# Measuring greenhouse-gas policies
# A new methodology

(Preliminary version)

Caspar Sauter

*PhD Candidate at the University of Neuchatel, Faculty of Economics and Business*

**Abstract**

One of the biggest obstacles in empirical research in the area of environmental economics is the absence of a sound indicator quantifying environmental policy stringency. A variety of indicators intending to capture the concept of environmental policy stringency have been proposed and are currently used in applied research. None of them relies on a rigorous methodology which would allow to conceptualize and operationalize the phenomenon to be measured. To overcome this problem, this paper proposes and implements a new methodology for the construction of such an indicator.

*Keywords:* Greenhouse gas emissions, environmental regulation, $CO_2$ policy stringency index, $CH_4$ policy stringency index, $SO_2$ policy stringency index

## 1. Introduction

Applied research in environmental economics involving environmental policy (stringency) as a variable is currently limited by the absence of a broadly accepted indicator of this phenomenon. One often encounters words of caution, mentioning the absence of pertinent indicators that are able to measure environmental policy stringency. In a working paper on the measurement of environmental policy change, Knill et al. (2011) conclude that the choice of indicators for environmental policy stringency is rarely theoretically motivated but rather driven by data availability. This paper proposes and implements a new methodology to overcome those problems.

This paper is organized as follow: the next section reviews frequently used indicators of environmental policy stringency and discusses their strengths and weaknesses. This literature review section is followed by Section 3 which outlines in detail the new methodology this paper is proposing and describes the data used to implement the proposed methodology. Section 4 summarizes the preliminary results obtained so far. A preliminary conclusion is made in Section 5.

## 2. Literature review

Cross country research involving environmental policy stringency as an independent or dependent variable operationalized the variable in a variety of ways, creating several different indicators. The following section

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*Email address:* `caspar.sauter@unine.ch` (Caspar Sauter)

summarizes and discusses the strength and weakness of the different indicators that are most frequently used in applied research.[1]

a) Survey based indexes

   *UNCED survey based index:* Dasgupta et al. (2001) developed an index of environmental policy stringency based on reports prepared for the United Nations Conference on Environment and Development (UNCED). Those reports contain self-reported information from countries on a variety of questions, complemented by responses from several NGO's in the attempt to make the data less exposed to biases from self-reporting. Their index is available for 31 countries. Using the methodology of Dasgupta et al., Eliste and Fredriksson (2002) extended the database for another 31 countries but only for the agricultural sector. Besides the potential bias induced by self-reporting of country officials, the approach of Dasgupta et al. and later Eliste and Fredriksson has one major flaw: their index exists only for one point in time and cannot be extended further because of the nature of their source for the data.

   *WEF survey based indicator:* In recent papers (see Kalamova and Johnstone (2011) or Timmins and Wagner (2009)), the indicator of regulatory stringency produced by the World Economic Forum (WEF) has been used. The WEF publishes a yearly Global Competitiveness Report (Sala-i Martin et al., 2011) in which they have one indicator called environmental regulatory stringency. An indicator based on their World Executive Opinion Survey. They obtain the data for this indicator by asking "business leaders" the survey question: "How would you assess the stringency of your countries' environmental policy? (scale: 1=very lax – 7=among the world's most stringent)". This indicator is available for more than 100 countries on a yearly base since the mid 90's. A major inconvenience of this indicator is that he is exclusively based on the opinions of the respondents of the survey.

b) Monetary indicators

   *Public expenditures based indicator:* Magnani (2000) and Pearce and Palmer (2001) use public expenditures for environmental protection as a measurement of environmental policy stringency. Their data covers OECD countries during the nineties. The data has been collected by a survey of the OECD Environmental Program. Public expenditures for environmental protection captures however only expenditure based policy instruments, excluding tax based instruments, regulatory instruments as well as voluntary approach based instruments. On top of that, because of potential efficiency differences, it is unclear if one can safely assume that just because a country has higher per capita public expenditures for environmental protection, the country follows a stricter environmental policy.

   *Abatement costs based indicator:* A lot of papers instrumentalized the stringency of environmental policy using data on pollution abatement costs. Some authors, as for instance Friedman et al. (1992), Crandall (1993), Co and List (2000) use total statewide pollution abatement costs as an indicator, others (Keller and Levinson (2002) for instance) use also total statewide pollution abatement costs but adjusted for each state's industrial composition. A third group of researchers used sectoral rather then state wide data on abatement costs (see Brunnermeier and Cohen, 2003). A fourth group used an indicator based on capital expenditures and operating costs in environmental protection activities (see Jug and Mirza

[1] Note that I focus here only on a selection of indicators of environmental policy stringency which are available for at least 10 countries and at least one common point in time.

(2005)). However, as Copeland (2008) points out, this approach has several major inconveniences. First of all, this data come from firm surveys. It is difficult for firms to correctly disentangle abatement cost from other cost. Moreover firms might have an incentive to strategically under or over report their abatement cost if this information is going to be used for future policy design. And even if correctly reported, reported abatement cost may be endogenous and thus induce biases in the analysis. Illustrating this argument, Copeland advances an example in which firms have heterogeneous costs of responding to environmental regulations. In this case, assuming that the competitiveness hypothesis is correct, stringent pollution policy will then drive the firms with the highest abatement costs out of business hence leaving the possibility that even in regions with a very strict environmental policy, observed abatement cost are low, which in turn would make abatement cost a very bad indicator for environmental policy stringency.

c) Policy-specific indicators

*Kyoto protocol ratification based indicator:* Nakada (2006) operationalized environmental policy stringency indirectly by using the timing of ratifying the Kyoto protocol as a measurement. This has been done by generating a dummy variable, taking the value of zero if a country has not ratified the Kyoto protocol by the year 2003 and the value of 1 if a country has ratified the Kyoto protocol by the year 2003. Proceeding in this way, a dataset for 38 countries has been generated. Besides the limited size of countries in the dataset, the very nature of this indicator does not allow covering more than one time period. On top of that, the indicator is very specific and does not include policy measures that are taken out of the context of the Kyoto protocol nor does it contain any information about the stringency of the implementation of the Kyoto measures.

*Enforcement adjusted treaty indicator* Smarzynska and Wei (2004) use and indicator based on the ratification of four international treaties in environmental politics (scale from 0 to 4). They adjust their initial measure by multiplying it with the ratio of environmental NGO's per million of people in a given country. Claiming that this adjustment reflects the degree of enforcement of those treaties. Suffering from similar problems as the index of Nakada (2006) an additional one concerns the validity of their proxy for enforcement.

*Clean air policy change indicator:* Knill et al. (2011) developed a "de-jure" indicator of clean air policy, capturing statutory laws "on the book" for 24 OECD countries covering the time span from 1976 to 2003. Their indicator codifies the different clean air laws of countries either as "policy expansion" or as "policy dismantling". The data used comes from their own database (compiled by the CONSENSUS project). Their indicator has the advantage that he relies on a well defined methodology, resulting in two indicators, one called "policy density" the other "policy intensity".

d) Performance based indicators

*Lead content of gasoline based indicators:* Several researcher as Hilton and Levinson (1998), Deacon (1999), Damania (2001), Broner and Bustos (2012) or Grether et al. (2012) use the lead content in gasoline as a indicator for environmental policy stringency. This data is taken from the Octel Worldwide Gasoline Survey. According to some of those authors, given the absence of an index on environmental stringency for the 80s and for a large number of countries, their index covers at least one of the most important environmental issues of the 1980s. However, even within this particular field of environmental policy, the lead content of gasoline is only an indirect measurement of policy stringency. As a performance indicator, he captures the problem policies try to solve (i.e. reduce the lead content of gasoline) and does not directly quantify the policy stringency.

*Total Emission and Energy consumption data indicators:* Several researchers simply take emission data as a measure for environmental policy stringency. As an example, Kostad and Xing (2002) use total $SO_2$ emissions on a country level and Smarzynska and Wei (2004) overall $CO_2$ emission reduction data as a indicator for environmental policy stringency. Others use energy intensity data as an index for environmental policy stringency (see Cole and Elliot (2003)). Harris et al. (2003) use energy consumption data as their measurement. This approach has several shortcomings. The most important one is obvious: raw emission and energy data quantify the problem policies try to solve (although in a rather crude way), not the policies itself. Variations in this kind of data may be due to a variety of factors (economic, climatic etc.) that are unrelated to policies. Taking this approach involves therefore a risk of using a highly biased measurement.

*Environmental Performance Index* The Yale Center for Environmental Law and Policy (YCELP) publishes the Environmental Performance Index (Emerson et al., 2012). Although the YCELP never claims that the EPI is a measure of environmental policy stringency, some researchers use the EPI as such. Instead the EPI is - as it's name states - a performance index, ranking the performance of countries in different environmental policy categories. The EPI quantifies thereby the problem policies try to solve, and not the policies (and their stringency) itself.

e) Other indicators

*Other indicators:* Other attempts to produce a valuable proxy for environmental stringency remain highly specific and include for instance the frequency of inspection visits (Jaffe and Palmer, 1997), or measures based on the timing of adopting single environmental measures (Johnstone et al., 2010).

