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ORIGINAL RESEARCH

Economic development and energy consumption in the GCC: an international sectoral analysis

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Abstract The relationship between economic development and energy consumption has important policy and geopolitical implications intersecting with future energy demand, economic growth and climate change. All countries in the GCC share a common goal to transition to economies less reliant on oil and gas. As part of this transition diversification and energy efficiency strategies have become major strategic priorities. If successful, such policies are likely to significantly change the relationship between domestic energy consumption and GDP. To inform discussion on this topic, this paper assesses the relationship between energy consumption at a sector level and GDP in the GCC relative to a reference group of OECD countries. While there is variation within each grouping and across sectors, the clear result is that energy consumption and economic growth are strongly linked to all sectors in the GCC. This is in contrast to the OECD group where energy and GDP have decoupled. These results highlight both the scope for further improvement in energy efficiency and the need for deeper integration of energy-intensive industry and higher value-added activities and services. We suggest a greater focus on energy productivity—or how maximum value can be obtained from energy consumption—can help guide industrial policy and increase the profile of energy efficiency efforts across the GCC.

Keywords Energy efficiency · Economic diversification · Sustainable development · Gulf Cooperation Council (GCC)

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Introduction

The relationship between energy consumption and economic development co-evolves and changes across time and location with each shifting national context. This relationship is not just important for energy market participants in assessing the need for future investments but is an important theme running through discussions on sustainable development and climate change [29] and the academic literature [21]. It is a particularly critical issue for countries in the GCC, where the concern is that carbon constraints may potentially limit industrialization and economic and social progress by restricting or penalizing the use of relatively inexpensive and abundant fossil fuels.

Driven mainly by the experience of the advanced OECD countries, there is an emerging view that growth and climate action need not be incompatible. In their report *Growth investment and the low carbon transition*, the OECD highlights how countries can achieve “strong and inclusive economic growth while reorienting their economies towards development pathways with low greenhouse gas emissions” [23]. It is argued that such growth-oriented decarbonization can be achieved through a combination of strong fiscal and structural reform combined with coherent climate policy. Indeed, it is suggested that such policies can increase long-run GDP by up to 2.8% across the G20 relative to a continuation of current policies.

At KAPSARC such topics are being investigated within the research theme of energy productivity [11]. In particular, KAPSARC research has been exploring how shifting to a growth model based around higher energy productivity can help GCC countries achieve long-held structural diversification goals, for example, as reflected in Saudi Arabia's Vision 2030 [18]. Energy productivity is both a policy agenda focusing on how energy can best be used to create value in the economy, as well as an indicator which integrates economic growth with energy consumption. At the macroeconomic level, energy productivity describes how much GDP can be produced using a given amount of energy. It is the mathematical inverse of energy intensity and is both a reflection of what activities energy is used for (the structural make-up for the economy), as well as how well energy is used in specific activities (the level of energy efficiency).

At the microeconomic level, energy productivity focuses on how much revenue is produced from economic activities from per unit of energy consumption. This is related but distinct from most common definitions of energy efficiency.

For instance, Patterson [26] states that energy efficiency generally refers to using less energy to produce the same amount of services or useful output. In the industrial sector, energy efficiency is thus typically measured by the amount of energy required to produce a ton of product. The issue then becomes how to precisely define the useful output and the energy input. This gives rise to a number of indicators which have been used to measure energy efficiency, which Patterson groups into four main categories:

1. *Thermodynamic* usually expressed as ratios, these indicators that relate actual energy use to an 'ideal' process.
2. *Physical–thermodynamic* hybrid measures where the energy input is measured in thermodynamic units, but the output is measured in physical units.
3. *Economic–thermodynamic* another hybrid indicator where the energy service (output) is measured in terms of market prices, and the input is (energy) is measured in terms of thermodynamic units.
4. *Economic* both the energy input and the output are measured in terms of market values.

Within this typology, energy productivity, which relates GDP at the macroeconomic level or company revenue at the microeconomic level, can be thought of as an economic–thermodynamic indicator. With its focus on growth or revenue, rather than energy savings (as with energy intensity), KAPSARC has argued that energy productivity can offer policy makers a positive and compelling policy narrative and target for how energy policy can support economic growth while contributing to sustainable development goals [17].

In this paper, we aim to contribute to this program of research to examine the relationship between energy consumption at the sectoral level and GDP focusing on the GCC region. Such analysis is central towards assessing the dynamics of economic development and energy consumption and the overall level of energy productivity in the economy at the macroeconomic level. It can also provide an important evidence base for policy makers looking to assess and implement structural diversification and energy efficiency policies, which we focus on in our conclusions.

This relationship has been well-examined in the energy economics literature across a wide range of countries, time periods, variables and econometric methodologies, although research has mostly focused on aggregate, rather than sectoral energy consumption (for a review see [25]). What is perhaps surprising is that these studies present a wide diversity of often conflicting results. Four key hypotheses emerge on the relationship between energy consumption and economic growth:

1. *The growth hypothesis* suggests energy consumption plays an important role in economic growth both directly and indirectly in the production process as a complement to labor and capital. Energy is, therefore, either a limiting or contributing factor to economic growth, and shocks or restrictions to energy supply will have a negative impact on economic development.
2. *The conservation hypothesis* suggests that policies conserving or restricting energy consumption can be implemented with little or no adverse effect on economic growth, such as in a less energy-dependent economy. The hypothesis is supported if an increase in real GDP is associated with stable or falling energy consumption.
3. *The feedback hypothesis* implies that energy consumption and economic growth are jointly determined and affected at the same time.
4. *The neutrality hypothesis* implies energy consumption is not correlated with GDP, which means that neither energy conservation nor expansion policies have any effect on economic growth. This hypothesis is supported by the absence of a causal relationship between energy consumption and growth.

To focus our own analysis we compared the six countries that make up the Gulf Cooperation Council with a selection of advanced OECD counties. The variables we focus on are:

- Total and per capita energy consumption in the industrial, non-energy use (energy feedstocks used in petrochemicals and fertilizers), transport and buildings sectors; and
- Total and per capita GDP as a proxy for the level of economic development.

This allows us to assess the evidence for:

- Any energy–GDP decoupling behavior.

