Income, Energy and the role of Energy Efficiency Governance

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Abstract:

Understanding the relationship between income and energy consumption is essential for the correct design of energy policy. Many works study this relationship, but none of them adequately control for double causality, which may lead to biased estimates. For a set of 32 OECD countries, we construct an energy efficiency governance index (EEGI) between 2000 and 2015. We propose an instrumental variable approach that draws on this index in order to characterize the aforementioned relationship. The EEGI affects growth only through energy consumption, favoring a more efficient use of energy in the production process and, thus, fostering growth. The elasticity between (energy-governance-driven) energy consumption and income growth is close to unity, which almost doubles that commonly found in the literature. For the other side of causality, we construct an adjusted income growth series, where the response of income to energy consumption is ruled-out. The resulting elasticity is negative (around -3.0), which is of opposite sign to the usual finding in the literature. Therefore, energy consumption driven by improvements in energy governance is good for growth, while income growth enhances energy efficiency. Since energy consumption is the main driver of carbon emissions in OECD countries, energy governance could play a remarkable role for decoupling carbon emissions from GDP growth.

Key-words: Income growth, energy consumption, energy governance, composite index, external instrument, OECD.

JEL-classification: O13, P48, Q43, Q48, Q50, Q58

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Abbreviations:

2SLS Two-Stage Least Squares

EEGI Energy Efficiency Governance Index

IEA International Energy Agency

IV Instrumental Variable

OLS Ordinary Least Squares

PCA Principal Components Analysis

SW Sanderson-Windmeijer

TFEC Total Finaly Energy Consumption

TPEC Total Primary Energy Consumption

WGI World Governance Index

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Conflicts of interest

The authors declare that they have not known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material

All the data used in this work are accessible in the databases indicated in the document.

1 Introduction

Since the seminal work of Kraft & Kraft (1978), there is a growing literature analyzing the relationship between energy consumption and economic growth. Energy is a fundamental factor in the production process (Pindyck & Rotemberg, 1983; Wei, 2003) and, at the same time, improving efficiency in the use of energy favors economic growth (Díaz, Marrero, Puch, & Rodríguez, 2019; Q. Wang & Wang, 2020).[1] Given that the use of energy is responsible of nearly two-thirds of world CO_2 emissions (IEA, 2019), figuring out this relationship is crucial to understand the trade-off between economic growth and a environmental damage (Den Butter & Verbruggen, 1994).

The relationship between energy and income is not clear on both sides of causality. On the one hand, energy is a complementary input to physical capital in the production function, and more efficient use can foster growth (Bretschger & Schaefer, 2017). In this line of research, Linn (2008) reveals how a reduction in energy driven by the price of energy is associated in the short term with lower economic growth, but subsequent increase in investment in more efficient technologies can compensate the direct effect in the long term (Andrew Atkeson & Kehoe, 1999). On the other hand, more income implies an increase in energy demand, but also more investment in energy-saving technologies (Wong, Chia, & Chang, 2013), improvements in energy governance (Bazilian, Nakhooda, & Van De Graaf, 2014; Holley & Lecavalier, 2017) and changes in less energy-intensive sectors of activity (C. Wang, 2013).

In an attempt to disentangle this complex relationship, we find a vast number of papers in the applied energy literature that characterize the link between income and energy consumption, leading to inconclusive results (see Yuan, Kang, Zhao, & Hu, 2008; and S. Wang, Li, & Fang, 2018, among others).[2] However, none of these papers considers an exogenous source of variation as an external instrument to control for the bias generated by double causality, which is the ideal approach to handle this problem in a macroeconomic panel data framework (Ciccone, Tesei, & Bruckner, 2012; Brückner, 2013; Acemoglu, Naidu, Restrepo, & Robinson, 2019, among many others).[3]

For a set of 32 OECD countries, we draw upon the theoretical framework proposed by the International Energy Agency (IEA, 2010) to construct an Energy Efficiency Governance Index (EEGI) representative for the 2000-2015 period, which is used as an external instrument to characterize the effect of energy consumption on income growth.[4] For the EEGI to be a valid instrument, the exclusion restriction, which is that energy governance affects income growth only through its impact of energy consumption, must be satisfied. The theoretical background that dictates this proposal draws on existing well-known results in the literature, in which institutional quality and governance have proven to be a highly relevant factor for economic growth and other environmental concerns such as CO_2 emissions and natural resource abundance (Ji, Magnus, & Wang, 2014; Dées, 2020). Energy governance, a very different concept from the general governance of a country (IEA, 2010; 2016), favors a more efficient use of energy (Goldthau & Sovacool, 2011; Holley & Lecavalier, 2017; Ringel & Knodt, 2017; Haley, Gaede, Winfield, & Love, 2020), and these gains in energy efficiency can benefit productivity (Boyd & Pang, 2000; Worrell, Laitner, Ruth, & Finman, 2003; IEA, 2014) and then economic growth (Florini & Sovacool, 2011; Bazilian et al., 2014; Lesage & de Graaf, 2016; Díaz, Marrero, Puch, & Rodríguez, 2019).[5]

In fact, we begin by showing that EEGI affects income growth only through its impact on energy consumption growth. Therefore, empirically, the exclusion restriction is satisfied and the EEGI is a good candidate to characterize the causal effect of energy consumption on economic growth. However, it does not mean that there are no other indirect (theoretical) channels through which energy governance could affect income growth, regardless of energy consumption (e.g., technological externalities derived from R&D applied to new, more efficient energy sources).

To analyze the effect of income on energy consumption growth, we use the Instrumental Variable (IV) estimates of the previous relationship and construct an adjusted per capita income growth series, in which the response of economic activity to energy consumption (driven by energy governance) is ruled-out (Brückner, 2012, 2013; Brueckner & Lederman, 2018). Then, the adjusted variable instruments income growth and, following previous works in this field (Ciccone et al., 2012; Esseghir & Khouni, 2014; Galiani, Knack, Colin Xu, & Zou, 2017; Dées, 2020), we apply a Two-Stage Least Squares (2SLS) approach to a first-differenced model.[6]

The construction of an unprecedented energy efficiency governance index is a relevant contribution of this work. Energy governance is defined as the combination of a regulatory framework (laws, plans and financing mechanisms), institutional arrangements (energy agencies, public-private agreements, among others) and the coordination mechanisms necessary for a successful development of energy policies (IEA, 2010). Our index captures these dimensions underpinning energy governance through the analysis of almost 1,800 entries on energy efficiency measures for the 32 OECD countries analyzed. These entries are extracted from the IEA's Energy Efficiency Database (2016), covering measures implemented for the 2000-2015 period. Next, we follow Dabla-Norris, Brumby, Kyobe, Mills, & Papageorgiou (2012), who build an indicator of efficiency in public investment management, to construct our composite index on energy efficiency governance.

We complement our proposal by considering an alternative instrument in which the EEGI interacts with international oil price series, since oil price shocks have a high impact on energy consumption and its use (Bélaïd & Abderrahmani, 2013), as well as on income growth (Gunning, Osterrieth, & Waelbroeck, 1976; Ciccone et al., 2012; Lippi & Nobili, 2012; Blanchard & Riggi, 2013). For validity purposes, in addition to the use of traditional tests such as the over-identifying restriction test and the weak instrument test, we also construct two counterfactual instruments and analyze their results. In the first alternative, we use the average level of a general governance index (the Word Governance Index –WGI– from Kaufmann, Aart Kraay, & Pablo Zoido-Lobaton, 1999) between 2000 and 2015 (the WGI alone and interacted with oil price shocks). In the second alternative, we use the oil exports and imports relative to GDP interacted with oil prices, the instrument proposed by Ciccone et al., (2012). We show that these alternatives are invalid to estimate the causal effect of energy on economic growth (i.e., they generally fail the exclusion restriction and/or the weak instrument test), while the EEGI and its cross effect with oil prices are not weak instruments and systematically affect income growth through its impact on energy consumption growth (i.e., the exclusion restriction is satisfied).

Our results suggest, firstly, that increasing energy governance by one standard deviation (around 32% over its average score) could reduce energy consumption growth by approximately 0.50% per year. Quantitatively, this amount is a little bit higher than the average drop of this variable in our panel of OECD countries between 2000 and 2015. Secondly, we find that the estimated elasticity from energy to income growth is close to unity. This result almost triples the elasticities estimated under OLS with fixed effects, which are likely to be biased, but it also almost doubles the elasticities commonly found in the related literature (Masih & Masih, 1996; Fatai et al., 2004; Esseghir & Khouni, 2014, among others). This means that the part of energy consumption driven by energy governance has a stronger effect on income growth than total energy consumption. A more efficient use of energy in the production process and the consequent impact on overall productivity and, thus, on growth, might explain this result.

Thirdly, for the other side of causality (from income to energy consumption growth), our 2SLS estimates shows a sizable negative elasticity (around -3.0), which is of opposite sign to our OLS fixed effects estimates and the usual finding in the literature (Chen, Chen, Hsu, & Chen, 2016; S. Wang et al., 2018). This change of sign must be explained because we are duly taking into account the double causality effect between income and energy. This finding represents a drastic change with respect to the results obtained up to now and the policy recommendations derived from them. Thus, for our set of 32 OECD countries between 2000 and 2015, while energy is a growth enhancing factor, economic growth may improve a more efficient use of energy in the economy. Moreover, to the extent that energy use is the main source of greenhouse gases (Tahvonen & Salo, 2001; Bosello, Buchner, & Carraro, 2003; Hassler & Krusell, 2012), improvements in energy governance would help to combat climate change and environmental damage by increasing energy efficiency without hampering economic growth.

The remaining of the paper proceeds as follows. In Section 2, we detail the process of building the EEGI, and show the estimated results for our 32 OECD countries. An extensive robustness analysis relative to the construction and the strength of the EEGI can be found in the Appendix. In Section 3, we describe the construction of alternative instruments for energy consumption and economic growth, and describe the 2SLS methodology. In Section 4, we analyze the causal relationship between energy consumption and economic growth, carrying out multiple robustness tests. Finally, we conclude and provide a set of final remarks related with energy policy.

2 An index of Energy Efficiency Governance

In this section, we build a composite index to measure the quality of energy efficiency governance in a set of 32 OECD countries.[7] To do this, we draw upon the theoretical framework proposed by the International Energy Agency (IEA, 2010), in which the energy efficiency governance areas are established and defined. The information used to build the index is obtained from the IEA's Energy Efficiency Database (2016) for the 2000-2015 period. The EEGI is built after analyzing almost 1,800 entries in the aforementioned database related to energy efficiency for the 32 countries in the sample. These entries include energy policies, specific programs and financing mechanisms, among others.

To build the index, we follow the recommendations from OECD (2008) and the work of Dabla-Norris et al. (2012), who build an indicator of efficiency in public investment management. The methodology used allows us to obtain a homogeneous and comparable energy efficiency governance measure between countries, which is mainly based on qualitative information. In this sense, it is necessary to establish criteria for the scoring and aggregation of the different indicators and to carry out an extensive robustness analysis.

2.1 The diagnostic framework and the components of the Index

Following IEA (2010), Figure 1 summarizes the theoretical diagnostic framework used to construct the EEGI. The energy efficiency governance is defined by the combination of a regulatory framework, the existence of institutional agreements and coordination mechanisms aimed at improving energy efficiency. Following this definition, we consider synthetically the information available in the following three areas to construct the index: Enabling Frameworks, Institutional Arrangements and Coordination Mechanisms. In turn, each area is composed of a series of identifying indicators.

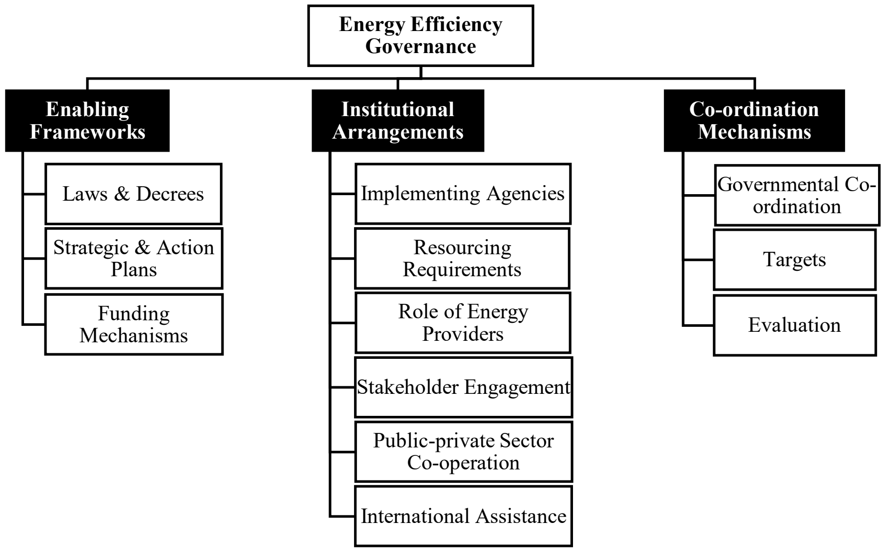

Figure 1. The structure of Energy Efficiency Governance. *Source* IEA (2010)

The first area, Enabling Framework, includes the legal and financial basis that permits the implementation of policies and programs linked to national energy efficiency objectives. Therefore, this area partially encompasses the other two, by establishing the regulatory framework on which the entire structure of the energy efficiency governance is based. It consists of three indicators: (i) Laws & Decrees, (ii) Strategic & Action Plans (i.e., practical guides for the achievement of the proposed goals) and (iii) the existence of Funding Mechanisms.

The second area, Institutional Arrangements, refers to the design and application of practical instruments that regulate the degree of intervention of the different agents that participate in the sector. The information from six indicators is used: (i) the existence and type of Energy Agencies, (ii) Resourcing Requirements (i.e., human and economic resources), (iii) the Role of Energy Providers, (iv) Stakeholder Engagement (i.e., the extent of participation of public and private agents in the proposal of policies and plans, among others), (v) Cooperation mechanisms between Public and Private Sectors and (vi) International Assistance for the development and improvement of energy efficiency.