### *2.1. Towards a GHG-specific indicator*

Although a variety of indicators have been proposed to capture the concept of environmental policy stringency, all of them seem to have several disadvantages. Survey based indicators depend on perceptions of either government officials, business leaders or experts and not on hard data. In the class of monetary indicators, abatement cost based indicators may suffer from serious problems due to the difficulty for firms to disentangle abatement cost from other costs. Potential endogeneity issues may also be problematic. Policy specific indicators remain mostly highly specific (as the international treaty based indicators) and can hardly be seen as measures of "environmental policy stringency" in a broad sense. Finally performance indicators quantify (at best) the problem(s) environmental policy is trying to solve[2], but by definition not the policies itself.

Besides the specific flaws of each of the indicator classes, they all share two common problems. First, none of the discussed indicators relies on a rigorous methodology which would allow to define, conceptualize and then operationalize the phenomenon to be measured. Hence, it is highly unclear what those indicators intend

[2]Which is by itself a very important task, as long as one does not use them as a measure of policy stringency.

to measure precisely[3]. "Environmental policy" and "environmental policy stringency" are rather vague concepts which could a priori include a wide range of policies (ranging from the protection of a particular flower, over the regulation of hunting, to the reduction of $CO_2$, to name only a few). Second, several indicators (explicitly or implicitly) mix input measures, process measures and output measures of the phenomenon they try to quantify. And this despite the fact that the literature on index construction clearly indicates that one should avoid this (Nardo et al., 2005).

To overcome those obstacles, a coherent methodological framework is developed. Allowing to measure specific types of environmental policies, based on an explicit definition. While making a clear distinction between input, process and output measures of the phenomenon. Instead of focusing on overall environmental policy, the focus is on policies aiming at reducing certain pollutants, so called pollutant policies. Indicators measuring "$CO_2$ policy stringency", "$SO_2$ policy stringency" and "$CH_4$ policy stringency"[4] are being developed. This approach has the advantage that one can start comparing "apples with apples". Given the availability of pollutant specific emission data sources, having pollutant specific policy stringency data is a big advantage. The next section describes the proposed methodology in detail.

## 3. The methodology

As a preliminary to this section, note that through the total methodological section, I will describe and illustrate the methodology at the example of a $CO_2$ policy stringency indicator. The other two indicators ($SO_2$ and $CH_4$ policy stringency indicators) will be constructed analogically.

### *3.1. Defining the concept*

In order to develop a sound methodology on which the indicators can be constructed one has first to define the phenomenon one intends to measure. I propose the following definition:

**Definition 1 (Policy).** *A policy is a set of decisions and their implementation, made by a government entity, that are oriented towards solving a particular problem*[5].

This definition of the phenomenon "policy" has the advantage that it is very flexible and hence applicable to all possible sorts of policies. According to the definition above, $CO_2$ policy is defined as the set of decisions and their implementations, made by a government entity, that are oriented towards reducing anthropogenic $CO_2$ [6].

[3] Note that the contribution of Knill et al. (2011) is a notable exception.

[4] See the methodology section for proper definitions of those concepts.

[5] Note that "problem" is here understood in a very broad sense, not necessarily with a negative connotation. "Problem" might refer to any task politics could address, from reducing income inequality, over augmenting national exports to reducing $CO_2$.

[6] In general, it follows from Definition 1 that a pollutant policy is a set of decisions and their implementations, made by a government entity, that are oriented towards reducing a particular pollutant.

### *3.2. Input measures, process measures and output measures*

Defined as such, one could a priori measure the phenomenon "pollutant policy" in three different ways. One could measure the input dimension of the phenomenon, the process dimension of the phenomenon and/or the output dimension of the phenomenon:

**Input dimension measure** Measuring the input dimension of the phenomenon, means capturing all different forms of decisions (i.e. policies), that are taken by government entities, and that are oriented towards solving the particular problem. The more decisions are taken, the higher the input dimension policy stringency.

**Process dimension measure** Measuring the process dimension of the phenomenon, means developing a metric that is able to capture how those inputs are implemented. The stronger the implementation, the higher the process dimension policy stringency.

**Output dimension measure** Measuring the output dimension of the phenomenon, means capturing by how much the particular problem has been solved by the policies. The better the particular problem has been solved [7], the higher the output dimension policy stringency.

While constructing an indicator one should avoid mixing input measures, process measures and output measures (Nardo et al., 2005) of the same phenomenon. The following subsections outline the methodology of each of the proposed dimensional measures at the example of $CO_2$ policy.

### *3.3. $CO_2$ policy input dimension measure*

A $CO_2$ policy stringency input dimension measure is a metric that captures the decisions taken to reduce $CO_2$ quantitatively. The proposed composite indicator captures the huge variety of $CO_2$ policy inputs (decisions observable in the countries jurisdiction as constitutional laws, ordinary laws, legal ordinances etc.). As such the indicator has to be seen as a so called "de jure" indicator (or in the terminology of Kaufmann and Kraay (2008) a "rule based indicator" which captures statutory laws "on the book"). In that sense, the indicator follows partially the work of Knill et al. (2011).

#### *3.3.1. The Data used*

For the construction of the input indicator, two different databases are used. Using those databases, two $CO_2$ input indexes are developed:

Taking Definition 1 in it's strict sense, one can classify a policy as a $CO_2$ policy only if the law explicitly refers to the goal of reducing $CO_2$. ECOLEX (FAO et al., 2013), the most comprehensive global source of environmental law, allows the extraction of such $CO_2$ policies. After selecting all laws in ECOLEX which contain the words $CO_2$ (or any derivative like carbon dioxide in any language), a selection process has been made to drop policies which, although containing the right keywords, cannot be classifies as $CO_2$ policies.[8]

[7] In the case of a $CO_2$ policy, the more $CO_2$ has been reduced.

[8] In the case of $CO_2$ there exist for instance laws on the minimum quantity of $CO_2$ in bottled water, those laws have been dropped.

Taking Definition 1 in a less strict sense, one can classify a policy as a $CO_2$ policy if the law implicitly refers to the goal of reducing $CO_2$. Taxes on fuels (although not necessarily containing a paragraph specifying the goal of $CO_2$ reduction) can in this sense be classified as $CO_2$ policies. The Database for instruments of environmental policy and natural resource management published by the OECD and EEA (2012) allows to select such policies. Unfortunately, this database contains several hundreds of missing date of enactment entries. This database has been completed by searching each law with a missing date of enactment entry in the national legislation of the concerned countries.

#### *3.3.2. Codification of the legal information*

Given the immense difficulty to properly quantify "de jure" information, I proceed as others did in constructing "de jure" indicators (see for instance the work of Global Integrity on the Global Integrity Index (see Global Integrity, 2011) or the work of the World Bank on their Doing Business indicator (see World Bank, 2012)). In order to capture this information quantitatively, dummy variables have been created. Each dummy reflects the answer to the question "Does measure $y$ exists in country $x$ in year $z$?". The dummy variables take the value of 1 if a measure exists in a certain country and in a given year and the value 0 if the measure doesn't exist for a given country and a given year.

#### *3.3.3. Weighting and normalization of the input indicator*

In this preliminary version of the paper, the input indexes displayed in the result section have been constructed using the "usual" equal weighting approach. The dummies are simply summed up by country and by year, resulting in the following index: $I_{i,t} = \sum_j Dummy_{j,i,t}$, where $j$ indexes the instruments, $i$ the countries and $t$ the time. Proceeding in this way gives each instrument exactly the same weight in the final index[9]. The index $I_{i,t}$ has subsequently been normalized to range between zero and one.

### *3.4. $CO_2$ policy output dimension measure*

A $CO_2$ policy stringency output dimension measure is a metric that captures by how much the particular problem has been solved by the policies. In order to construct an output dimension measure of $CO_2$ policy a two step approach has to be followed. In a first step, a measure of $CO_2$-performance of countries has been developed. This measure quantifies the particular problem - the one that $CO_2$ policies intend to solve - by country and over time. Variations in the so obtained measure will however not only be due to policies but may also be due to other non-policy related variables. The second step towards an output index would account for this, by "cleaning" the index obtained from step one of the effects of non-policy related variables. This papers limits itself to undertake step one.

[9] In a further step (not displayed in this preliminary version), an informed weighting approach has been undertaken: theoretical results are used in order to make an informed instrument category weighting. Several papers tried to evaluate the "usefulness" of different environmental policy instrument categories (see for instance U.S. Congress (1995)) with respect to the extent they are able to solve the problem. Some of them report qualitative scores (in the US Congress paper there are 4 attributes: "effective", "it depends", "use with caution" and "average"), ranking thereby the different instrument categories. Those qualitative rankings are transformed into weights. Then, using the informed weighting approach, the index will be given by: $I_{i,t} = \sum_c \gamma_c \sum_j Dummy_{j,i,t,c}$, where $i$ indexes the countries, $t$ the time, $c$ the different categories, $j$ the instruments within a given category and $\gamma_c$ indicates the weights for each of the categories. Measures within a certain category will then have the same weight, but measures in different categories will have a different weight depending on the category they are in.