We have also developed an empirical model which allows us to estimate energy demand equations where per capita energy consumption depends on powers of per capita income. This formulation allows for an assessment of several important relationships including:

- The income elasticity of demand for energy in each sector; and
- Potential per capita energy consumption turning points.

This sectoral perspective of the relationship between energy consumption and economic development provides a valuable view of the opportunities and challenges facing the GCC region as governments attempt to induce a transition away from an over-reliance on oil and gas.

The remainder of the paper is structured as follows. First, we provide an overview of previous studies tracking energy transitions in per capita energy consumption at the sectoral level and economic development. We draw from this review a set of theoretical relationships based on observed experience from different development and energy contexts from around the world. Next, we contribute to this body of work through an empirical assessment of the energy relationship between economic development and energy consumption at the sectoral level in the GCC. To help put these trends in the context we perform a comparative analysis based on a selection of OECD countries. In conclusion, we return to the themes of energy efficiency and structural diversification and draw out the main insights of this study for the current economic reform agenda in the GCC.

Previous studies tracking transitions in per capita energy consumption and economic development

Changes in the structure of the economy that occur as economic development progress are important factors in determining the growth of energy demand. At the same time, these structural shifts can facilitate a transition to better quality economic growth from a narrow base of lower value, highly polluting activities to a wider range of higher value, cleaner activities that also deliver higher per capita income and employment opportunities for citizens. This relationship is well documented and follows a pathway which can be generalized in Fig. 1 following the pattern set out by Kuznets [19].

The empirical literature around this topic is vast, see [1] for a summary. On the one hand, we have econometric studies which treat energy demand as part of a structural simultaneous equation system of either consumer demands for goods or of production inputs [27]. Within that context, energy is sometimes disaggregated by energy source, depending on data availability. On the other hand, we have standard single equation studies on energy demand conducted for either individual countries or at multi-country level. In the latter case, many authors have conducted cross-section time series studies for groups of countries, e.g., [4]. The possibility of disaggregation across sectors of use or energy sources is typically constrained by the availability of suitable data for a sufficient number of countries and/or time periods.

Energy–GDP elasticity

Energy economists have also shown a long-standing interest in the energy–GDP elasticity within the context of aggregate energy demand studies. If this elasticity is below one, then total energy use in the economy will increase at a slower rate than growth in GDP. This is a critical issue for energy consuming countries which often depend upon sources imported from abroad.

Achieving an energy–GDP elasticity of less than one is also important for energy producing countries, as reduced domestic consumption of energy frees resources to be sold abroad, thereby boosting their energy productivity. For example, in KAPSARC research on energy productivity [12] applies the MEGIR-SA general equilibrium model to suggest an economy-wide improvement in energy

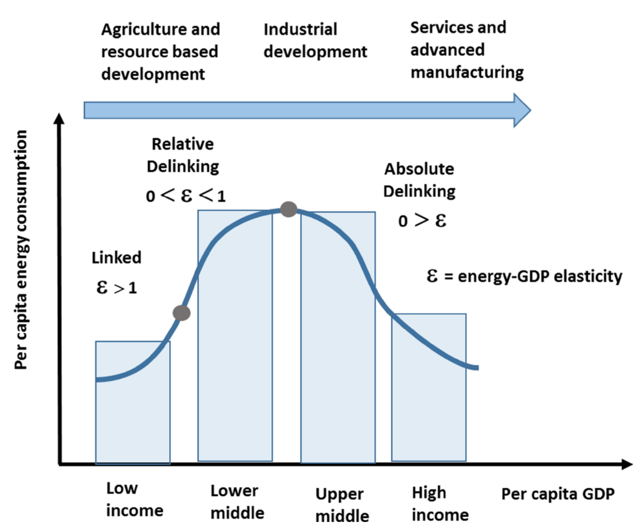

Fig. 1 Transition pathway for per capita energy consumption and development. Source: KAPSARC based on Kuznets [19]

efficiency of 4% per annum could result in around 1 million barrels of oil equivalent being avoided by 2030. If sold on international markets and reinvested in the economy, this could generate between SAR 50 billion to SAR 100 billion in extra government revenue per annum by 2030. Depending on international energy market conditions and if reinvested back into the economy it was found that this could lift GDP growth by between 0.3 and 0.6% per annum.

Energy income relationships

Brookes [2] was one of the first studies to suggest that the relationship between per capita energy consumption and income is non-monotonic. Using data for 22 countries for 1950–1965 energy demand equations were estimated for each yearly cross section showing that income elasticity declined over time. Zilberfarb and Adams [32] found the elasticity of energy consumption with respect to GDP in countries at earlier stages of development over the period 1970–1976 to be in the neighborhood of 1.35, and significantly above one. Galli [10] estimates a dynamic error correction model with a quadratic log-income term for a panel of ten Asian countries over the period 1973–1990. The author finds that the quadratic income term is negative and significant and that energy intensities tend to fall after some threshold level of per capita income.

Olatubi and Zhang [24] and Metcalf [22] are two studies which exploit the cross-sectional variations across US states. The first paper considers 16 states for the period 1977–1999 and finds inelastic income behavior with declining elasticities over time. The long-run value is about 0.40. The second paper considers 48 states for 1970–2001 and finds that energy intensity shows an inverted-U Kuznets curve behavior.

Looking at 76 countries during 1960–2006, van Benthem [31] estimates a dynamic quadratic energy demand model confirming the Kuznets curve behavior (an inverted U) for high-income countries, but not for low-income countries which on the contrary show a U-shaped tendency. In the latter case, however, the statistical significance of the relevant coefficients is weak, unlike the case for high-income countries.

Csereklyei and Stern [5] study the relationship between long-run growth rates—rather than levels—of per capita energy consumption and GDP for 93 countries in 1971–2010. Their results point to evidence of weak decoupling but no sign that at high-income levels the income elasticity turns negative—no Kuznets curve behavior. Over the same period for 99 countries Csereklyei et al. [6] find an income elasticity that is less than one.

This Kuznets behavior, as illustrated in Fig. 1, arises in part because the overall per capita energy consumption is a weighted average of the energy consumption within each sector. Structural changes within the economy are a major driver of the dynamics of energy–GDP elasticity over time. Figure 2 extends Fig. 1 to illustrate the main generalized relationships in per capita energy consumption and per capita income for the main energy consuming sectors.