The third area, Coordination Mechanisms, comprises the necessary mechanisms for the coordination of the different agents of the energy sector in order to achieve the objectives of the national energy policy. It also includes the monitoring and evaluation of the results. This area is made up of three indicators: (i) Governmental Coordination –both vertical and horizontal, (ii) Targets (i.e., the setting of quantified and precise objectives) and (iii) the existence of mechanisms for evaluating and monitoring the results.

2.2 Data collection and scoring procedure

The construction of the index is based on an exhaustive compilation, classification and analysis of the existing regulations on energy efficiency for the 32 OECD countries considered. Thus, we have collected information from the IEA's Energy Efficiency Database (2016), generating our own database drawing upon the information we get from 1,796 entries.[8] Most of the energy efficiency measures have been applied after the year 2000 or are already in force at that time, so we consider that our indicator is representative of the 2000-2015 period. After considering only those entries in force at some time in the aforementioned years, the final number of entries used is 1,699.

The information contained in each entry is mostly qualitative and provides the details of one or more policies, regulations or programs. Hence, each entry might contain information that is relevant for one or more indicators described in Figure 1. Consequently, we have performed a thorough analysis of each entry to define its characteristics and identify which area of the energy efficiency governance each piece of information is linked with. We have also distinguished between those measures that may be linked to more than one indicator.

Table 1 presents the number of entries analyzed initially (column 3) and finally (column 4) for each country. For the same country, the initial and final entries are similar. However, the numbers of entries between different countries are very diverse. In our sample, the average number of records finally considered per country is 54, with countries like Canada, USA or Germany with 245, 169 and 141, respectively, and countries like Chile, Estonia, Slovenia and Mexico at the other end, with less than 10 entries each (the number of entries in Switzerland, Turkey and Greece are also low). In the middle of these extreme cases, there are other countries, ranging from 30-31 records in the Czech Republic and Austria, to 78-89 in the UK or Italy. Likewise, for illustrative purposes, we also indicate in Table 1 the items found for the indicators Laws & Decrees and Strategic & Action Plans from the first area. The detailed analysis of these specific indicators is essential for the construction of the EEGI. Each law or strategic plan may have relevant information for the construction of several indicators belonging to different governance areas.

Table 1 Energy Efficiency Database entries by country and entries related to the indicators Laws & Decrees and Strategic & Action Plans

Country	Country code	Total entries	Revised entries	Laws & Decrees	Strategic & Action Plans
Australia	AUS	58	58	7	9
Austria	AUT	40	31	11	6
Belgium	BEL	68	66	30	7
Canada	CAN	256	245	13	20
Chile	CHL	4	4	1	1
Czech Rep.	CZE	30	30	46	4
Denmark	DNK	62	58	17	18
Estonia	EST	4	4	0	2
Finland	FIN	35	34	5	6
France	FRA	76	68	32	8
Germany	DEU	149	141	36	13
Greece	GRC	30	25	17	3
Hungary	HUN	65	54	30	9
Ireland	IRL	47	44	7	10
Italy	ITA	89	89	80	19
Japan	JPN	57	57	10	16
Korea	KOR	51	41	7	7
Luxembourg	LUX	50	43	22	6
Mexico	MEX	6	6	2	1
Netherlands	NLD	41	35	3	7
New Zealand	NZL	33	32	20	7
Norway	NOR	42	40	8	5
Poland	POL	28	28	12	9
Portugal	PRT	57	57	50	10
Slovak Rep.	SVK	16	16	15	8
Slovenia	SVN	3	3	0	2
Spain	ESP	47	47	28	13
Sweden	SWE	58	57	23	9
Switzerland	CHE	28	21	4	4
Turkey	TUR	18	18	7	3
UK	GBR	79	78	11	19
USA	USA	169	169	36	19
T O T A L		**1796**	**1699**	**590**	**280**

Source Own elaboration using information obtained from IEA's Energy Efficiency Database (2016)

Given the qualitative nature of the information, it is necessary to establish a score scale and evaluation criteria for each indicator, ensuring that these are as objective as possible. Following Dabla-Norris et al. (2012), we established a series of homogeneous and impartial criteria to assign to each indicator and each country a value between 0 and 4, with the highest score corresponding to a better quality. Depending on the type of indicator and the information available, the intermediate scores may vary, but the minimum and maximum values are always 0 and 4, respectively. For example, while the Laws & Decrees indicator has steps of 0.8, the Stakeholders Engagement indicator has steps of 1.33. This is because the available information is much more extensive and detailed in the first case. Below, we briefly explain some of these criteria and show some examples, leaving a much more detailed description for Appendix A.

In the Enabling Frameworks area, information has been obtained for two of the three indicators: (i) Laws & Decrees and (ii) Strategic & Action Plans.[9] In the first case, the extent of the existing regulation in each country is analyzed, paying special attention to the sectors of activity contemplated (transport or industry, among others). For example, the score for Italy is 4, because there are more than 80 legal references that cover all sectors. Conversely, Mexico has been assigned a 0.8, since only two references have been found in all the revised documentation. Regarding the Strategic & Action Plans indicator, we have analyzed their quantity, checking if the proposed objectives have been quantified and if the costs incurred have been estimated. For example, for the United Kingdom, the score is 4 points as 19 strategies of this type were found with costs and objectives estimated in 15 of them.

Regarding the Institutional Arrangements area, we were able to evaluate four of the six indicators shown in Figure 1: (i) Energy Agencies, (ii) the Role of Energy Providers, (iii) Stakeholder Engagement and (iv) Cooperation mechanisms between the Public and Private Sectors.[10] Regarding the Role of Energy Providers, we analyze the number of programs they promote or in which they are involved. Canada is the only country that receives the highest score, given that 58 programs have been found, of which 10 have been promoted directly by energy providers. Conversely, Korea obtains only 1 point, since only 3 initiatives have been detected. Regarding the Energy Agencies, for example, their proactivity is analyzed to propose energy efficiency measures and the legal support they have. In the case of Spain, the score is 4 because the national energy agency (IDAE) promotes a large number of plans and programs, and also has legal backing. Conversely, Belgium's score is 0.8 in this indicator, as there is no national energy agency.

Finally, in the Coordination Mechanisms area, we have quantified two indicators: (i) Targets and (ii) Evaluation.[11] In the second indicator, for example, we examine the number of evaluation and monitoring protocols that we have found in relation to the number of strategic and action plans of the country in question. Thus, while the score for Switzerland is 4 points, since mechanisms of this type are contemplated in 75% or more of the existing plans, the rating of Poland is a 2, given that the proportion (44%) is much lower.

2.3 The results of the index

Once each indicator has been scored, the next step is to add and weigh them. In general, individual indicators are added within each area, thus obtaining a (composite) sub-index for each area. Subsequently, the three resulting sub-indices are aggregated again to obtain the baseline EEGI. With respect to the weighting process, the EEGI weighs equally to each sub-index and indicator (i.e. it draws on the average), which coincides with the most common practice in the literature (OECD, 2008; Knack, Halsey Rogers, & Eubank, 2011; Dabla-Norris et al., 2012). In the Appendix B, an extensive robustness analysis relative to the weighting and aggregation methods for indicators and sub-indices is conducted, highlighting that the results are robust to the different alternatives considered.[12]

We show below the results of the baseline EEGI for each country. Figure 2 illustrates the score of the three areas and the EEGI, while Table 2 shows the detail of that score. In both cases, countries are ordered from best to worst result and a breakdown of the score of each sub-index is included. The average value of the EEGI is 2.420, with a standard deviation of 0.785, indicating a remarkable variability between countries. Also, Table 3 shows the thresholds of the EEGI quartiles (Q) and its sub-indices. On the one hand, it is always true that countries with scores higher than 3 (in the EEGI or in its sub-indices) are part of the first quartile (Q1), while those with scores below 2 are part of the fourth quartile (Q4). The thresholds of the intermediate quartiles

(Q2 and Q3) admit greater variability. On the other hand, it can be seen that the thresholds of the EEGI quartiles are quite similar to those of the first sub-index.

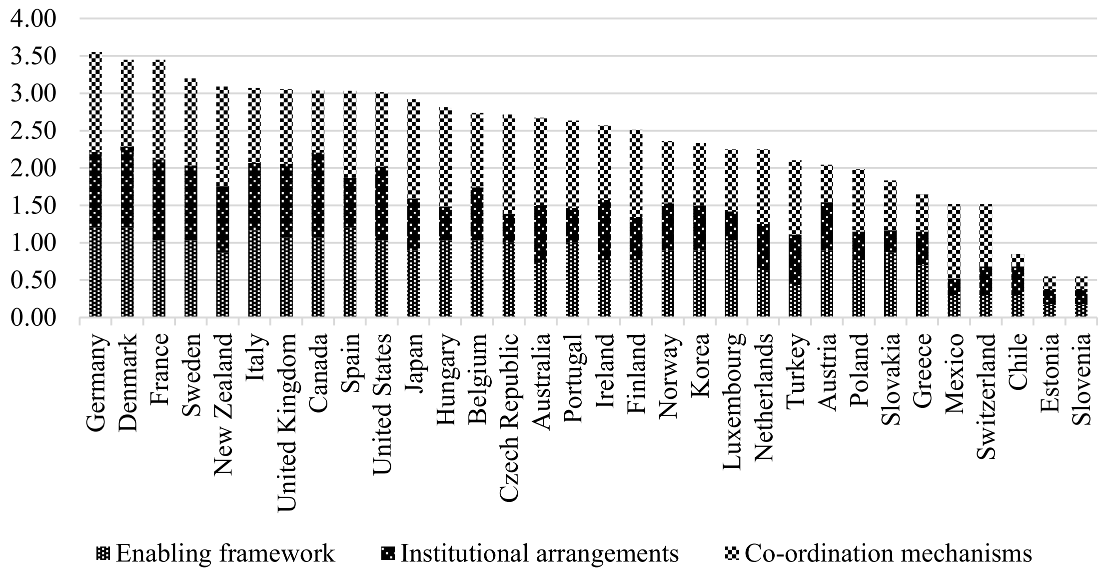

Figure 2 Energy Efficiency Governance index for OECD countries. *Source* Own elaboration using information obtained from IEA's Energy Efficiency Database (2016)

In Q1 we find countries such as Germany, Canada, Denmark, New Zealand or the United Kingdom, with Germany the country with the highest rating (3.55 out of a maximum of 4). In Q2, we find Spain, Japan, the United States, Belgium or Hungary, among others. In Q3, there are countries such as Ireland, Finland, Norway, the Netherlands or Turkey. Finally, in Q4 we have Switzerland, Mexico, Chile, the Slovak Republic, Slovenia or Estonia. These last two countries share the worst score: 0.55 out of a maximum of 4.

In Appendix C, we provide an extension of these results. We describe the variability detected in the EEGI and in the different sub-indices. We also highlight several cases of interest. In general, the EEGI provides a high variability of scores between countries and between areas, which constitutes a desirable feature for a composite index such as the one we construct (OECD, 2008; Dabla-Norris et al., 2012). We also assess the correlation between the EEGI and the number of entries available for each country in the database, observing that it is not relevant for our main results from Section 4.

Table 2 Energy Efficiency Governance index and sub-indices for OECD countries: scores and rankings

Country	Code	Baseline EEGI		Enabling framework		Institutional arrangements		Co-ordination mechanisms	
		Score	Rank	Score	Rank	Score	Rank	Score	Rank
Germany	DEU	3,55	1	3,60	1	3,05	4	4,00	1
Denmark	DNK	3,45	2	3,60	1	3,25	2	3,50	7
France	FRA	3,45	2	3,10	7	3,25	2	4,00	1
Sweden	SWE	3,20	4	3,10	7	3,00	5	3,50	7
New Zealand	NZL	3,09	5	2,60	19	2,67	9	4,00	1
Italy	ITA	3,07	6	3,50	4	2,72	8	3,00	13
UK	GBR	3,06	7	3,20	5	2,97	6	3,00	13
Canada	CAN	3,04	8	3,20	5	3,42	1	2,50	21
Spain	ESP	3,03	9	3,60	1	2,00	15	3,50	7
USA	USA	3,02	10	3,10	7	2,95	7	3,00	13
Japan	JPN	2,92	11	2,70	15	2,07	13	4,00	1
Hungary	HUN	2,82	12	3,10	7	1,35	22	4,00	1
Belgium	BEL	2,74	13	3,10	7	2,12	12	3,00	13
Czech Rep.	CZE	2,72	14	3,00	13	1,15	24	4,00	1
Australia	AUS	2,67	15	2,20	24	2,32	11	3,50	7
Portugal	PRT	2,63	16	3,00	13	1,40	21	3,50	7
Ireland	IRL	2,57	17	2,30	21	2,42	10	3,00	13
Finland	FIN	2,51	18	2,30	21	1,73	20	3,50	7
Norway	NOR	2,36	19	2,70	15	1,88	17	2,50	21
Korea	KOR	2,33	20	2,70	15	1,80	19	2,50	21
Luxembourg	LUX	2,25	21	3,10	7	1,15	24	2,50	21
Netherlands	NLD	2,25	21	1,90	26	1,85	18	3,00	13
Turkey	TUR	2,11	23	1,30	27	2,02	14	3,00	13
Austria	AUT	2,04	24	2,70	15	1,93	16	1,50	28
Poland	POL	1,98	25	2,30	21	1,15	24	2,50	21
Slovak Rep.	SVK	1,83	26	2,60	19	0,90	29	2,00	27
Greece	GRC	1,65	27	2,10	25	1,35	22	1,50	28
Mexico	MEX	1,52	28	0,90	28	0,65	30	3,00	13
Switzerland	CHE	1,52	28	0,90	28	1,15	24	2,50	21
Chile	CHL	0,85	30	0,90	28	1,15	24	0,50	30
Estonia	EST	0,55	31	0,50	31	0,65	30	0,50	30
Slovenia	SVN	0,55	31	0,50	31	0,65	30	0,50	30
AVERAGE		**2,42**		**2,48**		**1,94**		**2,83**	
Std. Dev.		0,785		0,907		0,827		1,006	

Source Own elaboration using information obtained from IEA's Energy Efficiency Database (2016)

Table 3 EEGI and sub-indices thresholds for quartiles

IGEEbase	Enabling frameworks	Institutional Arrangements	Co-ordination Mechanisms
Q1 ≥ 3.036	Q1 ≥ 3.100	Q1 ≥ 2.690	Q1 ≥ 3.500
2.603 ≤ Q2 < 3.036	2.700 ≤ Q2 < 3.100	1.908 ≤ Q2 < 2.690	3.000 ≤ Q2 < 3.500
2.014 ≤ Q3 < 2.603	2.150 ≤ Q3 < 2.700	1.150 ≤ Q3 < 1.908	2.500 ≤ Q3 < 3.000
Q4 < 2.014	Q4 < 2.014	Q4 < 1.150	Q4 < 2.500

Source Own elaboration using information obtained from Table 2

3 Data and the Instrumental Variable Approach

In this section, we first present data on per capita energy consumption and per capita real GDP and show their correlations (between and within countries) to illustrate the controversy existing in the literature when characterizing the income-energy relationship. The results of this analysis cannot be extrapolated to a causality finding. To analyze causality properly, we implement an IV approach, as described in the second part of the section. We use the EEGI as an exogenous instrument for energy consumption to estimate the effect from (energy-governance-driven) energy consumption growth to economic growth. Finally, following Brückner (2013), we construct an energy-adjusted income instrument to estimate the reverse causal relationship from income to energy consumption growth.