*3.4.1. The data used*

To my best knowledge, there is currently only one dataset available that will allow to implement the proposed methodology: the recently published World Input Output Tables (WIOD, 2012), an extension of the National Accounting Matrix including Environmental Accounts project of Eurostat (2009). This dataset combines the conventional national accounting framework with socioeconomic as well as environmental satellite accounts. For a total of 40 major countries, and 35 sectors, input-output tables, complemented with sectoral labor and capital input data as well as sectoral emission data are available for the time span between 1995 and 2009[10]. This unique dataset will be the data basis of the proposed indicators. Although the project which led to the elaboration of this dataset has been completed in 2012, prospects are good that the dataset will be extended in geographical and time coverage. The Statistical Division of the UN has launched the System of Environmental-Economic Accounts (SEEA) (see United Nations, 2012), which - once completed - would correspond to an extension of WIOT. Conditional on the successful implementation of SEEA, the proposed indicators could be extended, in time and in country coverage[11].

*3.4.2. $CO_2$-performance indicator*

According the Definition 1, $CO_2$ policies aim to solve the particular problem of reducing anthropogenic $CO_2$ emissions. A $CO_2$-performance indicator captures this particular problem quantitatively by country and over time. Conceptually, the proposed $CO_2$-performance indicator follows (and extends) the work of the Yale Center for Environmental Law and Policy (YCELP) which develops an Environmental Performance Indicator (EPI) (Emerson et al., 2012). This indicator intends to track national environmental results on a quantitative basis. The EPI is divided into several parts, one of them measuring "climate change and energy" performance[12]. There are two main differences between the "climate change-EPI" and the proposed $CO_2$-performance indicator. First, instead of trying to quantify overall "climate change" performance, the $CO_2$-performance indicator focuses only on the performance of one particular greenhouse-gas: $CO_2$. Second, the proposed $CO_2$-performance indicator is constructed on a sectoral scale.

*3.4.3. $CO_2$-performance indicator: sectoral indexes*

In a first step, sectoral $CO_2$-performance indicators by year and country have been developed for each of the 35 sectors in the data. In accordance with the work of the YCELP, two different relative measures of sectoral $CO_2$ emissions are included in the index (see Table 1): Sectoral $CO_2$ emissions per unit of sectoral GDP and sectoral $CO_2$ emissions per sectoral workers are common metrics used to asses the intensity in the use of carbon dioxide emissions in the economy (Emerson et al., 2012).

Having the advantage of detailed sectoral data, I can go one step further then the YCELP. An important additional element of the sectoral $CO_2$-performance is $CO_2$-efficiency. $CO_2$-efficiency is a measure of how

[10] Those 40 countries accounted for over 70% of global anthropogenic $CO_2$ emissions during the 00's.

[11] Should the SEEA project not be finished (which is however highly unlikely, the UN Statistical Division confirmed me recently that the project is on schedule), the indicator can still be extended. In order to integrate a new country into the index, one has to have comparable sectoral data on GDP, pollutants, workers, capital inputs and labor inputs.

[12] To quantify the climate change and energy part of this index four sub-indicators are used by the YCELP: $CO_2$ emissions per capita, $CO_2$ emissions per GDP, $CO_2$ emissions per kWh and the percentage of renewable energy in total energy production. All those sub-indicators are constructed using aggregated data (i.e. not sectoral data). Those sub-indicators are then weighted and aggregated.

far a sectoral production process is away from the contemporary best practice in terms of minimizing $CO_2$ emissions while holding the production output constant. The sectoral $CO_2$ efficiency score will be an indicator of how a country's sector performs in terms of what is theoretically possible. $CO_2$ efficiency is defined as the ratio of minimal feasible to observed use of $CO_2$, conditional on observed output levels and conventional inputs. Essentially there are two different approaches in the literature on environmental efficiency. The first one conceptualizes emissions as inputs in the production function while the second one considers emissions as bad outputs of the production process. Both approaches can be implement using either Stochastic Frontier Analysis (SFA) or Data Envelopment Analysis (DEA). Conceptualizing emissions as inputs has however several theoretical shortcomings. For a review on both approaches refer to Mandal (2010). This paper follows the second approach and conceptualizes emissions as a bad output.

The estimation of $CO_2$ efficiency scores follows the work of Färe (2012)[13]. First some notation, assume that a decision making unit[14] produces $M$ good outputs $(y_1, ..., y_M) \in \mathbb{R}_+^M$, $J$ bad outputs $(b_1, ..., b_J) \in \mathbb{R}_+^J$ while using $N$ inputs $(x_1, ..., x_N) \in \mathbb{R}_+^N$. In our case, there is one good output (value added by sector) and one bad output ($CO_2$) both produced using classical inputs (capital stock and hours worked). The technology set is given by $T = \{(x, y, b) : x \textit{ can produce (y,b)}\}$. Färe (2012) imposes structure on the technology set by assuming that the set is closed with bounded output sets. Inputs are assumed to be strongly disposable. Good outputs ($y$) and bad outputs ($b$) are assumed null-joint: if $(x, y, b) \in T, b = 0 \Rightarrow y = 0$. Bad and good outputs are assumed being together weakly disposable: if $(x, y, b) \in T, \textit{and } 0 \leq \alpha \leq 1 \Rightarrow (x, \alpha y, \alpha b) \in T$. Finally, Färe (2012) assumes that good outputs are strongly disposable: if $(x, y, b) \in T, \textit{and } y' \leq y \Rightarrow (x, y', b) \in T$.

Assuming that there are $K$ observations, $(x^k, y^k, b^k)$ for $k = 1, .., K$, Färe (2012) models $T$ in a DEA setting as follows: The pollution generating technology is given by[15]

$$\begin{aligned} T = \{(x, y, b) : \quad & \textstyle\sum_{k=1}^K \quad z_k y_{km} \geq y_m, \ m = 1, ..., M \\ & \textstyle\sum_{k=1}^K \quad z_k b_{kj} = b_j, \ j = 1, ..., J \\ & \textstyle\sum_{k=1}^K \quad z_k x_{kn} \leq x_n, \ n = 1, ..., N \\ & z_k \geq 0 \quad , \ k = 1, ...K\} \end{aligned} \tag{1}$$

The intensity variables $z_k$ in (1) are constrained to be non-negative, imposing thereby constant returns to scale. In addition the following constraints are imposed:

[13] The following presentation of the methodology follows closely the paper of Färe (2012)

[14] A decision making unit (DMU) may refer to an individual worker, a subsection of a firm, a firm but also - as in this paper - to a sector conceptualized as a representative firm.

[15] For an intuitive example which allows to see that $T$ can be seen as a pollution generating technology, refer to Färe (2012).

$$\sum_{k=1}^{K} y_{km} > 0,\ m = 1, ..., M \tag{2}$$
$$\sum_{m=1}^{M} y_{km} > 0,\ k = 1, ..., K \tag{3}$$
$$\sum_{k=1}^{K} x_{kn} > 0,\ n = 1, ..., N \tag{4}$$
$$\sum_{n=1}^{N} x_{kn} > 0,\ k = 1, ..., K \tag{5}$$
$$\sum_{k=1}^{K} b_{kj} > 0,\ j = 1, ..., J \tag{6}$$
$$\sum_{j=1}^{J} b_{kj} > 0,\ k = 1, ..., K \tag{7}$$
$$\tag{8}$$

Constraints (2)-(5), introduced by Kemeny (1956) generalize the Von Neumann (1945) assumptions (for a discussion see (Färe, 2012)). Constraints (2), (3), (5) and (6) constrain good and bad outputs to be null-joint.

To obtain $CO_2$ efficiency scores EE (relating the observed bad output level ($b^*$) to the smallest possible $CO_2$ level, given observed inputs ($x^*$) and good output levels ($y^*$)) the following linear programming problem will be solved for each observation:

$$EE = min\ \beta \tag{9}$$

Subject to:

$$\sum_{k=1}^{K} z_k y_{km} \geq y_m^*,\ m = 1, ..., M \tag{10}$$
$$\sum_{k=1}^{K} z_k b_{kj} = \beta b_j^*,\ j = 1, ..., J \tag{11}$$
$$\sum_{k=1}^{K} z_k x_{kn} \leq x_n^*,\ n = 1, ..., N \tag{12}$$
$$z_k \geq 0,\ k = 1, ...K \tag{13}$$

Constructed as such, I obtain one $\beta$ for each country, each sector at every point of time available. By construction, $\beta$ takes values between zero and one. A $\beta$ equal to one indicates full efficiency while a $\beta$ equal to 0 indicates full inefficiency of the DMU. To not rely on only one efficiency measure, the same methodology has been used to estimate EEs based on a revenue function instead of a profit function as discussed above.