Based on the empirical assessment conducted by Medlock and Soligo [21], the industrial sector shows the greatest transition as per capita incomes rise. Industrial consumption tends to be relatively large in the initial stages of development as the initial stock of modern infrastructure is built. This is an energy-intensive process involving high quantities of cement, steel and other basic materials. As the level of infrastructure reaches a certain level of maturity, the demand it imposes on industrial energy consumption will decline. While the production of energy-intensive goods is likely to continue at more mature stages of economic development, its importance relative to the other sectors is likely to diminish.

Continuing with the assessment conducted by Medlock and Soligo [21], as per capita incomes rise energy consumption in the buildings and transport sectors is seen to rise relative to industrial energy consumption. This is driven by growth in energy consumption from consumer durables (such as air conditioners, refrigerators, cars) and consumer services (health, education, restaurants and retail).

Furthermore, as households become saturated with energy consuming durable goods the energy–GDP elasticity in the buildings sector may fall below one. For example, even if operated 24 h a day the per capita growth in energy consumed from air conditioners should eventually reach some upper bound. From this point, advances in technology leading to greater energy efficiency will put downward pressure on per capita energy consumption in that sector putting downwards pressure on the elasticity.

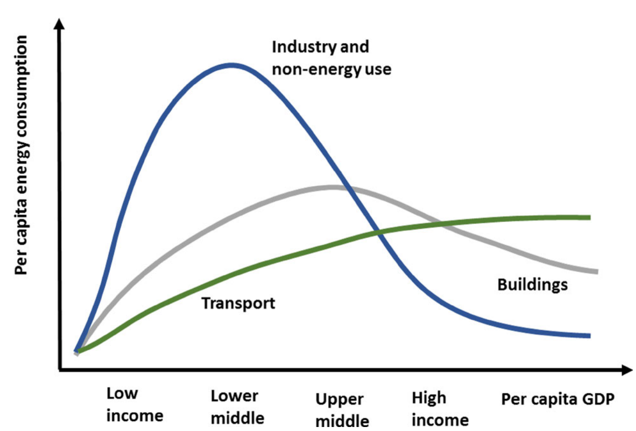

Fig. 2 Transition pathways for sectoral energy consumption. KAPSARC based on Medlock and Soligo [21]

Of course, these general findings from Medlock and Soligo [21] can be challenged in several ways. For example, a factor which can work against this saturation and efficiency effect in the buildings sector would be the expansion of floor space. As per capita incomes rise, individuals may demand bigger homes, which other things being equal, requires more energy to cool and heat.

The transportation sector faces similar effects once the number of vehicles per capita reaches the number which satisfies their basic mobility requirements and the number of cars that can be driven. From then, as per capita incomes rise, the opportunity cost of time also increases and individuals are likely to also try to reduce the amount of time spent in transit. One factor that may work against the efficiency-saturation effect in the transport sector, is the rise in air travel, which typically grows with increasing income and wealth. As international air travel is not included in the IEA domestic energy balance [14], this is outside the scope of our current paper.

From this discussion, we can see that per capita energy consumption in the buildings and transport sectors will be significantly shaped by urbanization. The potential concentration of inner-city living in smaller apartments as opposed to larger houses in the suburbs is, therefore, a potential driver of long-term downwards pressure on energy consumption in these sectors.

Prices and activity

Energy prices too will play out on these trends. As a basic necessity of living, energy often forms a large proportion of household budgets in countries at an earlier stage of development. This has led some governments to subsidize energy and underprice externalities. However, while low energy prices can play an important role improving social welfare in the early phases of development, it can also lead to waste and low levels of energy efficiency. As per capita income rise, low energy prices may also become less of an important tool to encourage economic development. This helps countries with higher per capita incomes to sustain higher retail energy prices through taxation and other measures which tend to increase energy efficiency and stimulate activity in less energy-intensive sectors.

Medlock and Soligo [21] studied sectoral energy use for a panel of 28 countries over the period 1978–1995. The authors consider final energy use in each end-use sector: transportation, residential and commercial, industrial and other. The authors estimate a log-linear partial adjustment dynamic model that is quadratic in per capita income. Aggregate GDP is used as a scale variable rather than sectoral value added. The findings indicate that the income elasticity of energy demand falls as income rises but differently across sectors. In particular, their study suggests that transportation energy demand will eventually capture the biggest share of end-use energy consumption (as depicted in Fig. 2). This work suggests that energy demand in transport is the least elastic with respects to per capita incomes. It should be noted that since the time of this study there have been significant shifts in technologies and transport use patterns. These have been driven by vehicle fuel economy policies as well as new growth in electric rail and electric vehicles as well as increasing urbanization and the advent of the sharing economy. These trends are reshaping the sector and serve as a reminder that past relationships may not necessarily hold into the future.

Judson, Schmalensee, and Stoker [15] estimate flexible spline Engel curves relating per capita energy consumption to per capita GDP in major economic sectors. Panel data for 69 nations are employed and the sample period runs 1970–1991. The authors consider the five major final demand sectors in the UN data: Industry, Construction, Transportation, Households and Other. They find that both country and income effects explain a large fraction of variation in sectoral energy demands, while time effects have considerably less explanatory power. There is general evidence that income elasticities decline with income, particularly at the highest income levels. The negative top-segment elasticity appears to be driven entirely by the Households and Other sector. As per capita income rises, the authors' estimates imply that these sector's share of aggregate energy consumption tends to fall, while the share of Transportation tends to rise, and the share of Industry and Construction follows an inverse-U pattern. These results also support the illustration of general sectoral transition pathways in Fig. 2.

Eller and Medlock [7] estimate a Koyck transformation of a static model relating per capita energy use to per capita level and squared aggregates of GDP and real energy prices. Total end-use demand for commercial energy is modeled by sector for 57 countries from 1980 to 2004. Demand sectors include Transportation, Industrial and Others (which is the sum of residential, commercial and agricultural demand for energy). Demand is disaggregated by energy source for the industrial and other sectors. Energy sources are electricity and sum of all other "direct-use fuels" such as petroleum products and natural gas. The results provide evidence that the income elasticity of energy demand decreases with economic growth.