3.1 Energy consumption and economic activity data

We measure energy consumption through per capita Total Primary Energy Consumption (TPEC), while economic activity is measured by means of the real per capita GDP. Data come from the IEA's World Energy Balances (2018) database. TPEC is expressed in tonnes of oil equivalent (toe) per capita and real GDP in thousand USD per capita.[13] Table 4 shows the sample average, initial and final values, and the yearly log-change in the 2000-2015 period of per capita TPEC (left panel) and real per capita GDP (right panel) for our sample of 32 OECD countries.

Drawing on the average levels (first column in each panel), we observe a clearly positive correlation between both variables. For instance, Canada, Luxembourg and USA are the countries with the highest levels of energy consumption (8.06, 8.13 and 7.42 per capita toe, respectively) and, at the same time, they are among the richest countries (with a per capita GDP of 39.93, 83.73 and 48.29 thousand USD per person, respectively). A similar result is observed if we look at the countries with the lowest level of energy consumption (about 1.60 per capita toe), which are Chile, Mexico and Turkey. In turn, these countries are among the poorest in the sample, with a per capita GDP of 17.14, 15.09 and 16.95 thousand USD per person, respectively. It is worth noting that the cross-correlation has apparently reduced between 2000 and 2015: from 0.704 in the former year to 0.613 in that latter. The cross-correlation across countries for the growth rates along this period is also positive and equal to 0.660. Thus, correlations between energy per capita consumption and per capita GDP in our set of OECD countries are positive and significant for both the levels and the growth rates.

Table 4 Energy consumption and GDP in 32 OECD countries: 2000-2015

	Per Capita TPEC (toe/person)[a]				Per Capita Real GDP (Thousand USD/person)[b]			
	Average 2000-2015	Level 2000	Level 2015	Ln-change 2000-2015	Average 2000-2015	Level 2000	Level 2015	Ln-change 2000-2015
Australia	5.60	5.38	5.21	-0.21%	41.13	36.11	44.77	1.43%
Austria	3.90	3.57	3.80	0.41%	41.01	37.68	42.80	0.85%
Belgium	5.31	5.67	4.75	-1.17%	39.24	36.39	41.00	0.79%
Canada	8.06	8.26	7.54	-0.61%	39.93	36.91	42.27	0.90%
Chile	1.82	1.63	2.00	1.35%	17.14	13.42	20.81	2.92%
Czech Rep.	4.23	4.01	4.00	-0.02%	25.93	20.64	29.72	2.43%
Denmark	3.39	3.49	2.83	-1.38%	43.34	41.45	44.57	0.48%
Estonia	3.96	3.36	4.14	1.38%	21.80	14.90	26.09	3.74%
Finland	6.57	6.25	5.93	-0.35%	37.94	33.96	37.98	0.75%
France	4.05	4.14	3.71	-0.73%	35.88	34.12	36.93	0.53%
Germany	4.03	4.13	3.77	-0.61%	39.14	36.03	42.52	1.10%
Greece	2.52	2.51	2.14	-1.07%	27.05	24.38	23.57	-0.22%
Hungary	2.56	2.45	2.56	0.30%	21.16	17.21	23.93	2.20%
Ireland	3.26	3.63	2.86	-1.60%	44.62	38.69	58.14	2.72%
Italy	2.92	3.01	2.51	-1.21%	35.18	35.40	33.18	-0.43%
Japan	3.83	4.08	3.38	-1.25%	33.40	31.58	35.14	0.71%
Korea	4.69	4.00	5.39	1.98%	27.87	20.77	34.41	3.37%
Luxembourg	8.13	7.61	6.54	-1.01%	83.73	75.73	89.05	1.08%
Mexico	1.60	1.49	1.55	0.24%	15.09	14.20	16.45	0.98%
Netherlands	4.79	4.74	4.36	-0.55%	43.61	40.88	45.42	0.70%
New Zealand	4.24	4.42	4.47	0.07%	30.74	26.79	33.63	1.51%
Norway	5.98	5.83	5.71	-0.14%	57.86	54.09	59.29	0.61%
Poland	2.47	2.32	2.47	0.41%	18.95	14.27	24.23	3.53%
Portugal	2.29	2.39	2.12	-0.80%	26.66	26.12	26.66	0.14%
Slovak Rep.	3.28	3.29	3.02	-0.55%	22.30	15.48	28.11	3.98%
Slovenia	3.48	3.22	3.19	-0.07%	26.46	22.01	28.25	1.66%
Spain	2.92	3.01	2.56	-1.06%	31.61	29.50	31.72	0.48%
Sweden	5.38	5.36	4.64	-0.97%	40.44	35.77	44.13	1.40%
Switzerland	3.38	3.45	2.96	-1.01%	51.18	47.52	53.88	0.84%
Turkey	1.37	1.18	1.66	2.28%	16.95	13.26	22.97	3.66%
UK	3.36	3.79	2.78	-2.07%	35.91	32.55	38.04	1.04%
USA	7.42	8.05	6.80	-1.12%	48.29	45.02	51.59	0.91%
AVERAGE	4.09	4.05	3.79	-0.35%	35.05	31.34	37.85	1.46%
STD. DEV.	1.75	1.77	1.56	1.00%	13.84	13.61	14.34	1.20%

[a] TPEC: Total Primary Energy Consumption. TPEC is expressed in tonnes of oil equivalent (toe) per capita. [b] Unit reference: 2010 USD PPPs. [a,b] Data come from the IEA's World Energy Balances (2018) database.

However, the sign of the correlation is not clear when looking at the evolution within each country. For instance, on average, the growth rate within this period has been -0.35% and 1.26% for per capita TPEC and per capita GDP, respectively; their standard deviations are about 1.0% and 1.2% for per capita TPEC and per capita GDP, respectively. If we examine each country, we find that both variables have increased in 9 countries (Austria, Chile, Estonia, Hungary, Korea, Mexico, New Zealand, Poland, Turkey), both variables have decreased in two countries (Italy and Greece), none countries show a negative GDP growth and a positive energy growth rate and, in the remaining 21 countries, per capita GDP has increased while energy consumption has decreased. In this latter group, the largest differences between the GDP and energy growth rates are shown in Denmark, UK and Belgium. This simple analysis emphasizes the existence of a positive correlation across countries, but the evidence is mixed if we look at correlations within each country.

3.2 The construction of the instruments for energy consumption

We need an exogenous source of variation (i.e., an exogenous instrument) to robustly estimate the causal effect from energy consumption to income growth (Hsiao, 2014). To do this, we exploit the cross-section variability of our EEGI. As shown below, the EEGI is correlated with both income and energy consumption. The EEGI has a direct and significant effect on energy consumption, since it provides an effective regulatory and financial framework that enables energy efficiency and energy consumption improvements (IEA, 2010; Florini & Dubash, 2011; Pereira & Pereira Da Silva, 2017). However, to be the EEGI a valid instrument, we hypothesize that energy governance only affect economic growth through its impact on energy consumption.

Our baseline IV model uses the EEGI as instrument for energy consumption. However, since the EEGI only provides one value for each country, using the EEGI alone presents a methodological limitation because it only captures the cross-section dimension of the sample. Moreover, this sort of instrument arises a conflict when including a cross-country fixed effect in the model, which is needed to estimate within-group causality (Brückner, 2013; Bruckner & Ciccone, 2008). Therefore, using an instrument capable of capturing also the time-varying effects driving energy consumption is a relevant task to avoid potentially biased estimates (Acemoglu et al., 2019).

In this vein, we follow the strategy proposed by Ciccone et al. (2012), and we construct an alternative instrument, which varies across countries and over time:

$$EEGIOil_{it} = EEGI_i \cdot \Delta ln(OilPrice_t) \tag{1}$$

where $\Delta ln(OilPrice_t)$ is the yearly growth rate of international oil prices, which is common to all countries but it is time variant. This series is measured as the average price in $/barrel between Dubai, Brent and Texas markets, obtained from UNCTAD (2018). Ciccone et al. (2012) shows that the log-change of this series is a good proxy to international oil shocks, because its level contains a unit root, but the first difference is stationary (Figure 3). Therefore, this second instrument, in addition to vary across time and countries, captures to some extent the manner in which energy governance modulates the impact of international oil price shocks on energy growth (Gunning et al., 1976).

In Section 4, we also consider two alternative counterfactual instruments, which disregard the use of the EEGI. The first one substitutes the EEGI in equation (1) by the average value between 2000 and 2015 of the general governance index (the WGI);[14] the second alternative is the instrument originally proposed by Ciccone et al. (2012).[15] By comparing the results of these two latter –counterfactual– instruments with the two instruments including the EEGI, we can further analyze the goodness of energy governance as a relevant instrument for energy consumption to characterize its causal effect on economic activity in OECD countries.

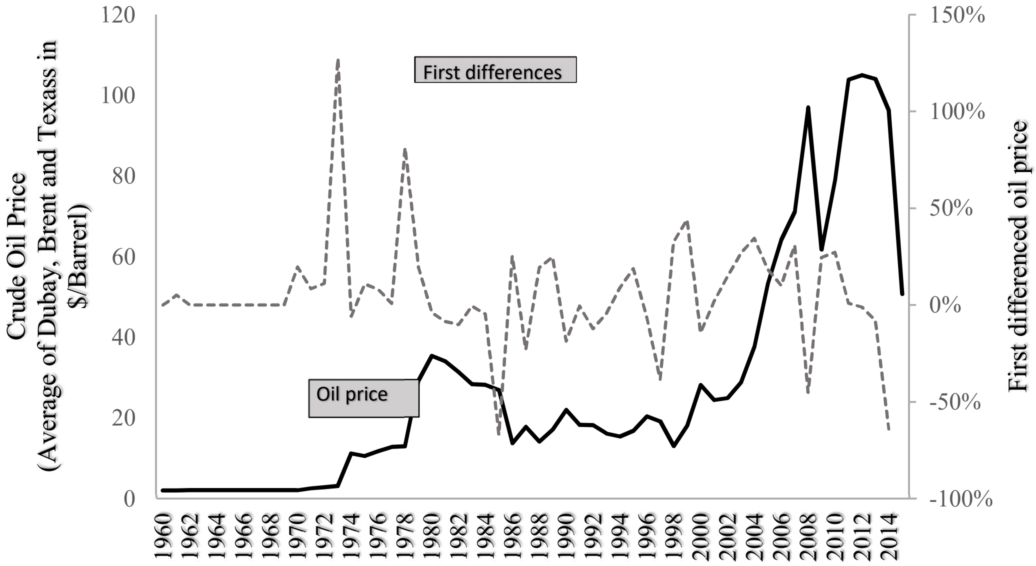

Figure 3 Time series plot of the oil price and its first difference, 1960-2015. *Source* Oil prices are measured as the average price in $/barrel between Dubai, Brent and Texas markets, from UNCTAD (2018)

3.3 The instrumental variable approach

We propose the next approach to estimate both sides of the causality: from energy consumption to income growth, and from income to energy consumption growth. Following Brückner (2013) and Ciccone et al. (2012), our energy-income models are expressed in first differences of the logs (variables are always in per capita terms). Thus, for the first side of causality:

$$\Delta\ln(y_{it}) = \lambda_i + \delta_t + \varphi\Delta ln(e_{it}) + u_{it}, \tag{2}$$

where $\Delta\ln(y_{it})$ is the log-change of real per capita GDP (i.e., real per capita GDP growth) and $\Delta ln(e_{it})$ is the log-change of per capita TPEC (i.e., per capita TPEC growth); λ_i are country fixed effects that capture the long-run (unobservable) difference across countries, and δ_t are year fixed effects that capture the global business cycle effects and other global shocks that may be jointly driving economic activity and energy consumption in our sample. For the reverse direction of the causality (from per capita GDP growth to per capita TPEC growth):

$$\Delta ln(e_{it}) = \eta_i + \kappa_t + \pi\Delta\ln(y_{it}) + \nu_{it}, \tag{3}$$

where now η_i and κ_t correspond to the country and temporal fixed effects of this reverse causal regression.

If per capita GDP growth has a significant effect on energy growth (i.e., in equation (3), $\pi \neq 0$), and the other way around (i.e., in equation (2), $\varphi \neq 0$), then the Ordinary Least Square (OLS) or the within group estimates of φ and π in (2) and (3), respectively, are biased, since $cov(\Delta ln(e_{it}), u_{it}) \neq 0$ and $cov(\Delta\ln(y_{it}), \nu_{it}) \neq 0$.