As a result of the above described procedure, the different sub-indicators listed in Table 1 - capturing together the sectoral $CO_2$ performance - are available for each sector, at each point in time and for each country. At this stage, sectoral composite indicators have been build based on the different sub-indicators. Principal Component Analysis (PCA) has been used in order to find the appropriate weights of each sub-indicator. PCA has become one of the major approaches in the construction of composite indicators. The use of PCA is preferred to equal weighting approaches, because it does not impose the strong assumption that all sub-indicators are "worth" the same in the composite indicator. Even if PCA based weighting does not (necessarily) reveal the theoretical importance of the different sub-indicators, it is able to account for overlapping information between the (correlated) sub-indicators (Nardo et al., 2005). As a result composite

**Table 1:** Indicators that capture the sectoral $CO_2$ performance

| **Indicator** | **Description** |
|---|---|
| $\frac{\text{observed sectoral } CO_2 \text{ emissions}}{\text{sectoral GDP}}$ at time t | Sectoral $CO_2$ emissions per sectoral GDP |
| $\frac{\text{observed sectoral } CO_2 \text{ emissions}}{\text{sectoral work force}}$ at time t | Sectoral $CO_2$ emissions per sectoral workforce |
| $EE_t$ | $CO_2$ efficiency score, based on a profit function |
| $EE_t^*$ | $CO_2$ efficiency score, based on a revenue function |

indicators of sectoral $CO_2$-performance for each sector in each country at several points in time are available. They have been subsequently bounded between 0 and 1.

#### *3.4.4. $CO_2$ performance indicator: aggregation and weighting of the sectoral indexes*

Having constructed sectoral $CO_2$-performance indicators for each country and time period, a weighting and aggregation technique has been chosen in order to construct the country $CO_2$-performance indicator. Note that this final index has to reflect an important property: The $CO_2$ performance of a country can either be improved by improving the *within* sector $CO_2$-performance (which is measured by the sectoral $CO_2$-performance indexes) or by altering the composition of sectors in the economy[16]. As an example, by reducing the share of a relatively polluting sector in the economy, and augmenting the share of a relatively clean sector, all other things equal, the $CO_2$-performance of the country improves. This is a priori possible without necessarily a change in the $CO_2$-performance *within* those sectors. Hence the weighting and aggregation technique has to be such that the country $CO_2$-performance indicator reflects this desired property.

In addition, the weighting system has to satisfy several other properties. First of all, a sectoral $CO_2$-performance score should weight more in the country $CO_2$-performance index, the more polluting the concerned sector is. Second, the country indicator should be able to keep track of the history of the $CO_2$ performance of a country[17].

Several possibilities have been taken into account, the baseline possibility is the following:

[16] In the literature the latter is commonly referred to as a "composition effect" while the former is commonly called a "technique effect".

[17] Other sectoral data based indexes, as for instance trade barrier indexes, encounter often the same problem in the aggregation phase. As an example: suppose a country improves the $CO_2$-performance within a given sector (and obtains a score of 1 for this sectoral $CO_2$ performance indicator), and in turn sectoral emissions approach zero (as an extreme case). If one now simply weights the sectoral $CO_2$-performance indicator (which is supposed to be one) by the corresponding contemporary sectoral emission share (which is here supposed to be zero), then the final effect on the country index would be zero. Hence the improvement in the $CO_2$-performance would not be reflected in the final indicator. This would be clearly undesirable.

- Using a linear weighting approach:

$$PI_t = \sum_{k=1}^{p} \frac{ES_{k,t=0} SI_{k,t}}{SS_{k,t}} \tag{14}$$

Where $PI_t$ is the country $CO_2$-performance index at time $t$, $SS_{k,t}$ is the share of sector $k$ in total GDP at time $t$, $SI_{k,t}$ the sectoral $CO_2$-performance index of sector $k$ at time $t$ (having a total of $K$ sectors) and $ES_{k,t=0}$ is the share of sectoral emission (from sector $k$) in total country emissions at time $t = 0$.

Proceeding as above produces a composite indicator on a country level which quantifies the $CO_2$-performance of the countries and which respects the above outlined desired properties.

### *3.5. $CO_2$ policy process dimension measure*

Given the complexity of any political process, I do not see a consistent way of directly measuring the process dimension of $CO_2$ policy for several countries over time. A wide variety of factors such as the form of the political system, the force of the government, corruption etc. might enter the picture. To the best of my knowledge, there exists also almost no theoretical work on policy implementation in environmental politics. As a second best option, one could use a general "quality of government" index as a proxy for implementation stringency of pollutant policies. One possibility would be to proceed as Fortunato and Panizza (2011). They construct such an index based on ICRG data by averaging the ICRG variables "Corruption", "Law and Order" and "Bureaucracy Quality".

## 4. Preliminary results

### *4.1. Input index*

#### *4.1.1. Input index based a strict interpretation of Definition (1*

The $CO_2$ input index based on a strict interpretation of Definition (1) has been implemented. Results are displayed in Figure 1, Figure 2 and Figure 3. The preliminary results displayed in those figures contain all countries which - according to the ECOLEX database - have laws in their national jurisdiction which explicitly mention the corresponding greenhouse gas. As described in the methodological section, a selection process has been made to distinguish between laws that can be classified as $CO_2$, $SO_2$ or $CH_4$ policies and laws which cannot (as for instance a law on the minimum quantity of $CO_2$ in sparkling water).

#### *4.1.2. Input index based on a broad interpretation of Definition (1)*

The Input index based on the broader interpretation of Definition (1) has been implemented. Given the broader interpretation, policies which not explicitly contain the keywords (such as taxes on cars) have been included. This has the advantage of having a more complete picture of the policies. But this comes with a cost, the clear distinction between pollutants is not possible anymore. Hence, the input index based on the broad interpretation of Definition (1) is a Greenhouse-Gas-Index (and not a $CO_2$ index). Two GHG-input indexes have been produced. The first one includes all policy instruments, the second one only tax instruments[18]. Results for the index covering all instruments are displayed in Figure (4). Results for the index covering only tax instruments are displayed in figure (5).

### *4.2. Performance indexes*

The proposed $CO_2$, $SO_X$ and $CH_4$ performance indexes have been implemented. Results are displayed in Figures (6), (7) and (8).

### *4.3. Comparison among the indicators and with other selected input and performance indicators.*

Table (2) displays the pairwise correlation among the constructed Performance Indicators. The $CO_2$, $SO_x$ and $CH_4$ performance indexes are all positively correlated among each others. All pairwise correlations are also highly significant. This results was expected. Two existing Performance Indicators have been chosen in order to have a benchmark for comparing the constructed ones with already existing ones. First the index of lead content in gasoline has been taken from Grether et al. (2012). The lower this index, the less lead is contained in gasoline. All three Performance indexes show a negative and significant correlation with lead. This result is a first indication that the constructed performance indicators seem to measure what they are intended to. Higher pollutant performance in a country goes hand in hand with lower lead content in gasoline in the country. Second, the "Climate Change and Energy" part of the EPI has been taken from Emerson et al. (2012). The $CO_2$ and $SO_x$ performance indexes show a positive and highly significant relationship with the EPI Climate Change index. Again, this seems to indicate that the constructed indexes work well, the better the $CO_2$ and the $SO_2$ performance in a country, the better the "Climate Change and Energy" performance of a country. However, the $CH_4$ performance index shows a negative correlation with the EPI Climate Change index. A result which needs further investigation.

**Table 2:** Pairwise correlations: Performance Indexes

| | CO2_PI | CH4_PI | SOX_PI | Lead | EPI |
|---|---|---|---|---|---|
| CO2_PerformanceIndex | 1 | | | | |
| CH4_PerformanceIndex | 0.5015* | 1 | | | |
| SOX_PerformanceIndex | 0.6554* | 0.2633* | 1 | | |
| Lead | -0.5159* | -0.2943* | -0.4144* | 1 | |
| EPI_ClimateChange | 0.2439* | -0.1525 | 0.2235* | . | 1 |

Note: *=0.01 significance level; PI=Performance Index

Table 3 displays the pairwise correlations among the constructed input indicators. All constructed Input Indicators are positively and significantly correlated among each other. This result was expected. In general the group of input indexes based on the strict interpretation of Definition (1) and the group based on the broad definition show higher within group correlations than between group correlations. As a benchmark the two Air policy input indexes from Knill et al. (2011) have been considered. Also here, all constructed input

[18] The OECD/EEA database has a good coverage of tax instruments among all countries. Depending on the country, other instruments are not 100% covered. Hence the two indexes.

indexes show highly positive and (mostly) highly significant correlations with the benchmark indexes. Again an indicator that the constructed indexes measure what they are intended to.