The paper by van Benthem and Romani [30] investigates the relationship between energy demand, economic growth and prices in 24 non-OECD countries and three sectors from 1978–2003. Linear and non-linear income and price elasticities are estimated leading to the conclusion that the income elasticity of energy demand is high and increases with income, both in the country and the sector level. This supports the notion that in countries at earlier stages of development energy consumption rises with economic growth.

Lescaroux [16] focuses on the commercial energy consumption of 101 countries for 1960–2006. A non-linear modeling approach for final energy demand is proposed and applied to the four main end-use sectors of consumption: road transportation, residential, industry and commercial and public services. Per capita energy use is modeled as a non-linear function of per capita aggregate GDP and other variables. Sectoral and total energy intensities do not systematically exhibit a bell-shaped pattern. According to the long-run parameters of the model, this is the case for the industrial and services sectors. On the other hand, residential and road transportation energy demand grow slower than real GDP, and so does total final energy demand.

Burke and Csereklyei [3] use per capita data for 132 countries over 1960–2010 to estimate elasticities of sectoral energy use with respect to GDP. Models in both levels and growth rates are estimated resulting in a very income inelastic residential energy demand. Residential use of electricity is more tightly linked to GDP, and so are transportation, industrial and services sectors. Agriculture typically accounts for a small share of energy use and is characterized by a modest energy–GDP elasticity. The aggregate energy–GDP elasticity tends to be higher for countries at higher income levels, in large part because traditional use of primary solid biofuels is less important.

Finally, Liddle [20] studies energy demand using panel data on 50 US states over 1987–2013 allowing for possible nonlinearities between energy consumption and income, possible asymmetries for total as well as industrial and transport sectors' energy consumption per capita as well as for the electricity consumed per capita in the residential and commercial sectors. In all cases, the log of per capita GDP is statistically significant and well below unity, implying an energy–GDP elasticity of less than one. Comparing the estimations across dependent variables, the income elasticities are smaller for residential and commercial electricity. Plotting the state-specific income elasticity estimates against individual state average incomes for the whole sample period shows evidence that the GDP per capita elasticity for both total energy and industrial energy consumption rises and then falls with average GDP per capita, thus forming an inverted-U consistent with the Kuznets hypothesis illustrated in Figs. 1 and 2.

Data used in this paper

Our analysis makes use of annual data developed by the Organization for Economic Cooperation and Development (OECD) and taken from the International Energy Agency (IEA) World Energy Balances [14]. Total final energy consumption (TFEC) (ktoe) is found in IEA Extended Energy Balances database, whereas population (POP) (millions) and Gross Domestic Product (billions of 2010 US dollars in PPP terms) are drawn from the IEA World Indicators database.

The sectors analyzed in this paper are: industry, transport, buildings, agriculture and non-energy sector. This disaggregation reflects the one that is available in the IEA database [14] for GCC countries, except for buildings which we have created by summing Residential and Commercial and Public Services. This is the most detailed disaggregation that is possible for GCC countries using official publicly available data.

One important issue has to do with the scale variable of our empirical investigation. We use real GDP for the total economy in each sectoral energy demand equation, rather than a measure of sectoral real value added (GDP originating in each sector) whose data are in principle available. For example, the UNSTAT database [28] provides information on value-added disaggregated for seven sectors: agriculture, hunting, forestry, fishing; mining, utilities; manufacturing; construction; wholesale, retail trade, restaurants and hotels; transport, storage and communication; other activities. To be precise "Mining, Utilities" are obtained by subtracting "Manufacturing" from "Mining, Manufacturing, Utilities"). The TFEC data reported by IEA are instead much more detailed in terms of sectoral breakdown. The IEA data would, therefore, need to be aggregated to match the sectoral breakdown above used by UNSTAT. However, in the case of GCC several data are missing for sub-sectors, sometimes for the whole sample period, making this level of disaggregation likely to be unreliable for econometric purposes.

There are two reasons for this choice, which is common to nearly all papers we reviewed. First, GDP is available in purchasing power parity terms, which makes cross country comparison possible and reliable, especially when considering countries at earlier stages of development and more mature industrialized countries together. Second, and more importantly, value added in each sector is the value generated by private and public enterprises of that sector. This does not consider the consumer's perspective which, in a sector like transport, refers to the benefit of mobility. A similar point can be made for the residential sector where a significant part of the value derived from the sector is in the form of shelter and comfort, rather than sectoral value added which, for example in this case, captures the business activities in wholesale and retail sectors.

What is the evidence from comparing GCC countries with the OECD reference group?

The countries considered are the members of the Gulf Cooperation Council (GCC): Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates. In addition, we also conduct a comparative analysis with a reference group of OECD countries including Canada, France, Germany, Italy, Japan, United Kingdom, and United States of America and Australia. We have selected this group as they comprise the major advanced economies that also are most likely to have evolved into a mature phase of economic development and infrastructure investment. The sample generally runs from 1971 to 2015 for all countries although, as said, data are missing for some periods for some GCC countries in a few sectors. Specifically, there were no data for Agriculture of Kuwait and Qatar, hence this sector is left out of the econometric analysis. For analytical purposes, here we consider the time period 1990–2014.

To set the stage, we first consider the relative importance of individual sectors in total final energy consumption (Figs. 3 and 4). The most obvious observation is that the buildings sector contributes a much higher proportion of overall energy consumption in the OECD reference group than in the GCC. The second observation from the structural shares of energy consumption is that industry and non-energy use is declining in relative terms in the OECD reference group, whereas it is increasing relative to the other sectors in the GCC. Transport energy consumption is also growing in importance in the OECD reference group, whereas in the GCC it is stable or even declining in its weight, relative to the other sectors.

Moving onto absolute levels of per capita energy consumption at the sector level in the GCC we can see that industry has the highest per capita energy consumption ranging from 1.5 toe per person per year in Bahrain up to just over 3 toe per person in the UAE (Fig. 5). Saudi Arabia has per capita industrial energy consumption of around 2 toe per person per year.