On the one hand, to handle the double causality bias in (2), we use the instruments described in 3.2 and estimate equation (2) by 2SLS. The first-stage model regress per capita TPEC growth over the corresponding instrument. Using a general notation, Z_{it} represents any of the aforementioned instruments. Thus, this first stage regression of (2) is described in equation (4):

$$\Delta\ln(e_{it}) = \theta_i + \phi_t + \beta Z_{it} + w_{it}, \tag{4}$$

where θ_i and ϕ_t are the correspondent fixed effects, β captures the strength of the energy governance and energy consumption relationship, and w is an i.i.d. error term. Notice that when the instrument Z contains the EEGI as a variable, we cannot use country fixed effects in this first-stage regression. Likewise, according to the exclusion restriction, the instruments should only systematically affect the endogenous variable (i.e., per capita GDP growth) through their impact on per capita energy consumption growth. Next, roughly speaking, the second stage uses the fitted part of the per capita energy growth explained by the instrument (i.e., the EEGI and their variations), $\hat{\beta}Z_{it}$, to estimate equation (2).

On the other hand, to evade the double causality bias in (3), following again Brückner (2013), we construct an adjusted per capita GDP growth series, $\Delta ln(y_{it})^*$, in which the response of economic activity to energy consumption is partialled out as in equation (5):

$$\Delta ln(y_{it})^* = \Delta \ln(y_{it}) - \hat{\varphi}\Delta ln(e_{it}) \tag{5}$$

where $\hat{\varphi}$ is an unbiased estimate (i.e., the IV estimates from equation (2)). Then, this adjusted series, $\Delta ln(y_{it})^*$, is used as an instrument of $\Delta \ln(y_{it})$ in equation (3). By construction, the IV estimator using this adjusted series does not suffer from the simultaneity bias providing, hence, a consistent estimate of the parameter π in equation (3).[16]

To test the validity of our instruments (in the estimation of equations (2) and (3)**),** we will conduct several widely used tests. First, we use the Hansen J-test of overidentifying restrictions, which assesses whether the instruments only affect the endogenous variable through the instrumented variable (i.e., the exclusion restriction). Second, we use the Chi-square underidentification test of Sanderson-Windmeijer (SW) in order to assess if our instruments are properly correlated with the endogenous regressor. The rejection of the null hypothesis supports identification, although not necessarily the absence of weak identification (Kleibergen & Paap, 2006).[17] Third, the Cragg-Donald Wald F-statistic complements the SW test to check the weakness of the instruments.[18]

4 Results

This section shows the results of estimating equations (2), (3) and (4) using the 2SLS approach described above. To analyze the differences in the estimates to control for double causality, we compare the 2SLS results with those obtained from traditional OLS with fixed effects. The section carries out an extensive robustness analysis.

4.1 The effect of energy consumption growth on economic growth

We start showing the estimated results for the causality from energy consumption growth to income growth. First, we estimate the reduced-form of this causality relationship, i.e., the relationship between the instruments and the dependent variable, which is per capita income growth in our case (left panel in Table 5). Second, we analyze the first stage results (equation (4)), i.e., the relationship between energy governance and energy consumption (right panel in Table 5). In this part of the section, we use the $EEGI_i$ and the $EEGIOil_{it}$ as instruments. Finally, we show the estimated results for equation (2) (see Table 6).

All regressions are controlled by year fixed effects and also by country fixed effects when they do not interfere with the instrument used. Each column in the tables uses a different set of instruments: the $EEGI_i$ in columns (a) and (e); the $EEGI_i$ and the $EEGIOil_{it}$ jointly in columns (b) and (f); the $EEGIOil_{it}$ alone in columns (c), (d), (g) and (h), but in columns (d) and (h) we also control for country fixed effects. The consideration of the model using $EEGIOil_{it}$ without fixed effects in columns (c) and (g) is justified only for comparative purposes with columns (b) and (f), respectively. All instruments are individually significant at 1% level (or very close to this level) for both per capita GDP growth and per capita TPEC growth. Likewise, the four instruments show negative coefficients, with very consistent magnitudes through the different specifications.

Table 5 First-stage estimates linking energy consumption, economic growth and energy governance

	Reduced-form model: pc income growth vs. energy efficiency governance				**First-Stage equation: pc energy growth vs. energy efficiency governance**			
	$\Delta \ln GDP_{pc}$				$\Delta \ln TPEC_{pc}$			
	(a) OLS	(b) OLS	(c) OLS	(d) OLS	(e) OLS	(f) OLS	(g) OLS	(h) OLS
$EEGI_i$	-0.006	-0.006			-0.006	-0.006		
	(0.000)	(0.000)			(0.007)	(0.015)		
$OilEEGI_{it}$		-0.018	-0.021	-0.018		-0.020	-0.023	-0.020
		(0.007)	(0.001)	(0.010)		(0.011)	(0.002)	(0.017)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	No	Yes	No	No	No	Yes
Number of observations	480	480	480	480	480	480	480	480

Note The method of estimation is Ordinary Least Squares (OLS), with p-values in parentheses. The dependent variable in columns from (a) to (d) is the yearly log-change real per capita GDP; in columns from (e) to (h) the dependent variable is the yearly log-change in per capita Total Primary Energy Consumption (TPEC). The excluded instrument in columns (a) and (e) is the $EEGI_i$; in column (b) and (f) the $EEGI_i$ and the $EEGIOil_{it}$; in columns (c), (d), (g) and (h), the excluded instrument is the $EEGIOil_{it}$, but also considering country fixed effects in columns (d) and (h)

On the one hand, the coefficient of the $EEGI_i$ is the same in all regressions (columns (a), (b), (e) and (f)). Therefore, the estimated coefficients for the $EEGI_i$ in columns (a) and (e) are equivalent to the impact that energy governance would have on economic growth and energy consumption growth, respectively, when oil prices remain constant (i.e., when $\Delta ln(OilPrice_t) = 0$). The size of the effect implies that increasing the EEGI in one standard deviation of its range (i.e., 0.785 points, which represents a total change close to 32% over its average score, which is 2.42) would lead to a reduction in energy consumption growth close to 0.5% (-0.006x0.785x100 = -0.47%). Given the fact that the 2000-2015 average change in energy consumption growth for our sample of countries is -0.35% and the standard deviation is about 1%, our results are quantitatively meaningful.[19] Consequently, to the extent that energy industries are the major responsible for CO_2 emissions growth in OECD countries, energy governance may play a remarkable role in the abatement of environmental damage and climate change.

On the other hand, the effect of the $EEGIOil_{it}$ is significant and consistent throughout the different models (columns (b), (c), (d), (f), (g) and (h)), with an average coefficient of about -0.020. This result indicates that the effect of the $EEGI_i$ on energy consumption growth –also on economic growth– depends on international oil price shocks. An increase in the international oil price causes a reduction in energy consumption growth. In the same vein, according to Ciccone et al. (2012), increases in oil price shocks perform a negative effect on economic growth for oil-importer countries (as are the vast majority of countries in our sample).

Looking at the models including the $EEGI_i$ and the $EEGIOil_{it}$ together (columns (b) and (f)), and taking into consideration an oil price growth of 10% (i.e., $\Delta ln(OilPrice_t) = 0.10$), the same change in one standard deviation of the $EEGI_i$ has now a greater impact on energy consumption growth. This impact is now about -0.63% (-0.0047-0.020x0.785x0.10 = -0.00628). A similar impact is found when the $EEGIOil_{it}$ is used alone (columns (c), (d), (g) and (f)).

The second-stage results are presented in Table 6. The table includes the baseline OLS with fixed effects and the 2SLS estimates of the effect that per capita TPEC growth has on per capita GDP growth. In columns (a) and (b) this effect is assessed using OLS and controlling for year fixed effects, and in column (b) we also control for country fixed effects. In these columns, the OLS estimates show a positive coefficient around 0.20, which implies that increasing per capita TPEC growth by 1% would increase per capita GDP growth, on average, by 0.2%. However, if per capita GDP growth has a significant effect on per capita TPEC growth, this OLS point estimate can be severely biased.

The remaining columns in Table 6 presents the 2SLS estimates that use the instruments described above: the $EEGI_i$ in column (c), the $EEGI_i$ and the $EEGIOil_{it}$ in column (d) and the $EEGIOil_{it}$ in columns (e) and (f). We control all regressions by year fixed effects, and in column (f) we also control for country fixed effects. To compare results with those in column (d), we do not include country fixed effects in column (e). For the 2SLS results in the table, in square brackets, we report the p-value of the Anderson-Rubin test of statistical significance (Andrews & Stock, 2005), which is robust to weak instruments (the weak instrument issue is analyzed in more detail below).

All estimates are significant at 1% level and its elasticity is much larger than the corresponding OLS estimate in columns (a) and (b). Indeed, when the $EEGI_i$ is the excluded instrument (column (c)), the estimated 2SLS elasticity is almost the unity (1.02). Using the alternative sets of instruments (columns (d)-(f)), estimated coefficients vary from 0.90 to 0.96. Thus, increasing per capita TPEC growth by 1% is associated with an average growth in per capita GDP between 0.9% and 1%. The Hausman test rejects that the OLS estimate is equal to the 2SLS estimate at the 1% level (p-value < 0.01), thus pointing out to a significant difference between the OLS and the IV estimates.

From the comparison between OLS and 2SLS estimates, we can draw two main conclusions: (i) the OLS with fixed effects estimates are downward biased; (ii) the energy consumption growth driven by energy efficiency governance shows a stronger effect on income growth than total energy consumption growth. The fraction of energy consumption driven by energy efficiency governance is related with improvements in energy efficiency and the consequent impact on overall productivity might explain this result.

Table 6 The effect of per capita energy consumption growth on per capita economic growth

		ΔlnGDP$_{pc}$					
		(a) OLS	(b) OLS	(c) 2SLS	(d) 2SLS	(e) 2SLS	(f) 2SLS
ΔlnTPEC$_{pc}$		0.231 (0.000)	0.181 (0.000)	1.019 [0.000]	0.960 [0.000]	0.901 [0.001]	0.881 [0.006]
Underidentification test	Sanderson-Windmeijer Chi-sq			7.660 (0.007)	15.850 (0.000)	9.610 (0.002)	6.380 (0.012)
Weak identification test	Cragg-Donald F			9.740	8.675	9.816	7.469
	Stock-Yogo 10%			16.38	19.93	16.38	16.38
	Stock-Yogo 15%			8.96	11.59	8.96	8.96
	Stock-Yogo 20%			6.66	8.75	6.66	6.66
	Stock-Yogo 25%			5.53	7.25	5.53	5.53
Overidentification test	Hansen J (p-value)			Exactly-identified	(0.785)	Exactly-identified	Exactly-identified
Year FE		Yes	Yes	Yes	Yes	Yes	Yes
Country FE		No	Yes	No	No	No	Yes
Number of observations		480	480	480	480	480	480

Note The method of estimation in columns (a) and (b) is Ordinary Least Squares (OLS). The method of estimation in columns from (c) to (f) is Two-Stage Least Squares (2SLS). P-values are reported in parentheses; below the 2SLS estimates, p-values in square brackets are reported based on the Anderson-Rubin test of statistical significance. The dependent variable in columns from (a) to (f) is the yearly ln-change in real per capita GDP. The independent variable is the yearly ln-change in per capita Total Primary Energy Consumption (TPEC). The IV in column (c) is the $EEGI_i$. In column (d) we have two IVs: the $EEGI_i$ and the $EEGIOil_{it}$. The IV in columns (e) and (f) is the EE governance shock, but in column (f) we control for country fixed effects. Stock-Yogo values for maximal IV size are based on Stock & Yogo (2005)

To assess causality, the instruments must fulfill the exclusion restriction (i.e., the instruments can only affect the endogenous variable through the instrumented one). The model is exactly identified (i.e., we use one excluded instrument for per capita energy growth) in columns (c), (e) and (f), hence we can only use the Hansen J-test in model (d), where the excluded instruments are $EEGI_t$ and $EEGIOil_{it}$. Here, the p-value of the Hansen J-test is 0.785, much higher than 0.1, which means that the test does not reject that the instruments are uncorrelated with the second-stage error term (i.e., u_{it} in equation (2)), hence they are not rejected as valid instruments for energy consumption growth.

Reporting the 2SLS estimates when the instruments are added to the right-hand side of the second-stage equation (i.e., equation (2)) provides a more specific and intuitively way to show that there are no systematically direct effects of our instruments on per capita GDP growth (Brückner, 2013). Based on column (d) from Table 6, Table 7 shows the estimated results when the $EEGI_i$ and the $EEGIOil_{it}$ are added as potential explicative variables to per capita income growth. The magnitude of the coefficient of the $EEGI_i$ on per capita GDP growth (column (a)) is, at least, onesixth of the size of the coefficient that was obtained in the reduced-form (columns (a) and (b) in Table 5). Furthermore, the coefficient is not significant at any conventional confidence level. The same occurs when the $EEGIOil_{it}$ is added to the right-hand side of the second-stage equation. In fact, the estimated coefficient flips sign, another symptom of lack of significance. These results resonate the outcome of the Hansen J-test, which does not reject the validity of $EEGI_i$ and the $EEGIOil_{it}$ as instruments for energy consumption growth.