**Table 3:** Pairwise correlations: Input Indexes

| | CO2_II | SO2_II | CH4_II | GHG_tax | GHG_all | Air_density | Air_intensity |
|---|---|---|---|---|---|---|---|
| CO2_InputIndex | 1 | | | | | | |
| SO2_InputIndex | 0.9211* | 1 | | | | | |
| CH4_InputIndex | 0.6280* | 0.5358* | 1 | | | | |
| GHG_taxonly | 0.1770* | 0.2938* | 0.2255* | 1 | | | |
| GHG_all | 0.1995* | 0.2491* | 0.1679* | 0.8260* | 1 | | |
| Air_Policy_density | 0.5764* | 0.5493* | 0.6236* | 0.1734 | 0.1188 | 1 | |
| Air_Policy_Intensity | 0.6653* | 0.6482* | 0.7031* | 0.2994* | 0.1735 | 0.8894* | 1 |

Note: *=0.01 significance level; II=Input Index

Finally, Table (4) displays the pairwise correlations among the constructed input indicators and Performance Indicators. Most importantly, all input indexes are positively correlated with the performance indicators. The correlations are also (mostly) highly significant. Meaning that the stricter the pollutant policy, the better the pollutant performance. A result which was expected.

**Table 4:** Pairwise correlations: Input Indexes and Performance Indexes

| | CO2_PI | CH4_PI | SOX_PI | CO2_II | SO2_II | CH4_II | GHG_taxonly | GHG_all |
|---|---|---|---|---|---|---|---|---|
| CO2_PerformanceIndex | 1 | | | | | | | |
| CH4_PerformanceIndex | 0.5015* | 1 | | | | | | |
| SOX_PerformanceIndex | 0.6554* | 0.2633* | 1 | | | | | |
| CO2_InputIndex | 0.3202* | 0.3754* | 0.4251* | 1 | | | | |
| SO2_InputIndex | 0.3976* | 0.4034* | 0.4666* | 0.9211* | 1 | | | |
| CH4_InputIndex | 0.0968 | 0.2441* | 0.3042* | 0.6280* | 0.5358* | 1 | | |
| GHG_taxonly | 0.2377* | 0.3789* | 0.1497* | 0.1770* | 0.2938* | 0.2255* | 1 | |
| GHG_all | 0.2374* | 0.4399* | 0.1269* | 0.1995* | 0.2491* | 0.1679 | 0.8260* | 1 |

Note: *=0.01 significance level; II= Input Index; PI= Performance Index

## 5. Preliminary Conclusion

In this article a new methodological framework has been developed to measure $CO_2$ policy-, $SO_2$ policy- and $CH_4$ policy-stringency. By doing so, the paper aims to overcome a severe obstacle in empirical research in the field of environmental economics (especially environmental economics focusing on Greenhouse-gases): the absence of a theoretically rooted indicator of environmental policy stringency. The methodology sets the foundation to measure separately the input, process and output dimensions of each of the three "pollutant policies" considered. Allowing thereby to solve important shortcomings of existing indicators. A pollutant input index and a pollutant performance index have been implemented. Given that the implementation relies on data-sources that will be extended in the near future, it will also be possible to extend the proposed indicators over time and to integrate successively more countries.

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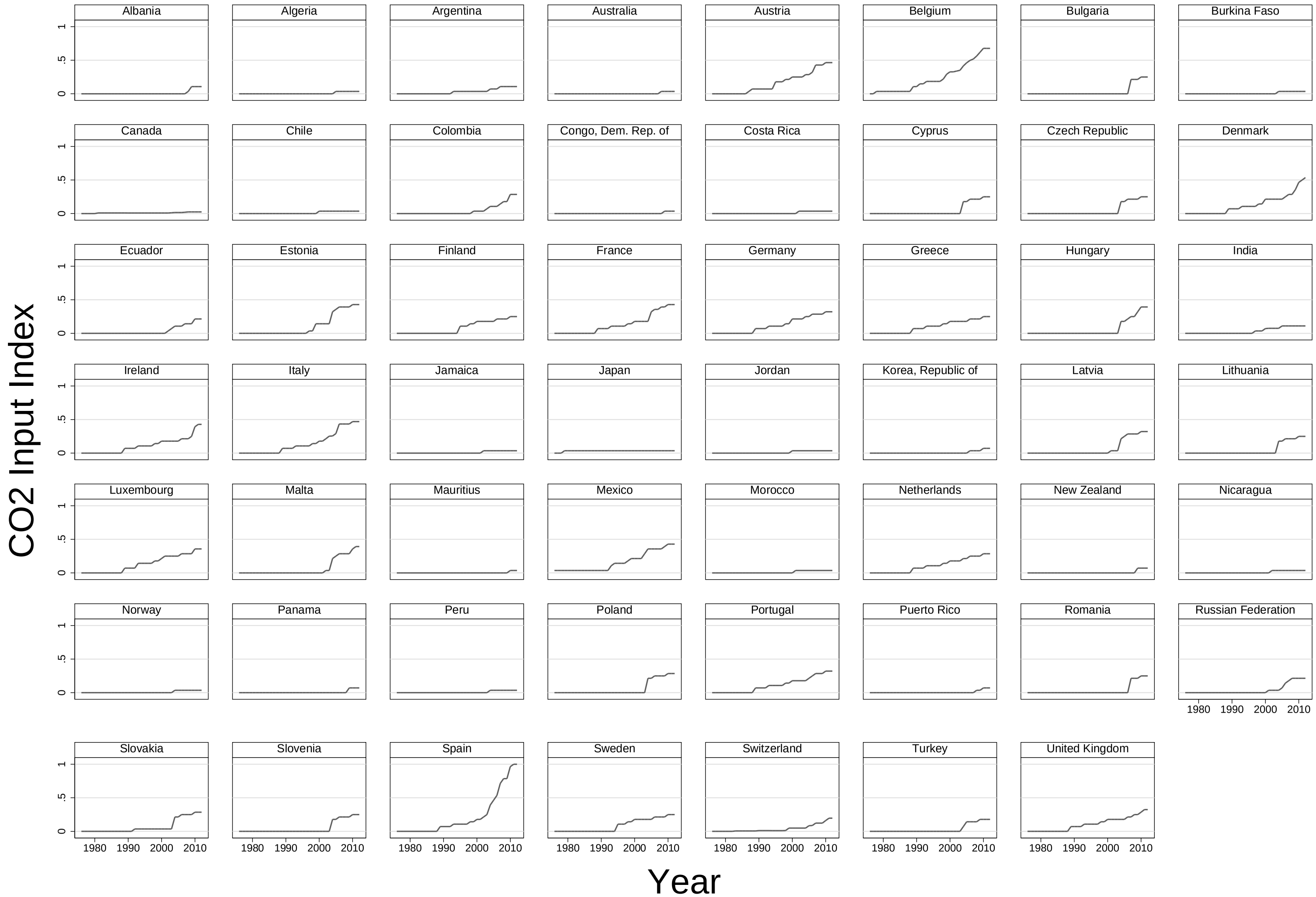
## 7. Appendix