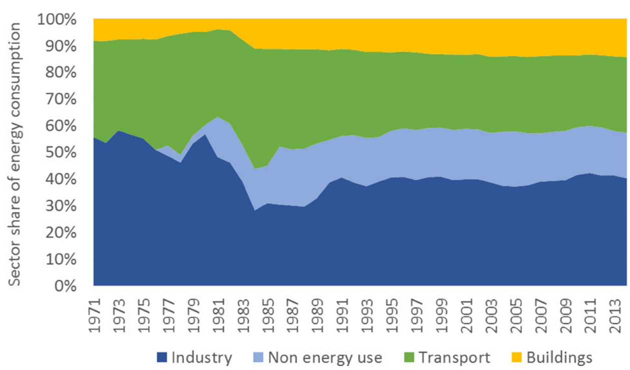

Fig. 3 Sectoral composition of energy consumption—GCC countries. Source: KAPSARC based on IEA energy balances

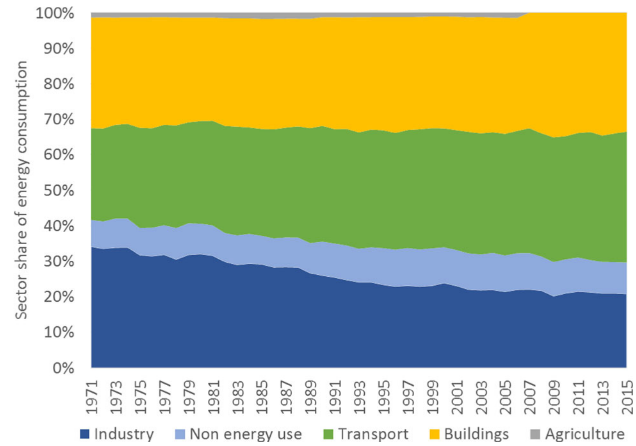

Fig. 4 Sectoral composition of energy consumption—OECD reference countries. Source: KAPSARC based on IEA energy balances

This is much higher than in the OECD reference group where per capita industrial energy consumption has been declining and ranges between 1.5 toe per person per year in Canada through to less than 0.5 toe per person in the UK.

Non-energy use, which encompasses the feedstocks used in petrochemical and fertilizer production is also very high in the GCC, relative to the OECD reference group, especially in Qatar, Bahrain and Saudi Arabia with per capita energy consumption of around 2, 1.5 and 1 toe per person per year respectively. This compares to the OECD group which per capita energy consumption in the non-energy use sector is stable and declining and is almost all under 0.5 toe per person, except for Canada.

The most significant energy consuming sector for the OECD reference group is the buildings sector with per capita energy consumption around 1.5 toe per person per year in the United States and Canada, with the lowest just under 1 toe per person in most of the other countries in the group. As a general rule buildings sector energy consumption is decreasing. By contrast, GCC per capita energy consumption in the buildings sector is increasing, but from a lower base to around 1 toe per person per year. GCC buildings energy consumption is characterized by the need for all year round air conditioning that peaks in summer, whereas in Europe heating is the main source of demand.

The transport sector presents a more heterogeneous picture across countries, with very high per capita energy consumption in Australia, Canada and the United States between 1.5 and 2 toe per person per year reflecting the tradition of travelling longer distances by road in North America and Australia. In the European countries and Japan per capita transport energy consumption is much lower at around 0.5 toe per person per year, reflecting the

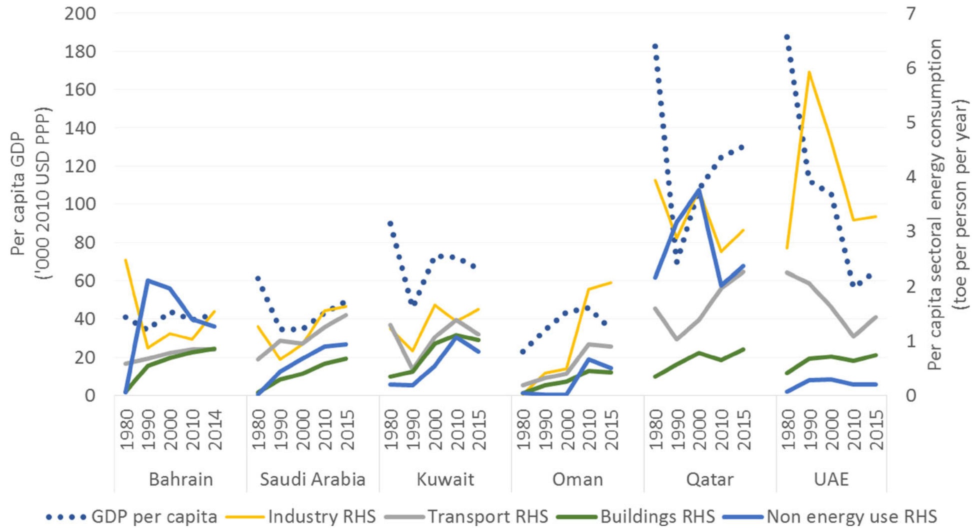

Fig. 5 Per capita income and per capita energy consumption—GCC countries. Source: KAPSARC based on IEA energy balances

patterns of denser urbanization and higher use of public transport in those countries. Separating passenger and freight transport and normalizing by population and GDP respectively could offer further insight in a more focused analysis, but is beyond the scope of this paper (Fig. 6).

As a general rule, across the OECD group per capita transport energy consumption is fairly stable. This is in contrast to the GCC group where transport energy consumption is rising strongly from a relatively low base. Across the GCC per capita transport energy consumption ranges between 1 and 2 toe per person per year, putting them on a similar level compared to North America and Australia.

On average real per capita GDP is higher in GCC relative to OECD reference group, but it should be noted that the higher per capita incomes in the GCC are due to the significant proportion of oil-based income from energy exports. Rapidly growing populations in GCC countries are also a notable feature contrasting with the OECD reference group where populations are growing much more slowly. The share of oil-based revenue in GDP and differences in population growth also explains some of the large variation in the GCC regarding per capita income.

Turning now to Figs. 7 and 8 we compute an index using energy consumption in each sector and total GDP using 2010 purchasing power parity measure to look for evidence of sectoral per capita energy–GDP decoupling.