Table 7 Test of exclusion restriction: energy and income growth extended with instruments

		ΔlnGDP$_{pc}$	
		(a) 2SLS	(b) 2SLS
ΔlnTPEC$_{pc}$		0.881 [0.006]	1.039 [0.000]
EEGI$_i$		-0.001 (0.771)	
OilEEGI$_{it}$			0.003 (0.794)
Underidentification test	Sanderson-Windmeijer Chi-sq	6.710 (0.010)	6.130 (0.013)
Weak identification test	Cragg-Donald F	7.474	7.397
	Stock-Yogo 10%	16.38	16.38
	Stock-Yogo 15%	8.96	8.96
	Stock-Yogo 20%	6.66	6.66
	Stock-Yogo 25%	5.53	5.53
Overidentification test	Hansen J	Exactly-identified	Exactly-identified
Year FE		Yes	Yes
Country FE		No	No
Number of observations		480	480

Note The method of estimation is Two-Stage Least (2SLS). P-values are reported in parentheses; below the 2SLS estimates p-values in square brackets are reported based on the Anderson-Rubin test of statistical significance. The dependent variable in columns (a) and (b) is the ln-yearly change real per capita GDP. In column (a) the IV is the $EEGIOil_{it}$, whereas the $EEGI_i$ is added to the right-hand side of the second-stage equation. In column (b) the IV is the $EEGI_i$, whereas the $EEGIOil_{it}$ is added to the right-hand side of the second-stage equation. Stock-Yogo values for maximal IV size are based on Stock & Yogo (2005)

To finish with the analysis about the validity of instruments, we assess whether the instruments are properly correlated with the endogenous regressors (i.e., the instruments are not weak). Otherwise, the estimators would perform poorly and the IV results would not yield consistent second-stage estimates (Nelson & Startz, 1990). In this vein, the SW Chi-square underidentification test provides a significance close to the 1% level in all cases (columns (c)-(f) in Table 6). Furthermore, according to the F-statistics reported, the maximal IV relative bias (with respect to OLS) is less than 20%. Keeping these findings in mind, the correct identification of models in columns (c-f) is supported and weak instruments should not be an important concern in our estimations. Moreover, as commented above for 2SLE, we are also reporting p-values based on the Anderson-Rubin test of statistical significance (in square brackets), which is valid even under the existence of weak instruments.

4.2 The effect of economic growth on energy consumption growth

We show next the estimated results for the causality from GDP growth to energy consumption growth. As commented in Section 3.2, for this side of the causality, we use the adjusted per capita GDP growth series $\Delta ln(y_{it})^*$ obtained from equation (5) to instrument per capita income growth in equation (3). To construct the adjusted series, we use the 2SLS estimates from equation (2). Hence, the per capita GDP growth is adjusted by the (energy-governance-driven) energy consumption growth. By construction, this instrument is highly correlated with income growth, and weakly correlated with the error term in (3). For that reason, for this side of the causality, we just show results for the second stage regressions (first stage results are available upon request).

Table 8 presents the baseline OLS and 2SLS estimates of the effect that per capita GDP growth has on per capita TPEC growth (equation (3)). In columns (a) and (b), this effect is assessed using OLS and controlling for year fixed effects, but in column (b) we also control for country fixed effects. The two OLS estimates are very similar, with a positive average coefficient of 0.47, which implies that increasing per capita GDP growth by 1% is associated with an increase in per capita TPEC growth around 0.47%. This positive effect is the one usually obtained in the literature (Masih & Masih, 1996; Fatai et al., 2004; Esseghir & Khouni, 2014; among others), but recall that these works (as our OLS estimates) do not control for double causality. In our case, since energy consumption growth significantly affects economic growth (as showed in Table 6), the OLS estimate of equation (3) can be severely biased, which is what happens in our case.

The remaining columns in Table 8 present the 2SLS estimates using the adjusted GDP series as the instrument of per capita GDP growth. The instrument is constructed from equation (5), using 2SLS estimates from columns (c)-(f) in Table 6. In all cases, the regressions are controlled for year fixed effects and, in column (f), we also consider country fixed effects. We provide again the p-values (in square brackets) of the Anderson-Rubin test of statistical significance. Our 2SLS estimates produce considerably changes in the estimates of the effect that economic growth has on energy consumption growth, not only in size, but also in sign. All estimates are significant at the 1% level and are meaningful in magnitude. We obtain negative coefficients (elasticities) ranging from -2.84 to -3.24, which implies that increasing the per capita GDP growth by 1% is associated, on average, with a reduction of per capita TPEC growth by about 2.9%.

Table 8 The effect of per capita economic growth on per capita energy consumption growth

		ΔlnTPEC$_{pc}$					
		(a) OLS	(b) OLS	(c) 2SLS	(d) 2SLS	(e) 2SLS	(f) 2SLS
ΔlnGDP$_{pc}$		0.482 (0.000)	0.459 (0.000)	-3.242 [0.000]	-2.837 [0.000]	-2.477 [0.000]	-2.992 [0.000]
Underidentification test	Sanderson-Windmeijer Chi-sq			14.540 (0.000)	17.350 (0.000)	20.830 (0.000)	18.160 (0.000)
Weak identification test	Cragg-Donald F			62.157	78.221	98.427	84.769
	Stock-Yogo 10%			16.38	16.38	16.38	16.38
	Stock-Yogo 15%			8.96	8.96	8.96	8.96
	Stock-Yogo 20%			6.66	6.66	6.66	6.66
	Stock-Yogo 25%			5.53	5.53	5.53	5.53
Overidentification test	Hansen J			Exactly-identified	Exactly-identified	Exactly-identified	Exactly-identified
Year FE		Yes	Yes	Yes	Yes	Yes	Yes
Country FE		No	Yes	No	No	No	Yes
Number of observations		480	480	480	480	480	480

Note The method of estimation in columns (a) and (b) is Ordinary Least Squares (OLS). The method of estimation in columns from (c) to (f) is Two-Stage Least Squares (2SLS). P-values are reported in parentheses; below the 2SLS estimates p-values in square brackets are reported based on the Anderson-Rubin test of statistical significance. The dependent variable in columns from (a) to (f) is the ln-yearly change in per capita Total Primary Energy Consumption (TPEC). The independent variable is the ln-yearly change in real per capita GDP. The IVs for columns from (c) to (f) are the ln-yearly change of per capita GDP series that are adjusted for the reverse effect that ln-yearly change per capita TPEC has on ln-yearly change on per capita GDP, according to the estimates of the models presented in columns from (c) to (f) in Table 6 (see table's footnote). Stock-Yogo's maximal IV sizes for Cragg-Donald F statistic are based on Stock & Yogo (2005)

As commented above, since the adjusted income growth instrument does not suffer from simultaneity bias (by construction), all IV tests result satisfactory. First, the overidentifying test (the Hansen J-test) indicates that the model is exactly-identified in all cases. Second, the underidentification test also provides the expected results, since the SW test is significant in all our models (columns (c)-(f)). Finally, the weak identification test (i.e., the Cragg-Donald F statistic) is clearly over 10, which implies that weak instruments are not a concern.

According to these results and those from Section 4.1., the existence of a bidirectional causal relationship between energy consumption and income growth is verified in our sample of OECD countries. The causal relationship obtained from energy consumption growth (driven by energy governance) to income growth is positive and its elasticity is almost equal to one. However, the causal relationship obtained from economic growth to energy consumption is highly negative. Improving the use of energy driven by the improvement of energy efficiency governance shows a double benefit on the economy. It favors energy efficiency and income growth and, at the same time, the consequent improvement of income growth would reduce per capita energy consumption. Energy efficiency governance is the main driver for the existence of these two positive effects simultaneously. Therefore, since economic growth and energy consumption are essential aspects for the abatement of environmental damage, our results indicate that energy governance can play a remarkable role for decoupling carbon emissions from GDP growth.

Our results are especially relevant for (energy) policy making. At the aggregate level, the existence of a bidirectional causality implies that the adoption of conservationist energy policies (i.e., measures aimed at reducing the amount of energy consumed) can damage economic growth. On the contrary, the negative sign of the causality from economic growth to energy consumption implies that policies aimed at improving economic growth tend to reduce energy consumption growth, which implies an increase in energy efficiency. Consequently, energy governance in the OECD should be focused on ensuring that energy policy making is designed to increase energy efficiency, rather than to reduce energy consumption (Esseghir & Khouni, 2014).

Each of the elements underpinning energy governance (recall from Figure 1) should reflect this condition. As a result, economic growth could be improved, while energy consumption can be reduced, which is what our 2SLS estimates suggest. For instance, laws and energy plans aimed at promoting the development of renewable energies, which are more efficient than oil-based technologies, must preferred to those which promote a reduction in energy consumption. Similarly, policies that advocate for the use of more efficient cooling and heating systems (through equipment labeling standards, for example) will be preferred, rather than those aimed at reducing heating and cooling energy demand. This same idea may easily be extended to the industrial sectors, building, electrical appliances, lighting, etc.

4.3 A counterfactual analysis: using alternative instruments

We replicate our energy-income analysis, but using the two counterfactual instruments proposed in Section 3 for per capita energy consumption growth. We show that, while our instruments based on EEGI are suitable for the double causality assessment, alternative instruments based on general governance or oil trade variables do not provide proper instruments for an energy-income model.

For the first alternative, we use the cross-section value of the WGI between 2000 and 2015, given by WGI_i, which captures general governance quality, in order to substitute the EEGI as instrument for energy consumption. Following equation (1), we also construct the alternative time-varying instrument as $WGI_i \text{x} \Delta ln(OilPrice_t)$, and we denote this new instrument by $WGIOil_{it}$. For the second alternative, our $EEGI_i$ is replaced by a fixed term, θ_i, which represents oil export minus oil imports relative to GDP over the whole time period 2000-2015 (the one used in Ciccone et al., 2012). Thus, the time-varying instrument is now given by $\theta_i \text{x} \Delta ln(OilPrice_t)$, and we denote it by $TradeOil_{it}$.

Table 9 presents the 2SLS estimates of the effect that per capita TPEC growth has on per capita GDP growth using these counterfactual instruments. To simplify the exposition of results, we present the results relative to the time-invariant instruments, the combination of the time-invariant and time-varying instruments and, finally, the time-varying instruments when country fixed effects are considered (the remaining results are available upon request). Therefore, the instruments used are the WGI_i in column (a), the WGI_i and the $WGIOil_{it}$ jointly in column (b), and the $WGIOil_{it}$ in column (c); in column (d) we use the θ_i, the θ_i and the $TradeOil_{it}$ jointly in column (e), and the $TradeOil_{it}$ in column (f). All regressions are also controlled for year fixed effects.

On the one hand, the estimated coefficient when the WGI_i is used as instrument (column (a)) is significant and comparable to that found when the $EEGI_i$ instruments energy consumption (columns (c) and (d) in Table 6). However, the resulting (weak identification) F-statistic is slightly lower in this case, which provides a relative higher Stock-Yogo bias (close to 20%). Moreover, when the instrument used is $WGIOil_{it}$ (in columns (b) together with WGI_i and in (c) alone), the estimated coefficients are higher (specially in (c)), but the instruments are weak and performs poorly (i.e., the F-statistic is about 4.0 and 0.27 in columns (b) and (c), respectively), thus providing coefficients that are biased. The non-significance of the under-identification test in column (c) resonates this conclusion.

Table 9 The effect of per capita energy consumption growth on per capita economic growth considering counterfactual instruments

		ΔlnGDP$_{pc}$					
		(a) 2SLS	(b) 2SLS	(c) 2SLS	(d) 2SLS	(e) 2SLS	(f) 2SLS
ΔlnTPEC$_{pc}$		0.896 [0.001]	0.959 [0.000]	2.817 [0.037]	24.33 [0.002]	0.288 [0.002]	0.212 [0.700]
Underidentification test	Sanderson-Windmeijer Chi-sq	6.76 (0.009)	6.94 (0.031)	0.30 (0.584)	0.00 (0.982)	0.33 (0.850)	0.27 (0.605)
Weak identification test	Cragg-Donald F	7.798	4.026	0.266	0.002	0.370	0.751
	Stock-Yogo 10%	16.38	19.93	16.38	16.38	19.93	16.38
	Stock-Yogo 15%	8.96	11.59	8.96	8.96	11.59	8.96
	Stock-Yogo 20%	6.66	8.75	6.66	6.66	8.75	6.66
	Stock-Yogo 25%	5.53	7.25	5.53	5.53	7.25	5.53
Overidentification test	Hansen J	Exactly-identified	(0.300)	Exactly-identified	Exactly-identified	(0.100)	Exactly-identified
Year FE		Yes	Yes	Yes	Yes	Yes	Yes
Country FE		No	No	Yes	No	No	Yes
Number of observations		480	480	480	480	480	480

Note The method of estimation is Two-Stage Least Squares (2SLS). P-values are reported in parentheses; below the 2SLS estimates p-values in square brackets are reported based on the Anderson-Rubin test of statistical significance. The dependent variable in columns from (a) to (f) is the ln-yearly change in real per capita GDP. The independent variable is the ln-yearly change in per capita Total Primary Energy Consumption (TPEC). The IV in column (a) is the WGI_i, in column (b), the WGI_i and the $WGIOil_{it}$ together, and in column (c), it is the $WGIOil_{it}$. The IV in column (d) is the θ_i, in column (e), the θ_i and the $TradeOil_{it}$ together, and in column (f), it is the $TradeOil_{it}$. Stock-Yogo values for maximal IV size are based on Stock & Yogo (2005)

On the other hand, the effect of per capita TPEC growth on per capita GDP growth is significant at 1% level when the instrument θ_i is used alone or combined with $TradeOil_{it}$ (columns (d) and (e), respectively). However, this effect is not significant at any conventional level when the $TradeOil_{it}$ alone is considered (column (f)). Moreover, in these three cases their under-identification tests are not rejected (p-values much higher than 0.10), and the Cragg-Donald F statistics are very low, which implies that the instruments are strongly weak and the point estimates are severely biased. In addition, the Hansen J-test in column (e) is only significant at the 10% level, which suggest that θ_i and $TradeOil_{it}$ have also a direct effect on income growth, thus they are invalid instruments for energy consumption growth.

4.4 Further robustness checks

We conduct a robustness analysis to our main results. First, we consider Total Final Energy Consumption (TFEC) instead of the primary energy sources TPEC. Second, we extend our model and include several additional explicative variables, such as energy prices or the general quality of governance.

With respect to the first analysis, in general, when analyzing the determinants of energy consumption, the literature uses the primary source (S. Wang et al., 2018), while it tends to use the final consumption when analyzing efficiency (Metcalf, 2008). In our sample of 32 OECD countries, between 2000 and 2015, primary consumption of oil, natural gas and coal represents 82%, while this same item accounted for only 72% in final consumption, due to the greater weight of renewables. Therefore, it is important to check if our results are robust to the use of primary or final energy consumption.