### *7.1. Sector coverage of the performance indicator*

**Table 5:** Sector coverage

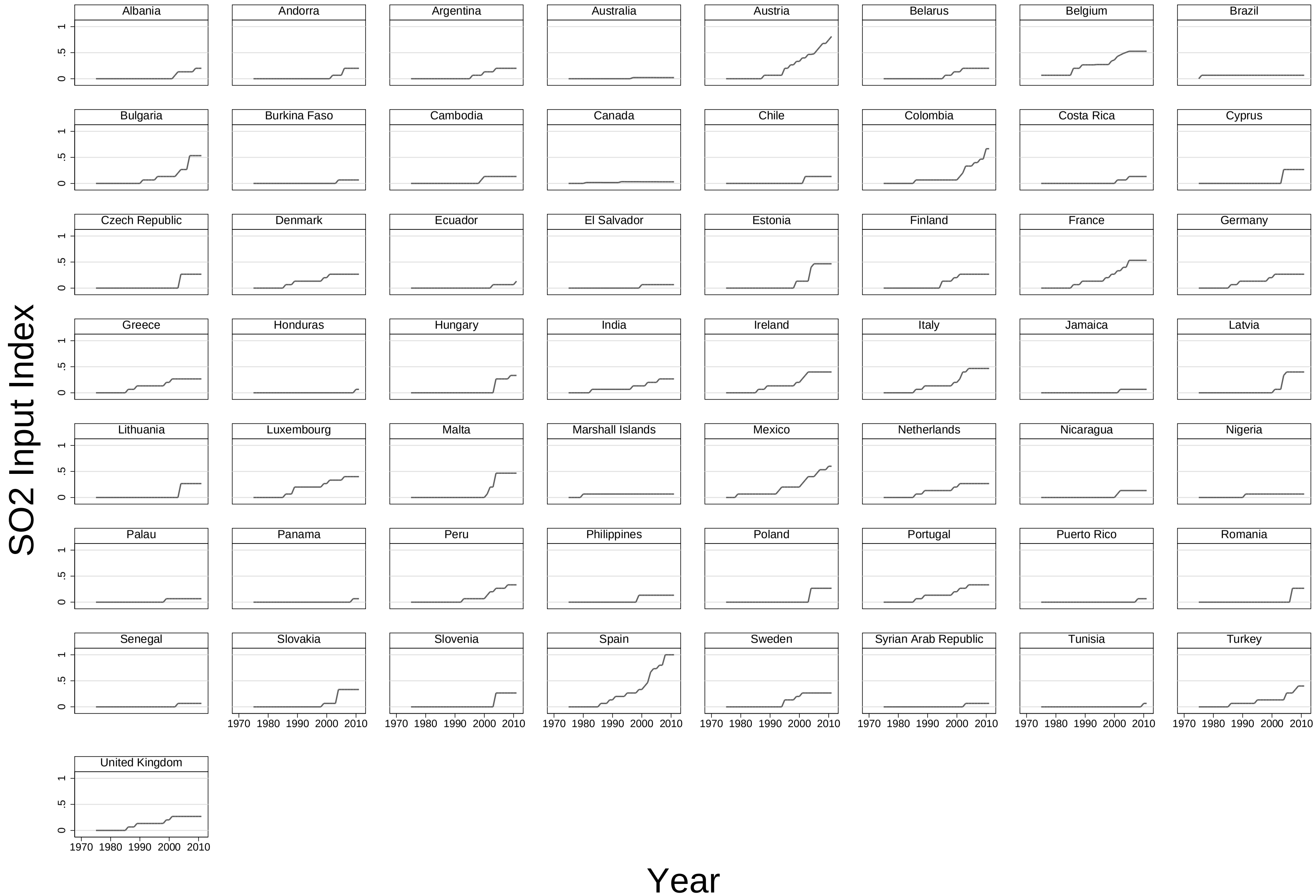
| Code | NACE | Description |
|---|---|---|
| 1 | AtB | Agriculture, Hunting, Forestry and Fishing |
| 2 | C | Mining and Quarrying |
| 3 | 15t16 | Food, Beverages and Tobacco |
| 4 | 17t18 | Textiles and Textile Products |
| 5 | 19 | Leather, Leather and Footwear |
| 6 | 20 | Wood and Products of Wood and Cork |
| 7 | 21t22 | Pulp, Paper, Paper , Printing and Publishing |
| 8 | 23 | Coke, Refined Petroleum and Nuclear Fuel |
| 9 | 24 | Chemicals and Chemical Products |
| 10 | 25 | Rubber and Plastics |
| 11 | 26 | Other Non-Metallic Mineral |
| 12 | 27t28 | Basic Metals and Fabricated Metal |
| 13 | 29 | Machinery, Nec |
| 14 | 30t33 | Electrical and Optical Equipment |
| 15 | 34t35 | Transport Equipment |
| 16 | 36t37 | Manufacturing, Nec; Recycling |
| 17 | E | Electricity, Gas and Water Supply |
| 18 | F | Construction |
| 19 | 50 | Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel |
| 20 | 51 | Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles |
| 21 | 52 | Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods |
| 22 | H | Hotels and Restaurants |
| 23 | 60 | Inland Transport |
| 24 | 61 | Water Transport |
| 25 | 62 | Air Transport |
| 26 | 63 | Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies |
| 27 | 64 | Post and Telecommunications |
| 28 | J | Financial Intermediation |
| 29 | 70 | Real Estate Activities |
| 30 | 71t74 | Renting of M&Eq and Other Business Activities |
| 31 | L | Public Admin and Defence; Compulsory Social Security |
| 32 | M | Education |
| 33 | N | Health and Social Work |
| 34 | O | Other Community, Social and Personal Services |
| 35 | P | Private Households with Employed Persons |

### *7.2. Figures*



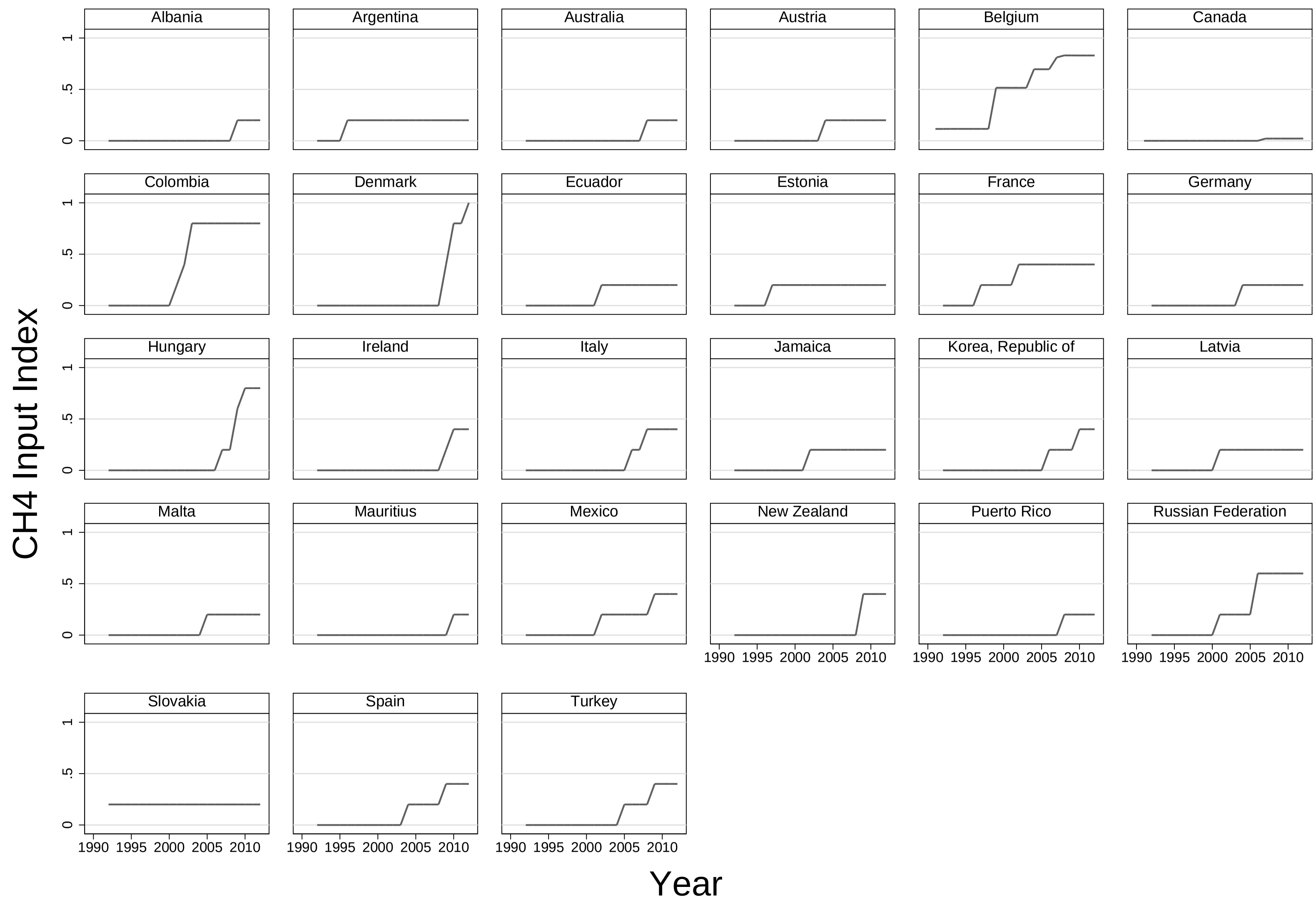

Note: the CO2 Input Index is based on a strict interpetation of Definition (1)