The first observation is that in the GCC the index of energy consumption in each sector lies above that for GDP. This suggests that per capita energy consumption and per capita GDP in the GCC are linked with per capita energy consumption growing at a faster rate than that of GDP in all sectors except perhaps for transport where GDP and energy consumption are rising almost step by step. For instance, between 1990 and 2015 industrial energy consumption in the GCC grew 66% more than GDP, 132% more in the buildings sector, 76% more in the non-energy use sector,

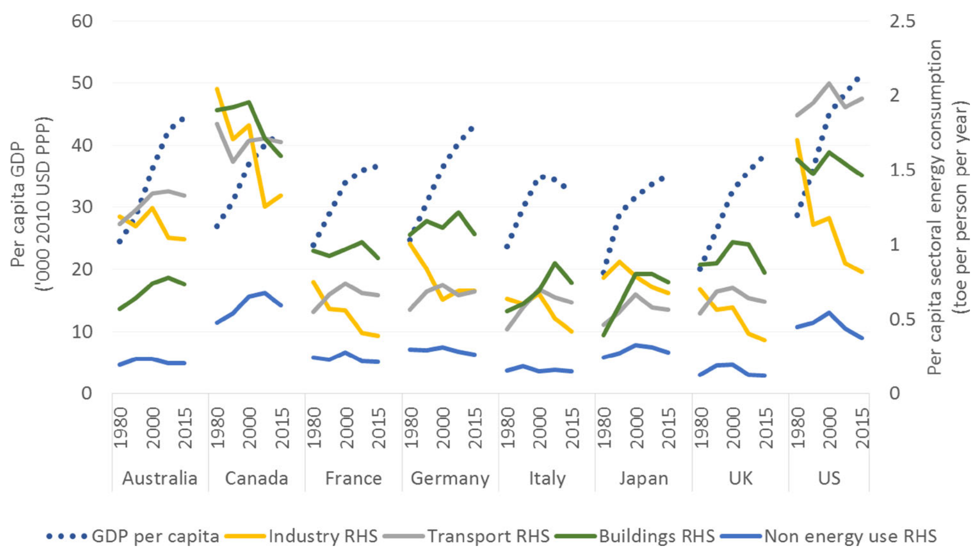

Fig. 6 Per capita income and per capita energy consumption—OECD reference counctries. Source: KAPSARC based on IEA energy balances

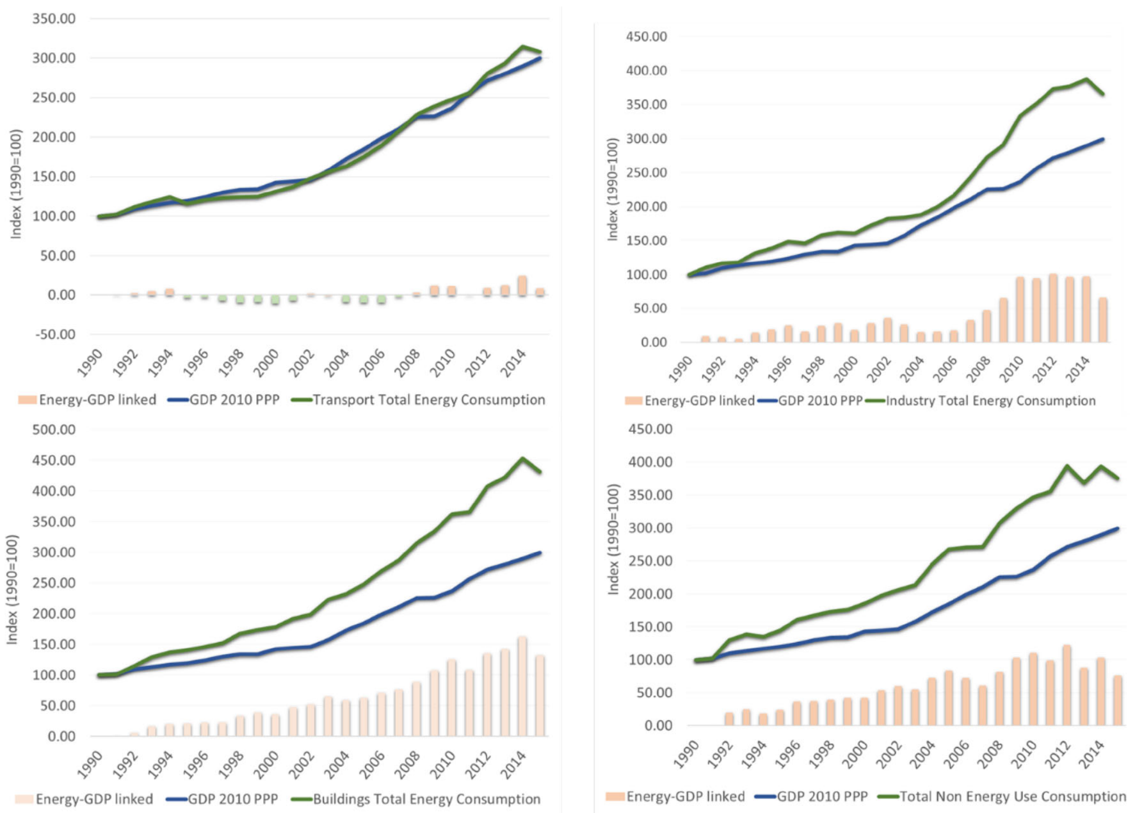

Fig. 7 Energy consumption and GDP linking and delinking—GCC countries. Source: KAPSARC based on IEA (histogram shows difference energy-GDP)

while GDP and energy consumption have moved together more or less on a one to one basis in the transport sector.

This is in strong contrast to the OECD group where the energy consumption index lies below that for GDP for all sectors. For instance, between 1990 and 2015 while energy consumption still rose in the transport and buildings sectors, it grew by 55 and 39% less than growth in GDP, respectively. In the industrial and non-energy use sectors energy consumption actually declined while the overall economy grew with GDP rising 71 and 58% more than the change in energy consumption. This suggests relative decoupling in the transport and building sector and absolute decoupling of energy demand and GDP in the industrial and non-energy use sectors.

