity of GDP_{ppp} (*e_int*), and CO_2 emission intensity of TPES (*c_int*). Secondly, partial correlations were calculated. This step was necessary as more than one variable conveyed the same information -the problem of multicollinearity- which made it difficult to draw any inference about the relative contribution of a particular driver. Tests were applied to measure the correlation between CO_2 emissions and each independent variable to be included in our econometric model (next step), controlling for the effect of the remaining variables.

Thirdly, a stepwise regression analysis quantified the contribution of the various drivers of CO_2 emissions and made it possible to test the hypothesis that the CO_2 emission intensity of TPES (c_int) had the greatest impact. The analysis sequentially assessed the unique value of independent variables on CO_2 emissions. If the addition of a variable contributed to the model, it was retained, while all other variables were re-tested to identify whether they were still significant contributors. When a variable no longer contributed significantly to the model, it was removed. Our aim was to identify the regression equation that explained the greatest part of the variance of CO_2 emissions (i.e. the highest adjusted R^2), where p-values < 0.05 (for independent variables), the variation coefficient was lowest and there was no evidence

[1] The I=PAT equation evaluates the contribution of population P, affluence A (GDP per capita or level of consumption per person), and technology level *T* (environmental impact per unit of GDP) on the overall environmental impact I.