Panel A in Table 10 presents the 2SLS estimates of the effect that per capita TFEC growth has on per capita GDP growth.[20] We consider the same instruments and their combination in columns (a)-(d) than in Table 6. Results are similar to those in Table 6, showing elasticities systematically greater than one (ranging between 1.1 and 1.2) and significant at the 1% level. Meanwhile, panel B in Table 10 shows the estimates of the other side of the causality, from per capita GDP growth to per capita TFEC growth, using the equivalent adjusted per capita GDP as instrument. All estimates are significant at the 1% level, with similar coefficients ranging from -2.53 to -3.23, thus leading also to a similar result than for primary energy consumption. Moreover, in both cases, the different tests indicate the validity of the instruments used. Thus, the exclusion restriction and the identification condition are fulfilled. Likewise, the resulting F-statistics are very close to 10 in Panel A, which indicates that weak instruments should not be a concern. We only obtain a low F-statistic when using the $EEGIOil_{it}$ as instrument (column (d)). However, the maximal IV relative bias is around 20%, which can be accepted as a reasonable threshold, as proved in Brückner (2013).

Table 10 Relationship between per capita economic growth and per capita energy consumption growth measured through Total Final Energy Consumption

PANEL A		$\Delta \ln GDP_{pc}$			
		(a) 2SLS	(b) 2SLS	(c) 2SLS	(d) 2SLS
$\Delta \ln TFEC_{pc}$		1.216 [0.000]	1.165 [0.000]	1.109 [0.001]	1.091 [0.006]
Underidentification test	Sanderson-Windmeijer Chi-sq	9.270 (0.002)	21.410 (0.000)	10.55 (0.001)	7.290 (0.007)
Weak identification test	Cragg-Donald F	9.562	8.243	9.035	6.899
	Stock-Yogo 10%	16.38	19.93	16.38	16.38
	Stock-Yogo 15%	8.96	11.59	8.96	8.96
	Stock-Yogo 20%	6.66	8.75	6.66	6.66
	Stock-Yogo 25%	5.53	7.25	5.53	5.53
Overidentification test	Hansen J	Exactly-identified	(0.776)	Exactly-identified	Exactly-identified
Year FE		Yes	Yes	Yes	Yes
Country FE		No	No	No	Yes
Number of observations		480	480	480	480
PANEL B		$\Delta \ln TFEC_{pc}$			
		(a) 2SLS	(b) 2SLS	(c) 2SLS	(d) 2SLS
$\Delta \ln GDP_{pc}$		-3.225 [0.000]	-2.867 [0.000]	-2.527 [0.000]	-3.113 [0.000]
Underidentification test	Sanderson-Windmeijer Chi-sq	9.320 (0.002)	11.170 (0.001)	13.580 (0.000)	10.660 (0.001)
Weak identification test	Cragg-Donald F	42.648	52.261	64.741	52.226
	Stock-Yogo 10%	16.38	16.38	16.38	16.38
	Stock-Yogo 15%	8.96	8.96	8.96	8.96
	Stock-Yogo 20%	6.66	6.66	6.66	6.66
	Stock-Yogo 25%	5.53	5.53	5.53	5.53
Overidentification test	Hansen J	Exactly-identified	Exactly-identified	Exactly-identified	Exactly-identified
Year FE		Yes	Yes	Yes	Yes
Country FE		No	No	No	Yes
Number of observations		480	480	480	480

Note The method of estimation in panels A and B is both Two-Stage Least Squares (2SLS). P-values are reported in parentheses; below the 2SLS estimates p-values in square brackets are reported based on the Anderson-Rubin test of statistical significance. In Panel A, the dependent variable is the yearly ln- change in real per capita GDP and the independent variable is the yearly ln-change in per capita Total Final Energy Consumption (TFEC). In Panel B, we use the same variables but their roles are swapped. In Panel A, the instrumental variable in column (a) is the $EEGI_i$; in column (b), both the $EEGI_i$and the $EEGIOil_{it}$; in columns (c) and (d), the $EEGIOil_{it}$. In Panel B, the instrumental variables are the yearly ln-change in per capita GDP series that are adjusted for the reverse effect that the yearly ln-change in per capita TFEC has on GDP series. Stock-Yogo's maximal IV sizes for Cragg-Donald F statistic are based on Stock & Yogo (2005).

Table 11 summarizes results for the second type of robustness checks. Panel A shows results for the causality from energy to income, and panel B the other way around. Regressions in column (a) of both panels are controlled for the lagged level of the dependent variable, following (Brückner, 2013; Ciccone et al., 2012). In column (b), we include the effect of the lagged level of per capita GDP and per capita GDP squared on per capita primary energy consumption growth. Finally, in columns from (c) to (e), we control for exogenous variables such as the general governance quality (measured through the WGI), the energy prices growth and both variables together, respectively.[21] In all cases, we have used the $EEGIOil_{it}$ as reference instrument since it captures both time-varying and country fixed effects affecting energy consumption.

According to column (a) in Table 11, when we control for the lagged level of the dependent variable, the size of the coefficients obtained for both causality relations is slightly lower than the magnitude shown in Tables 6 and 8. The estimated GDP-energy consumption growth elasticities are positive and between 0.8 and 0.9, while those elasticities estimated for the other side of the causality (the energy-GDP growth) are negative and between -2.0 and -3.0, approximately. In all cases, they are significant at the 1% level. Moreover, the under-identification and the over-identification tests provide similar results, while the F-statistic for weak instrument is slightly improved in both cases.

Focusing on column (b) of Panel B, when we control for the lagged levels of per capita GDP and per capita GDP squared, the size of the coefficient for per capita GDP growth and its significant remains almost unchanged. The lagged level of per capita GDP shows a positive coefficient, whereas the quadratic term has a negative coefficient. Both of them are significant at the 10% level. This result suggests that the initial growth of the economy induces a higher energy consumption but, at some stage, if the economy continues growing, energy consumption reduces. As in the previous case, the different tests indicate the validity of the instruments used (the $EEGI_i$ and the $EEGIOil_{it}$).

Table 11 Relationship between per capita income growth and per capita energy consumption growth (robustness of IV estimates to different exogenous variables)

PANEL A		ΔlnGDP$_{pc}$				
		(a) 2SLS	(b) 2SLS	(c) 2SLS	(d) 2SLS	(e) 2SLS
ΔlnTPEC$_{pc}$		0.781 [0.010]	0.881 [0.006]	0.881 [0.006]	0.845 [0.027]	0.845 [0.027]
L1.lnGDP$_{pc}$		-0.055 (0.012)				
WGI				-0.009 (0.747)		-0.007 (0.798)
ΔlnEnergy prices					-0.096 (0.079)	-0.096 (0.079)
Underidentification test	Sanderson-Windmeijer Chi-sq	6.600 (0.010)	6.380 (0.012)	6.380 (0.012)	4.750 (0.0293)	4.750 (0.029)
Weak identification test	Cragg-Donald F	7.830	7.469	7.469	6.342	6.342
	Stock-Yogo 10%	16.38	16.38	16.38	16.38	16.38
	Stock-Yogo 15%	8.96	8.96	8.96	8.96	8.96
	Stock-Yogo 20%	6.66	6.66	6.66	6.66	6.66
	Stock-Yogo 25%	5.53	5.53	5.53	5.53	5.53
Overidentification test	Hansen J	Exactly-identified	Exactly-identified	Exactly-identified	Exactly-identified	Exactly-identified
Year FE		Yes	Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes	Yes
Number of observations		480	480	480	480	480

PANEL B		ΔlnTPEC$_{pc}$				
		(a) 2SLS	(b) 2SLS	(c) 2SLS	(d) 2SLS	(e) 2SLS
ΔlnGDP$_{pc}$		-2.235 [0.000]	-3.102 [0.000]	-2.992 [0.000]	-2.748 [0.000]	-2.748 [0.000]
L1.lnTPEC$_{pc}$		-0.178 (0.002)				
L1.lnGDP$_{pc}$			4.016 (0.068)			
(L1.lnGDP$_{pc}$)^2			-0.210 (0.061)			
WGI				0.081 (0.198)		0.081 (0.237)
ΔlnEnergy prices					-0.467 (0.005)	-0.467 (0.005)
Underidentification test	Sanderson-Windmeijer Chi-sq	25.970 (0.000)	166.720 (0.000)	18.160 (0.000)	19.800 (0.000)	19.800 (0.000)
Weak identification test	Cragg-Donald F	136.708	81.385	84.769	98.372	98.372
	Stock-Yogo 10%	16.38	16.38	16.38	16.38	16.38
	Stock-Yogo 15%	8.96	8.96	8.96	8.96	8.96
	Stock-Yogo 20%	6.66	6.66	6.66	6.66	6.66
	Stock-Yogo 25%	5.53	5.53	5.53	5.53	5.53
Overidentification test	Hansen J	Exactly-identified	Exactly-identified	Exactly-identified	Exactly-identified	Exactly-identified
Year FE		Yes	Yes	Yes	Yes	Yes
Country FE		Yes	Yes	Yes	Yes	Yes
Number of observations		480	480	480	480	480

Note The method of estimation is 2SLS in both panels. P-values are reported in parentheses; below the 2SLS estimates p-values in square brackets are reported based on the Anderson-Rubin test of statistical significance. In Panel A, the dependent variable is the yearly ln-change in real per capita GDP and the instrumental variable is $EEGIOil_{it}$. In Panel B, the dependent variable is the yearly ln-change in per capita Total Primary Energy Consumption (TPEC). In Panel B, the instrumental variables are the yearly ln-change in per capita GDP series that are adjusted for the reverse effect that the yearly ln-change in per capita TPEC has on GDP. Stock-Yogo's maximal IV sizes for Cragg-Donald F statistic are based on Stock & Yogo (2005).

According to column (c) in Table 11, the effect that the WGI has on both per capita TPEC growth and per capita GDP growth is not significant at any conventional level. However, the IV tests remains valid, which means that our instrument is robust to the inclusion of additional exogenous variation. In column (d), we control for the energy prices growth. As expected, the effect that this variable has on per capita primary energy consumption growth is negative and significant (at the 10% level). The effect of energy prices growth on per capita GDP growth is also negative, but it is significant at the 1% level. Exclusion restriction and identification condition are fulfilled. Likewise, despite that the F statistic is slightly lower than in the previous cases, the maximal IV relative bias is very close to 20% again. Finally, if we control for the effect of the WGI and energy prices growth at the same time (column (e)), the results obtained do not differ from the results provided when controlling individually for each variable.

5 Conclusions and policy implications

We analyze the causal relationship between energy consumption growth and income growth for 32 OECD countries between 2000 and 2015. Traditional OLS fixed effects estimates are biased, unless we have an exogenous source that control for double causality. Energy governance combines aspects related with energy efficiency laws, decrees and financing mechanisms, the existence of energy agencies, or the existence of coordination mechanisms necessary for a successful development of energy policies. The literature has emphasized the relevance that energy governance improvements might have in the use of energy and, as a consequence, in income growth. The construction of an Energy Efficiency Governance Index (EEGI) for our OECD sample, which is used as a potential exogenous source to characterize the causal relationship from energy consumption to income growth, is a relevant contribution of this paper. We then use the 2SLS estimates of this causal relationship to construct an adjusted per capita GDP growth series, which is used to estimate the other side of the causality.

Our EEGI results show that countries such as Germany, Denmark and France have a highly developed energy governance, while others such as Slovenia, Estonia or Chile have ample room for improvement. In those countries with better energy governance performance, the regulatory aspects (laws, decrees, strategic planning) are the ones showing a higher level of development. Also, to a lesser extent, the establishment targets and evaluation mechanisms are common practices in better energy governance economies. Our EEGI breaks new ground in the energy governance literature, since indices about energy governance are not available to date and it can complement available general governance indices, such as the World Governance Indicator.

Concretely, our results suggest that increasing energy governance quality by one standard deviation (around 32% over its average score) could reduce energy consumption growth by approximately 0.50%. The meaning of increasing the EEGI by one standard deviation varies across countries. For example, in a country with a low developed Enabling Frameworks area (e.g., Netherlands or Turkey), energy governance can be easily improved by drafting additional laws and decrees that cover new sectors (e.g., building, industry, appliances) or by expanding the existing regulation. Furthermore, energy governance could also be improved in these cases by establishing strategic plans that identify both the quantitative objectives of these laws, as well as the economic costs necessary to monitor and enforce them. On the contrary, a country with an underdeveloped Co-ordination Mechanisms area (e.g., Austria) can easily improve its energy governance score by defining evaluation mechanisms that help policy-makers to verify the development of their strategic plans and the achievement of their energy targets.

We also provide new insights on the channels through which energy use and economic development interact. Specifically, we show the existence of a bidirectional causal relationship between energy consumption and income growth, in which energy governance plays a crucial role. On the one hand, from energy to income growth, we find that the estimated elasticity is close to unity in most cases. This result almost triples the elasticities estimated under OLS with fixed effects and, at least, doubles the elasticities commonly found in the literature. Therefore, (energy-governance-driven) energy consumption growth has a much stronger effect on income growth than overall energy consumption growth. On the other hand, from income to energy consumption growth, the instrumental variable estimates show a sizable negative elasticity (around -3.00), which is of opposite sign to the usual finding in the literature and to our OLS fixed effects estimates. Thus, for our set of OECD countries between 2000 and 2015, improving the use of energy driven by the improvement of energy efficiency governance is growth enhancing and, at the same time, the consequent improvement of income growth would reduce per capita energy consumption.

The need to correctly identify the causal relationship between energy consumption and economic growth is important to ensure the effectiveness of the energy policies and to minimize their negative impacts on the economy. According to our results, adopting conservationist energy policies in our sample of 32 OECD countries (i.e., reducing total energy use) can harm aggregate economic growth. In these cases, improving energy governance allows a more efficient use of energy, which can improve energy efficiency and hence income growth, at the same time the posterior use of overall energy consumption can be reduced. Therefore, this work, in addition to offering for the first time a measure of the quality of energy governance, contributes to improving the understanding of the relationship between energy consumption and economic growth, favoring the development of effective energy policies that do not hinder the economy. Moreover, to the extent that energy use is the main source of greenhouse gases, improvements in energy governance would help to combat climate change without hampering economic growth.