**Figure 1:** Input dimension indicator of CO2 policy



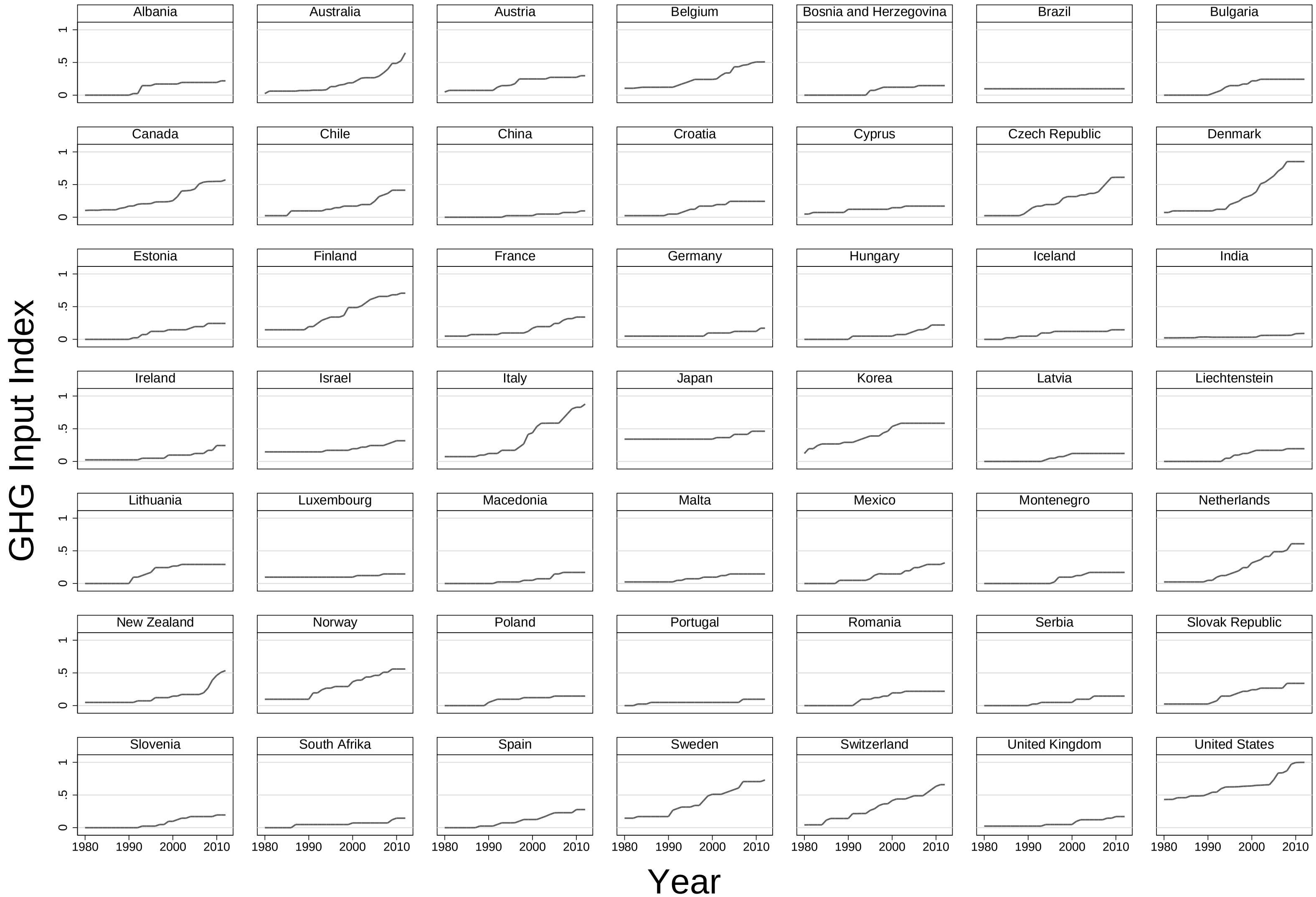

Note: the SO2 Input Index is based on a strict interpetation of Definition (1)

**Figure 2:** Input dimension indicator of SO2 policy



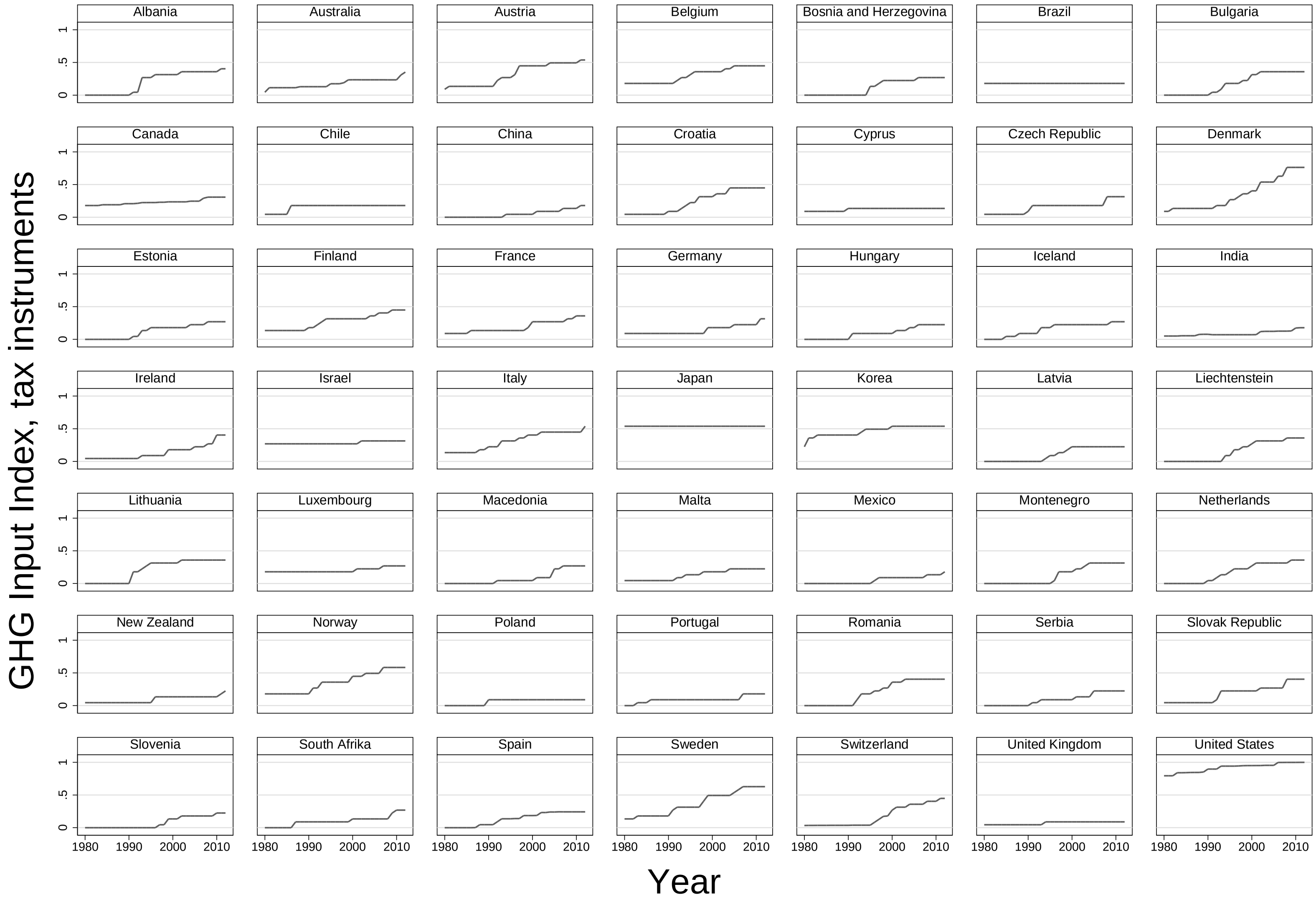

Note: the CH4 Input Index is based on a strict interpetation of Definition (1)

**Figure 3:** Input dimension indicator of CH4 policy




Note: the GHG Input Index is based on a broad interpetation of Definition (1)

**Figure 4:** GHG Input dimension indicator, all instruments




Note: the GHG Input Index is based on a broad interpetation of Definition (1)