The core result here is the increasing energy to GDP intensities of the GCC countries relative to the absolute and relative decoupling of OECD economies. On the face of it, this makes the GCC countries unusual, with the energy–GDP relationship driven by a range of socio-political constraints and factors of production which have been historically dominated by a singular dependence on oil and oil purchased imports.

These relationships can also be examined econometrically, by investigating the income elasticity of energy consumption, or percentage change in energy consumption relative to a percentage change in economic growth. A GDP elasticity below one entails decoupling of energy consumption from GDP, implying that energy grows slower than GDP. It may be possible that the elasticity is negative, that is while the economy grows its total energy consumption declines. That would be a sign of absolute decoupling, consistent with the declining portion of the Kuznets curve in Fig. 1.

Empirical model and results for estimating energy–GDP elasticities

For each of the sectors under consideration we estimate energy demand equations where per capita energy consumption depends on powers of per capita income. This basic formulation follows Burke and Csereklyei [3] and Galeotti, Howarth and Lanza [9] in that it allows for a non-linear effect of per capita income. The income elasticity of energy demand is, therefore, not constant and it can account for the decoupling of energy use from economic growth, possibly with a Kuznets curve behavior. One simple way to capture non-linear Engel curves is to add powers of per capita income to a simple log-linear

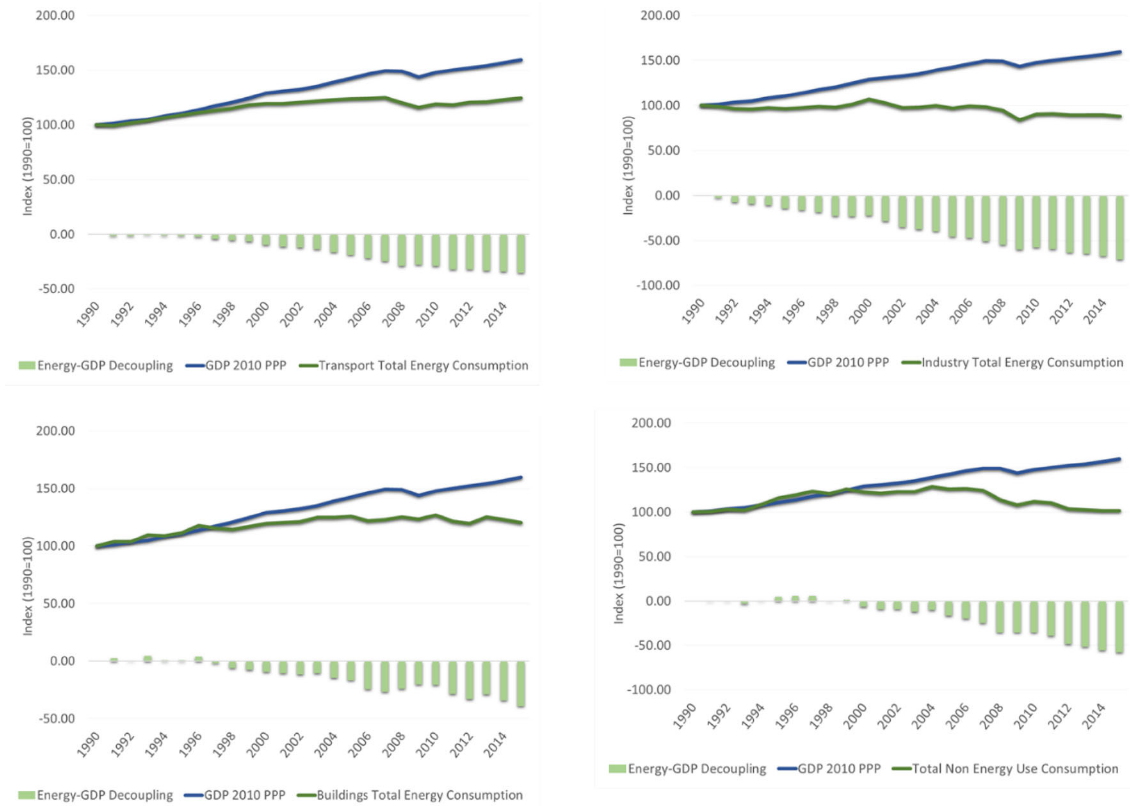

Fig. 8 Energy consumption and GDP linking and delinking OECD reference group. Source: KAPSARC based on IEA (histogram shows the difference between the indices)

specification. Thus, for each sector we estimate an equation like the following:

(1)

$$\ln\left(\frac{E_{it}}{P_{it}}\right) = \alpha_1 \ln\left(\frac{Y_{it}}{P_{it}}\right) + \alpha_2\left[\ln\left(\frac{Y_{it}}{P_{it}}\right)\right]^2 + \alpha_3\left[\ln\left(\frac{Y_{it}}{P_{it}}\right)\right]^3$$

where E stands for final energy use in the sector under consideration, Y for overall GDP, and P for population. Time runs from $t = 1, \ldots, T$ and countries are denoted as $i = 1, \ldots, N$. Of course, the estimated coefficients α_i are specific to each estimated sectoral equation. In the literature on energy demand that allows for non-linear income effects it is customary to add a quadratic per capita income term. This is sufficient for capturing decoupling—or delinking—and inverted-U Kuznets behaviors. However, this practice rules out the possibility of relinking between energy use and income after some high level of per capita GDP, as indicated in Fig. 5. In keeping with the Kuznets curve literature we include a cubic per capita income term in our estimated specifications [9].