Notes

1 The models of energy use analyze the relationship between economic value-added, physical capital and energy use, and emphasize the channels through which energy is substituted for capital in the production process, and the role of the technology in such substitution (see Andrew Atkeson & Kehoe, 1999; Díaz, Puch, & Guilló, 2004; Díaz & Puch, 2019).

2 Four types of causal relationships are detected between income growth and energy consumption (Payne, 2010): unidirectional causality from energy to income (the growth hypothesis), unidirectional causality from income to energy (the conservation hypothesis); bidirectional causality (the feedback hypothesis); the lack of causality (the neutrality hypothesis). In general, for a cross-country analysis, the feedback hypothesis is widely confirmed (Chen, Chen, & Chen, 2012; Dedeoglu & Kaya, 2013; Chen, Chen, Hsu, & Chen, 2016). For instance, the results of Dedeoglu & Kaya (2013) support the feedback hypothesis for all OECD countries, while Narayan & Prasad (2008) shows that when looking inside of many of these countries (e.g., Australia, Italy and the UK), the growth hypothesis is confirmed instead.

3 From a methodological point of view, most works analyzing the bi-directional causality between income growth and energy consumption uses Vector Autoregressive (VAR) models, time series unit root and cointegration tests, or panel data unit root and cointegration tests (see, among others, Mehrara, 2007; Esseghir & Khouni, 2014). Regardless of the approach used, results are inconclusive (Chen et al., 2016).

4 In Section 2, we explain the reason for the selection of this sample.

5 For expository reasons, we use energy efficiency governance and energy governance indistinguishable throughout this paper.

6 Although the use of multivariate models can alleviate the problem of omitted variables bias and capture multiple causality channels, bivariate models provide a simpler interpretation of the results and can be applied to small data sets (Yuan et al., 2008). In this vein, the consideration of an exogenous instrument (i.e., the EEGI) allows also to reduce the bias due to unobserved variables and to analyze the different channels of causality (Brückner, 2013; Acemoglu et al., 2019).

7 The countries included in the sample are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. Israel and Iceland have been excluded from the final sample due to lack of data.

8 The countries that are part of the IEA are subject to strict evaluation criteria at the time of accession, which must continue to be satisfied even once they are adhered to. Among other aspects, the members must obligatorily be part of the OECD and, in addition, they must guarantee the existence of legislation and sufficient measures to be able to provide all the information requested by the IEA.

9 The third indicator, Funding Mechanisms, is not evaluated because homogeneous information on EE expenditure is not available for a reasonable sample of countries. However, the Appendix B offers an assessment of the effect of introducing this indicator in the EEGI for a short sample of 18 European countries.

10 On the one hand, the indicator Resourcing Requirements has not been considered because it has been included in very few measures in the sample. In addition, the initiatives that have been taken into account still show little degree of detail in their results (IEA, 2010). On the other hand, International Assistance is not considered due to the lack of homogeneous information for a reasonable sample of countries.

11 The Governmental Coordination indicator is not evaluated because the information available is national in nature. There is no data at regional or international level to evaluate the vertical and horizontal coordination of governments.

12 In the robustness analysis, aspects such as the solidity of the aggregation and weighting process are evaluated (making use of the Principal Components Analysis –PCA, among others) or the sensitivity of the index with respect to the addition (or lack) of indicators. The constructed sub-indices and the baseline EEGI are also validated by means of the scale of reliability coefficient and an analysis of the correlations between indicators and sub-indices. Furthermore, several agreement measures are also assessed.

13 The equivalent of 1 toe is 11.63 GWh.

14 The WGI measures the quality of general governance by averaging the information of six indicators: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, compliance with the law and control of corruption.

15 In the instrument originally proposed by Ciccone et al. (2012), the $EEGI_i$ is replaced by another fixed term (θ_i) that represents oil export minus oil imports relative to GDP over the whole time period 2000-2015. This instrument is used to determine how oil price shocks affect democracy through economic growth. Data on oil imports and oil exports are obtained from: NBER–United Nations Trade Database (Feenstra, Lipsey, Deng, Ma, & Mo, 2005).

16 If there were omitted variables that are part of both equations (2) and (3), the zero covariance assumption would be violated and the IV estimator would not solve the omitted variables problem. However, the IV would still solve the simultaneity problem.

17 Based on the Sanderson-Windmeijer (SW) test, the null hypothesis is that the matrix of coefficients from the first-stage conditional regressions is not full rank, signaling a complete failure of identification (i.e., the excluded instruments are uncorrelated with the endogenous regressor).

18 The null hypothesis is that the instruments are weak, and it is rejected if the F statistic exceeds the critical value. It is typical to considered that a F-statistic higher than the threshold of 10 should not arise weak instrument concerns (Staiger & Stock, 1997). However, it is merely a rule of thumb (Brueckner & Lederman, 2018). Thus, we also use the Stock & Yogo (2005) approach and critical values. These authors express the weakness in terms of the size of the bias of the IV (i.e., 2SLS) estimator relative to that of the OLS estimator.

19 The negative coefficient of the $EEGI_i$ in the reduced-form of the model is reflecting the fact that, in our sample, energy governance is positively correlated with per capita GDP (i.e., the average cross-country correlation is 0.31), which, in addition, coincides with countries showing a slower growing process (i.e., there exists evidence of per capita GDP conditional convergence in OECD countries). A similar argument can be used to interpret the results in columns (b), (c) and (d).

20 Data on TFEC is extracted from the IEA's World Energy Balances (2018) database.

21 Data on energy prices growth is extracted from the IEA's Energy Prices and Taxes (2018) database.

22 The countries assessed in the extended versions of the EEGI are Austria, Belgium, Czech Republic, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Turkey and the United Kingdom. The data used comes from Janeiro, Groenenberg, Surmeli-anac, & Monschauer (2016).

23 The rankings are used instead of the original scores since the numerical scores of PCA are measured in a very different scale, which would difficult the understanding of the results.

Appendix A. Scoring criteria for indicators

The application of scoring criteria for each indicator is inspired on the Dabla-Norris et al. (2012), who build an indicator of efficiency in public investment management.

Table A.1 Scoring criteria for indicators

No.	Question	Indicator	Scoring criteria
		1. Enabling Frameworks	
1.	Is the regulation enough?	1.1. *Laws and decrees*	The score is 0 if no document has been found; 0.8 if some regulation has been found but it is extremely limited; 1.6 if the regulation is adequate but the sectors covered are scarce (residential, industry, buildings, transport, lighting, energy utilities, commercial/industrial equipment); 2.4 if the regulation is adequate and several important sectors are covered; 3.2 if the regulation is abundant and dedicated to several important sectors; and 4 if the regulation is extremely abundant and dedicated to several important sectors.
2.	Are strategies and actions plans enough? Are the costs of the plans estimated and the targets set for strategic and action plans?	1.2. *Strategies and action plans*	The score is 0 if strategies and action plans have not been found; 1 if the number of plans is extremely limited; 2 if some plans have been found and in some cases costs are estimated and/or targets are set; 3 if abundant plans have been found and in some cases costs are estimated and/or targets set OR if an adequate amount of plans have been found and the costs are estimated and/or targets set for most of them; 4 if abundant plans have been found and for the most costs have been estimated and/or targets have been set.
3.	What percentage of GDP is dedicated to Energy Efficiency?	1.1. *Funding mechanisms*	The score is 0 if no energy efficiency spending has been detected; 0.8 if the percentage of energy efficiency spending over GDP is lower than 0.01%; 1.6 if the percentage is in the range $0.01 \leq \% < 0.05$; 2.4 if the percentage is in the range $0.05 \leq \% < 0.1$; 3.2 if the percentage is in the range $0.1 \leq \% < 0.5$; and 4 if the percentage is greater than or equal to 0.5%

Table A.1 Continued

No.	Question	Indicator	Scoring criteria
		2. Institutional Arrangements	
4.	Does the Energy Efficiency agency promote actively plans or programmes? Is the Energy Efficiency agency supported by a proper legal basis?	2.1. *Implementing agencies*	The score is 0 if no national energy agencies have been found; 0.8 if despite the fact of the absence of national agencies, local or regional agencies can be found; 1.6 if national agencies are not supported by a legal basis; 2.4 if national agencies account with limited legal basis OR the legal basis is adequate but scarce programs are promoted; 3.2 if national agencies account with adequate legal basis AND the amount of programs promoted is adequate; 4 if the legal basis is abundant and programs are broadly promoted.
5.	Do energy providers play a null, discreet or significant role implementing policies and programmes based on Energy Efficiency?	*2.2. Role of energy providers*	The score is 0 if no plans or programmes aimed at improve energy efficiency and promoted by energy providers have been found; 1 if a scarce promotion of plans and programmes to improve energy efficiency have been detected, oriented to at least one of the main sector (residential, industry, buildings, transport, lighting, energy utilities, commercial/industrial equipment); 2 if a scarce promotion of plans and programmes to improve energy efficiency has been detected oriented to some important sectors; 3 if energy providers play a limited active role promoting numerous plans, programmes and actions to improve energy efficiency in the majority of the important sectors; and 4 if energy providers play a wide active role promoting numerous plans, programmes and actions to improve energy efficiency in the majority of the important sectors
6.	To what extent is promoted the stakeholder engagement?	*2.3. Stakeholder engagement*	The score is 0 if no regulation, plans and programmes which promote the stakeholder engagement have been found; 1.33 if the promotion of stakeholder engagement is extremely limited; 2.66 if it has been found regulation, plans or programmes which promote a weak stakeholder engagement (stakeholders are involved by surveys or similar methods); 4 if the regulation or programmes found promote a close engagement (committees, councils and working groups are constituted).
7.	Is the public-private sector co-operation properly promoted?	*2.4. Public-private co-op.*	The score is 0 if no programmes or regulation have been found to promote public-private co-operation; 1 if public-private co-operation is extremely limited; 2 if some programs promoting public-private coop. have been found but the amount of them is not enough adequate; 3 if an adequate amount of programmes or regulations have been detected promoting public-private sector co-operation in several of the main aspects (voluntary agreements, public-private partnerships, mobilising energy service companies and regulating end-use equipment); and 4 if abundant programmes or regulation have been detected promoting public-private sector co-operation in several of the main aspects.

Table A.1 Continued

No.	Question	Indicator	Scoring criteria
		3. Enabling Frameworks	
8.	Have targets been set for the most important sectors? Have been the costs for these targets estimated?	*3.1. Targets*	The score is 0 if targets have not been found; 1 if numerical targets have been found but for a very limited amount of the main sectors (one or two between residential, industry, buildings, transport, lighting, energy utilities, commercial or industrial equipment); 2 if numerical targets have been found for three or four of the main sectors; 3 if numerical targets have been found for five sectors or for four sectors including estimations of the costs; 4 if numerical targets have been found for all the main sectors or for five sectors including estimations of the costs.
9.	There are evaluation mechanisms or means to assess the outcomes of each strategy or action plan?	*3.2.* Evaluation	The score is 0 if no evaluation mechanisms have been detected; 1 if evaluation mechanisms have been detected in less than 25% of strategic and action plans; 2 if evaluation mechanisms have been found for between 25% and 50% of strategic and action plans; 3 if evaluation mechanisms have been detected for between 50% and 75% of strategic and action plans; 4 if evaluation mechanisms have been found for a higher percentage of strategic and action plans.

Appendix B. Strength and robustness of the index

In this appendix, we analyze the process of building the index. First, we assess whether a sufficient number of elements (indicators) have been incorporated in the construction of the index, and to what extent those indicators reflecting similar aspects have been grouped together. Secondly, we check whether the results of the baseline EEGI are robust to different aggregation and weighting alternatives.

The analysis begins by examining the construction of the index, that is, the groups of indicators and sub-indices. We use two measures: (i) Spearman's rank correlation (average inter-item correlation) and (ii) the scale of reliability coefficient (Dabla-Norris et al., 2012). On the one hand, the correlations analyze the relationship between the different indicators that make up the same sub-index or between the sub-indices that constitute the EEGI. Relatively low correlations, between approximately 0.15 and 0.50, report that the indicators are properly related without raising concerns about multicollinearity. On the other hand, the reliability coefficient takes values between 0 and 1 (the closest to 1, the higher the reliability). It is a positive function of average inter-item correlation and of the number of items included (Dabla-Norris et al., 2012). Values close to 1 indicate a strong robustness of the indicator.

We consider four alternative indices to check for robustness (Dabla-Norris et al., 2012). The first is our baseline index, which we denote by EEGI8-A1: it uses 8 indicators added first at the sub-index level and then at the general index level, all of them weighted equally. Second, we build an extended version of the baseline, denoted by EEGI9-A1, which includes an additional third indicator –Funding Mechanisms– into the first sub-index (thus, we also have an extended version of the Enabling Frameworks sub-index). This extension is available only for 18 European countries.[22] Third, we consider the versions EEGI8-A2 and EEGI9-A2, which differ from the EEGI8-A1 and EEGI9-A1 in that the different indicators are averaged directly without being added first in sub-indices.

Table B.1 shows the results of the average inter-item correlation and the scale of reliability coefficient for the sub-indices and the four versions of the EEGI considered. The second column includes the estimated Spearman inter-item rank correlations; column 3 specifies the number of indicators of each sub-index, and column 4 shows the scale of reliability coefficient. In general, the figures shown for the Spearman rank correlations are similar to those obtained by Dabla-Norris et al. (2012), while the reliability coefficients are higher in our case.