**Figure 5:** GHG Input dimension indicator, tax instruments only

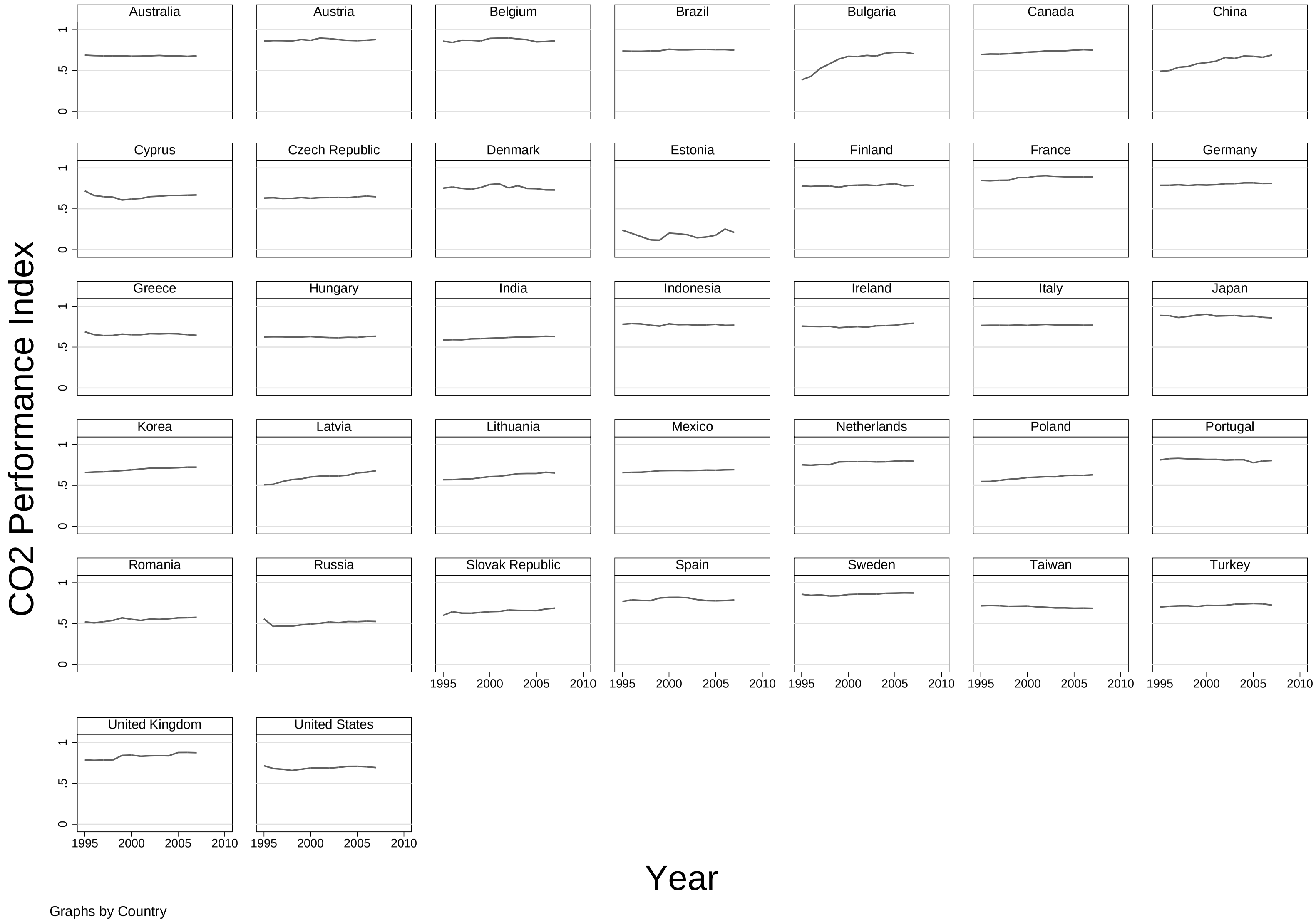



**Figure 6:** CO2 performance indicator

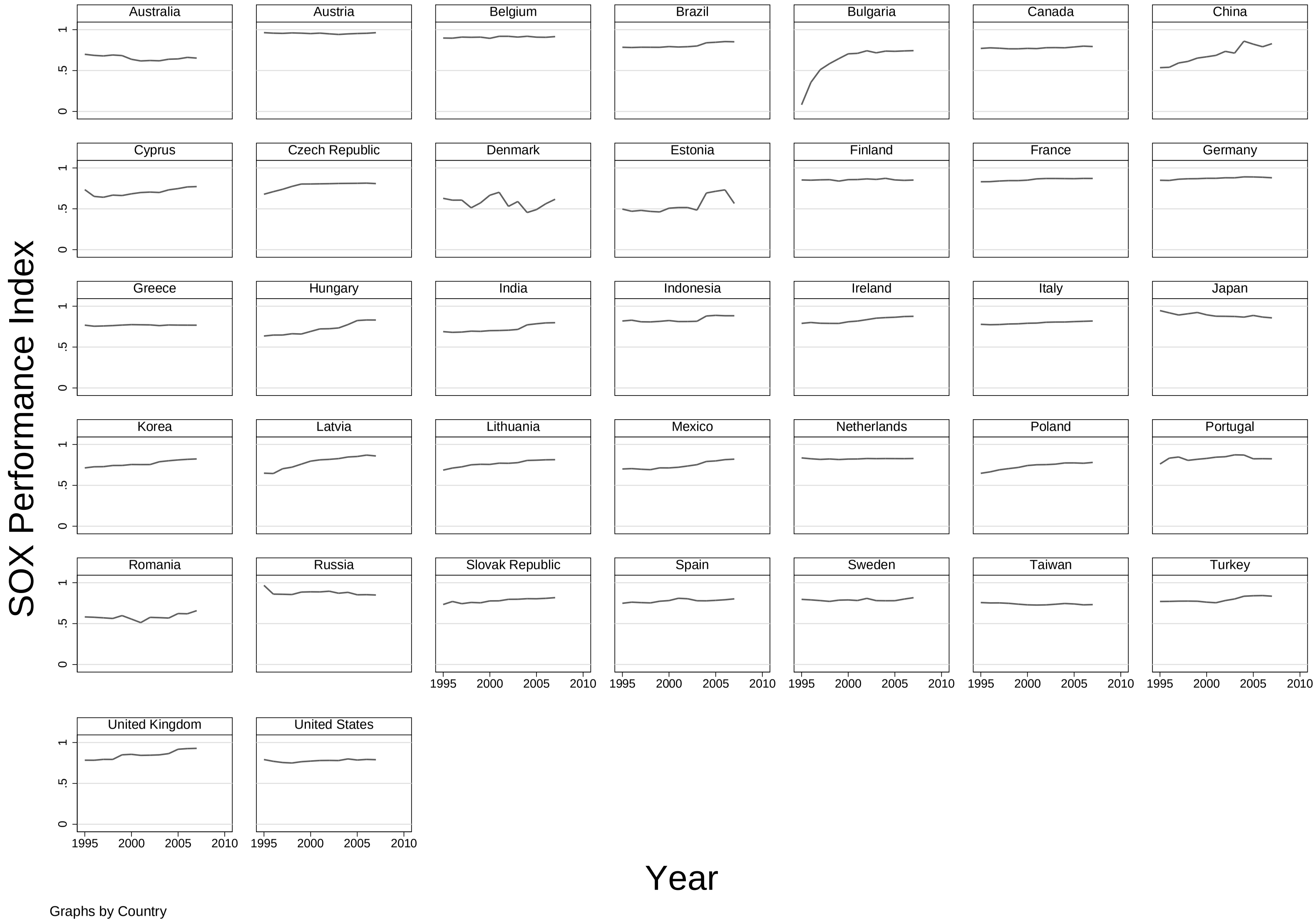



**Figure 7:** SOX performance indicator

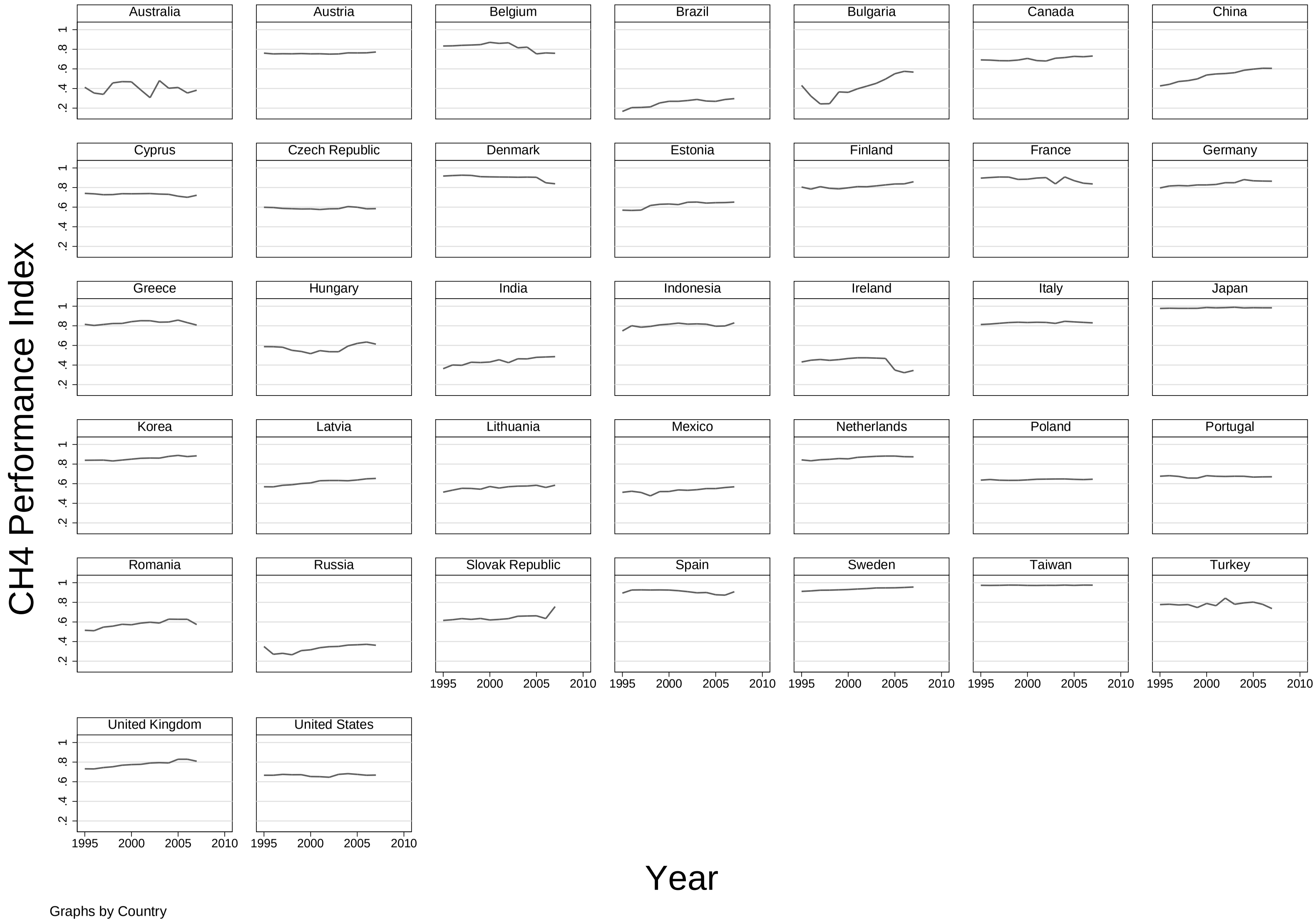



**Figure 8:** CH4 performance indicator