Table B.1 Robustness of the alternative indices for energy efficiency governance: average inter-item Spearman's Rank correlation and scale of reliability coefficient

	Average inter-item Spearman rank correlation	No. of items	Reliability coefficient
Sub-indices			
Enabling frameworks	0.335	2	0.64
Enabling frameworks$_{extended}$	0.036	3	0.48
Institutional arrangements	0.371	4	0.71
Co-ordination mechanisms	0.369	2	0.66
Baseline EEGI (EEGI8-A1)	0.553	3	0.82
EEGI9-A1	0.316	3	0.67
EEGI8-A2	0.349	8	0.84
EEGI9-A2	0.235	9	0.84

Baseline EEGI (EEGI8-A1): Average of 3 sub-indices with 8 indicators; EEGI9-A1: Average of 3 sub-indices with 9 indicators; EEGI8-A2: Average of 8 indicators; EEGI9-A2: Average of 9 indicators

The average inter-item Spearman's rank correlation takes small and non-significant values when considering the extended versions of the index. For instance, the correlation for the indicators included in the extended Enabling Framework sub-index is 0.036, while it rises to 0.335 in the baseline situation. A similar result is obtained for the reliability coefficient, where the extended sub-index performs worse than the baseline one. Thus, according to this analysis, the index constructed with 8 indicators is more robust than the index constructed with 9 indicators; moreover, the former provides information for a larger sample of countries. The alternative strategies to aggregate the sub-indices (i.e., comparing EEGI8-A1 with EEGI8-A2, or EEGI9-A1 with EEGI8-A2) do not make a big difference. Therefore, we can conclude that the baseline EEGI (EEGI8-A1) is a robust and recommended alternative.

Our second robustness check relies on alternative weighting strategies. This test consists of assessing whether the EEGI scores are modified (and to what extent) if we choose a different weighting method. Thus, in addition to the four indices explained above, four additional variants have been constructed. Now, we use a Principal Components Analysis (PCA) for weighting the sub-indices and indicators, obtaining other four versions of the index: EEGI8-A1-PCA, EEGI9-A1-PCA, EEGI8-A2-PCA and EEGI9-A2-PCA. Table B.2 collects the rankings of these 8 versions of the index.[23]

Table B.2 Country ranking for different EEGI versions

	Ranking							
Country	EEGI8-A1	EEGI9-A1	EEGI8-A2	EEGI9-A2	EEGI8-A1-PCA	EEGI9-A1-PCA	EEGI8-A2-PCA	EEGI9-A2-PCA
Germany	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0
France	2.5	2.0	2.5	2.0	3.0	2.0	3.0	1.0
Denmark	2.5	-	2.5	-	2.0	-	1.0	-
Sweden	4.0	-	4.0	-	4.0	-	8.0	-
New Zealand	5.0	-	8.5	-	8.0	-	9.0	-
Italy	6.0	3.0	8.5	3.0	6.0	3.0	7.0	4.0
UK	7.0	5.0	6.0	4.0	7.0	4.0	6.0	3.0
Canada	8.0	-	5.0	-	5.0	-	4.0	-
Spain	9.0	4.0	10.0	5.0	10.0	5.0	10.0	5.0
USA	10.0	-	7.0	-	9.0	-	5.0	-
Japan	11.0	-	11.0	-	11.0	-	11.0	-
Hungary	12.0	7.0	15.0	9.0	12.0	8.0	14.0	7.0
Belgium	13.0	9.0	12.5	7.0	13.0	9.0	12.0	6.0
Czech Rep.	14.0	6.0	16.5	8.0	14.0	6.0	17.0	12.0
Australia	15.0	-	12.5	-	15.0	-	13.0	-
Portugal	16.0	10.0	16.5	10.0	16.0	10.0	16.0	10.0
Ireland	17.0	8.0	14.0	6.0	17.0	7.0	15.0	8.0
Finland	18.0	11.0	18.0	11.5	18.0	11.0	18.0	9.0
Norway	19.0	-	19.0	-	19.0	-	20.0	-
Korea	20.0	-	20.0	-	20.0	-	21.0	-
Netherlands	21.5	12.0	21.0	13.0	22.0	12.0	19.0	11.0
Luxembourg	21.5	-	24.0	-	21.0	-	23.0	-
Turkey	23.0	16.0	22.0	15.0	24.0	14.0	24.0	13.0
Austria	24.0	13.0	23.0	11.5	23.0	13.0	22.0	14.0
Poland	25.0	14.0	25.0	16.0	25.0	15.0	25.0	15.0
Slovak Rep.	26.0	15.0	26.0	14.0	26.0	16.0	26.0	17.0
Greece	27.0	17.0	27.0	17.0	27.0	17.0	27.0	16.0
Switzerland	28.5	-	28.0	-	28.0	-	28.0	-
Mexico	28.5	-	29.0	-	29.0	-	29.0	-
Chile	30.0	-	30.0	-	30.0	-	30.0	-
Slovenia	31.5	18.0	31.5	18.0	31.5	18.0	31.5	18.0
Estonia	31.5	-	31.5	-	31.5	-	31.5	-

Baseline EEGI (EEGI8-A1): Average of 3 sub-indices with 8 indicators; EEGI9-A1: Average of 3 sub-indices with 9 indicators; EEGI8-A2: Average of 8 indicators; EEGI9-A2: Average of 9 indicators; EEGI8-A1-PCA: PCA of 3 sub-indices with 8 indicators; EEGI9-A1-PCA: PCA of 3 sub-indices with 9 indicators; EEGI8-A2-PCA: PCA of 8 indicators; EEGI9-A2-PCA: PCA of 9 indicators

In order to compare the results, we conduct correlation and concordance assessments. On the one hand, correlations such as those proposed by Spearman or Kendall allow us to test whether there is an association in the changes of two variables (in our case, rankings). On the other hand, the concordance as examined by the Lin and Kendall coefficients allows us to determine whether two variables that measure the same are equivalent and interchangeable. Thus, if we detect high correlation and concordance between the rankings corresponding to the baseline EEGI and to the alternative formulations, it will mean that the construction procedure is valid and robust.

Results are strongly robust. In fact, the first 11 countries in the ranking are independent of the version of the index used, as well as the 10 worst countries rated. Table B.3 collects the Spearman rank correlation matrix between the 8 variants proposed for the EEGI, while Table B.4 does the same with the Kendall's range correlation. The average value of the Spearman rank correlation (between all rankings) is 0.97 (with a p-value <0.001 for each pairwise correlation); the Kendall's range correlation also takes high values (i.e., $\tau a = 0.890$, $\tau b = 0.892$, with a p-value<0.001 in all cases). Regarding the concordance measures, the Lin coefficients are collected in Table B.5 and the Kendall's concordance coefficients are provided in Table B.6. The average Lin coefficient is 0.97 (with a p-value<0.001) and the average Kendall concordance coefficient is 0.98 (the smallest p-value detected is 0.012).

Summing up, the baseline EEGI is a good option, since it allows us to use the information from the sub-indices separately, maximize the number of countries in the sample and, in addition, the arithmetic aggregation allows a simpler interpretation of the results. In this sense, our conclusions are similar to those reached by Dabla-Norris et al. (2012).

Table B.3 Spearman's rank correlation coefficients

	EEGI8-A1	EEGI9-A1	EEGI8-A2	EEGI9-A2	EEGI8-A1-PCA	EEGI9-A1-PCA	EEGI8-A2-PCA	EEGI9-A2-PCA
EEGI8-A1	1							
EEGI9-A1	0.97 ***	1						
EEGI8-A2	0.98 ***	0.96 ***	1					
EEGI9-A2	0.96 ***	0.97 ***	0.98 ***	1				
EEGI8-A1-PCA	0.99 ***	0.98 ***	0.98 ***	0.96 ***	1			
EEGI9-A1-PCA	0.96 ***	0.99 ***	0.97 ***	0.99 ***	0.97 ***	1		
EEGI8-A2-PCA	0.99 ***	0.96 ***	0.99 ***	0.97 ***	0.99 ***	0.96 ***	1	
EEGI9-A2-PCA	0.96 ***	0.92 ***	0.98 ***	0.94 ***	0.96 ***	0.92 ***	0.98 ***	1

Table B.4 Kendall's rank correlation coefficients

		EEGI8-A1	EEGI9-A1	EEGI8-A2	EEGI9-A2	EEGI8-A1-PCA	EEGI9-A1-PCA	EEGI8-A2-PCA	EEGI9-A2-PCA
EEGI8-A1	τa	1							
	τb	1							
EEGI9-A1	τa	0.895***	1						
	τb	0.895***	1						
EEGI8-A2	τa	0.928***	0.850***	1					
	τb	0.931***	0.853***	1					
EEGI9-A2	τa	0.863***	0.889***	0.895***	1				
	τb	0.866***	0.892***	0.901***	1				
EEGI8-A1-PCA	τa	0.987***	0.909***	0.915***	0.876***	1			
	τb	0.987***	0.909***	0.918***	0.879***	1			
EEGI9-A1-PCA	τa	0.869***	0.948***	0.876***	0.941***	0.882***	1		
	τb	0.869***	0.948***	0.879***	0.944***	0.882***	1		
EEGI8-A2-PCA	τa	0.922***	0.869***	0.967***	0.889***	0.935***	0.869***	1	
	τb	0.922***	0.869***	0.971***	0.892***	0.935***	0.869***	1	
EEGI9-A2-PCA	τa	0.869***	0.791***	0.915***	0.811***	0.856***	0.791***	0.922***	1
	τb	0.869***	0.791***	0.918***	0.813***	0.856***	0.791***	0.922***	1

Table B.5 Lin's concordance coefficients

	EEGI8-A1	EEGI9-A1	EEGI8-A2	EEGI9-A2	EEGI8-A1-PCA	EEGI9-A1-PCA	EEGI8-A2-PCA	EEGI9-A2-PCA
EEGI8-A1	1							
EEGI9-A1	0.97 ***	1						
EEGI8-A2	0.99 ***	0.96 ***	1					
EEGI9-A2	0.96 ***	0.97 ***	0.98 ***	1				
EEGI8-A1-PCA	0.99 ***	0.98 ***	0.99 ***	0.96 ***	1			
EEGI9-A1-PCA	0.97 ***	0.99 ***	0.97 ***	0.99 ***	0.97 ***	1		
EEGI8-A2-PCA	0.98 ***	0.97 ***	0.99 ***	0.97 ***	0.99 ***	0.96 ***	1	
EEGI9-A2-PCA	0.97 ***	0.92 ***	0.98***	0.94 ***	0.96 ***	0.92 ***	0.98 ***	1

Table B.6 Kendall’s concordance coefficients

	EEGI8-A1	EEGI9-A1	EEGI8-A2	EEGI9-A2	EEGI8-A1-PCA	EEGI9-A1-PCA	EEGI8-A2-PCA	EEGI9-A2-PCA
EEGI8-A1	1							
EEGI9-A1	0.99 ***	1						
EEGI8-A2	0.99 ***	0.98 ***	1					
EEGI9-A2	0.98 ***	0.99 ***	0.99 ***	1				
EEGI8-A1-PCA	0.99 ***	0.99 ***	0.99 ***	0.98 ***	1			
EEGI9-A1-PCA	0.98 ***	0.96 **	0.99 ***	0.97 **	0.98 ***	1		
EEGI8-A2-PCA	0.99 ***	0.98 ***	0.99 ***	0.98 ***	0.99 ***	0.99 ***	1	
EEGI9-A2-PCA	0.98 ***	0.96 **	0.99***	0.97 **	0.98 ***	0.99 ***	0.99 ***	1

Appendix C. Further results on the EEGI

We describe next some aspects of interest related to the EEGI results that, for reasons of space, were not detailed in the main document. First, we analyze the relationship between the EEGI and its sub-indices. Next, we assess in more detail the case of some countries that offer striking results. Finally, we examine the sensitivity of the EEGI score with respect to the number of entries available in the database for each country.

If we compare the different areas of the EEGI, the average value of the sub-indices Enabling Frameworks, Institutional Arrangements and Coordination Mechanisms sub-indices is 2.48, 1.94 and 2.83, respectively. The score in the third area is, on average, the highest. This fact highlights the growing interest in establishing objectives and monitoring results as a means to promote energy efficiency. As expected, a positive and significant correlation is observed between the baseline EEGI and its three sub-indices (the average correlation is 0.858, significant at 1%). Specifically, the indicator of Laws & Decrees (within the first sub-index) is the one that seems to maintain a greater relationship with the EEGI score.

However, there are some interesting cases to be discussed. The first is Canada, located in Q1 in the sub-indices Enabling Frameworks and Institutional Arrangements, but in Q3 for Coordination Mechanisms. The same is valid for The US, although it is located in Q2 for the third sub-index. Other examples to highlight are New Zealand and Australia, for which each sub-index is located in a different quartile: Enabling Frameworks in Q3, Institutional Arrangements in Q2 and, finally, Coordination Mechanisms in Q1.

In general, there is significant variability in the energy efficiency governance quality score when comparing countries, and also when analyzing each of the three areas considered. This variability is a good symptom to measure the usefulness of an index of these characteristics. Thus, for example, we find countries such as Denmark, which has high scores in all areas, or the opposite cases in Chile or Estonia, which show low scores in the three areas. There are also intermediate situations, such as Spain, with high scores in the areas of Regulatory Framework and Coordination Mechanisms, but low in the corresponding Institutional Agreements. Even, cases like those already mentioned in Australia and New Zealand. Finally, the results for Slovenia, Estonia, Mexico and Chile should be interpreted with caution, due to the limited information found for these countries.

To conclude the description of our results, it is important to analyze the correlation between such results and the number of entries available for each country in the database (recall Table 1). In this sense, having a reduced (or high) number of regulations and programs may be indicative of a lower (or greater) degree of energy governance. However, as we see below, the existing correlation is far from perfect. For the total sample, the correlation is 0.6, significant at 1%. It seems logical to find that countries with the lowest number of entries (Slovenia, Estonia, Mexico or Chile, which have less than 10 entries in the database) obtain much lower scores than other countries with the highest number of entries (Canada, USA or Germany, which have more than 100 entries). However, if we calculate the correlation for groups of countries with similar index values (dividing the sample by quartiles, Q1, Q2, Q3 and Q4), the results are different. In fact, the correlation is not significant between countries in Q1 and Q3, while it is only 0.32 for those in Q2. On the other hand, the correlation is only high and significant among the countries belonging to Q4 (0.77). In the analyses carried out in Section 4, we take into account this anomalous behavior of the countries in Q4 and we demonstrate that it does not affect to our results, since they remain consistent even when we control our models for the number of entries (results available upon request).

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