Given

(1) the sectoral variable income elasticity, denoted by η_{ijt}, is given by:

(2) $\eta_{it} = \frac{\partial \ln E_{it}}{\partial \ln Y_{it}} = \alpha_1 + 2\alpha_2 \ln\left(\frac{Y}{P}\right)_{it} + 3\alpha_3\left[\ln\left(\frac{Y}{P}\right)\right]^2_{it}$

which is seen to change with per capita GDP. Note that one useful property of the log-linear specification is that per capita energy equations like (1) can be equivalently expressed in terms of energy intensity specifications. Indeed, from (1) we can easily obtain:

(3) $\ln\left(\frac{E_{it}}{Y_{it}}\right) = \tilde{\alpha}_1 \ln\left(\frac{Y_{it}}{P_{it}}\right) + \alpha_2\left[\ln\left(\frac{Y_{it}}{P_{it}}\right)\right]^2 + \alpha_3\left[\ln\left(\frac{Y_{it}}{P_{it}}\right)\right]^3$

where $\tilde{\alpha}_1 = \alpha_1 - 1$. Equation (1) is estimated separately for each sector and as a panel of different countries over a time period. Thus, we add a stochastic error term as follows:

(4) $\ln\left(\frac{E_{it}}{P_{it}}\right) = \alpha_1 \ln\left(\frac{Y_{it}}{P_{it}}\right) + \alpha_2\left[\ln\left(\frac{Y_{it}}{P_{it}}\right)\right]^2 + \alpha_3\left[\ln\left(\frac{Y_{it}}{P_{it}}\right)\right]^3 + u_{it}$

where the disturbance term is specified as follows:

(5) $u_{it} = \alpha_i + \beta_{it} + \gamma_t + \varepsilon_{it}$

This error component model includes a country-specific effect, a heterogeneous time effect, a common time effect, and a white noise error. Energy demand equations like (1) are often made to depend

Table 1 GDP elasticity of energy consumption

Country group	Period	GDP per capita 2010 PPP USD/person	GDP elasticity of total final energy consumption per capita			
			Industry	Transport	Buildings	Non Energy
GCC	1990	42440.05	1.65	0.91	1.10	2.14
	2000	46616.34	1.87	1.11	1.24	2.72
	2015	54945.83	2.00	1.32	1.30	3.16
OECD reference countries	1990	31801.85	0.39	0.27	− 0.41	− 0.43
	2000	38334.55	0.68	0.46	− 0.60	0.54
	2015	42918.00	0.57	0.60	− 0.18	0.11

Calculated elasticities are based on GDP per capita is expressed in 2010 PPP dollars per person; energy consumption is in toe per person and the value of estimated coefficients as explained in "Appendix E"

upon covariates other than per capita GDP. Energy prices, trade, intra-sectoral composition are natural candidates (see, e.g., [9]). Data for these variables are typically unavailable for cross country studies conducted at sector level. Perhaps the oil price is the only additional explanatory variable that can be added to the specification. However this variable is both sector- and country-invariant. Thus, fixed time effects are able to capture movements over time of the oil price. We have estimated sectoral energy demand equations including the price of oil (and excluding time effects): they are not reported here for brevity, but are available from the authors upon request. To account for inter country variation in energy prices, we have used after tax prices for petrol in the regression.

A fixed effects least squares estimator is used so that country- and time-effects can be properly dealt with by means of suitable dummies and time trends. Specifically:

(6) $\alpha_i = \sum_{i=1}^{N} a_i CD_i; \beta_{it} = \sum_{i=1}^{N} b_{it} t CD_i$

where t is a time trend and CD_i are dummy variables taking on a value of one for country i and zero otherwise. We do not consider a country-invariant time effect γ because, if proxied by a time trend, it would be collinear with the country-specific time effects.

A useful feature of the analytical framework underlying this paper is that the GDP elasticity of energy consumption is variable, so that it may take on both positive values—above or below one—as well as negative values (see "Appendix E" for technical details). This would be the case with a "well-behaved" Kuznets curve.

We computed GDP elasticities of energy consumption based on this econometric approach. Our detailed results are presented in "Appendix E" for the sample 1990–2014. To the best of our knowledge, there is no previous evidence on the GDP elasticity of energy consumption for the GCC countries at the sectoral level. Table 1 presents a summary of results and Tables E1 and E2 a detailed view of the estimation. Elasticities are computed for the initial, mid, and end of sample values.

Looking at GCC countries the first aspect to note is that elasticities for industry, transport and non-energy sector are above one. This suggests that no decoupling has taken place over the sample period and that energy consumption in each sector and GDP are strongly linked. The second aspect to be mentioned is that over time elasticities have risen, suggesting that this linking relationship has grown stronger over time.

Taken at face value, therefore, a 1% increase in GDP (whether per capita or not) in 2015 induced an increase by 2% in industrial energy consumption (whether per capita or not), a 1.32% increase in transport, 1.3% in buildings and 3.16% increase in the non-energy sector. These results are broadly consistent with the observed data in the Figures above, and suggest that no Kuznets "inverted U"—type behavior has emerged from the data over the sample period—or rather that the GCC countries are still on the upwards sloping part of the curve.

How do the OECD reference countries behave in this respect? Here, the most apparent aspect is that elasticities are all under 1 for every sector suggesting energy consumption and economic growth have decoupled and these countries are on the downwards sloping part of the hypothetical Kuznets curve.

For instance, in 2015 this analysis suggests a 1% increase in GDP leads to a 0.57% increase in energy consumption for the industrial sector, a 0.6% increase for transport energy consumption a 0.18% fall in energy consumption in the buildings sector and a 0.11% rise in the non-energy use sector.

As a general final remark, Table 1 shows that GDP elasticities of energy consumption for the OECD reference group of countries are all smaller than the corresponding ones for the GCC group, as expected.

Conclusions

All countries in the GCC share a common goal to transition to economies less reliant on oil and gas. As part of this transition diversification and energy efficiency strategies have become major strategic priorities. If successful, such policies are likely to significantly change the relationship between domestic energy consumption and GDP.

In this paper, we have explored the nature of the relationship between energy consumption and economic development in the GCC from a range of theoretical and empirical perspectives. What emerges from the analysis is the GCC is unusual both compared to other countries and standard theoretical models.

According to the Kuznets theory of economic development and energy consumption, as countries grow richer they move through phases of primarily agriculture and resource dependent growth, into a process of industrialization and the installation of modern infrastructure; and finally into a phase of consumer driven growth relatively geared toward services and higher value manufacturing activities. According to this stylized view of the energy–economic growth relationship as per capita incomes rise per capita energy consumption at first increases rapidly before slowing down, peaking and eventually declining as economic complexity, prosperity and policy shift the structure and improves the energy efficiency of the economy.

In contrast to this stylized view, despite having among some of the highest levels of per capita income in the world, energy and GDP are strongly linked in the GCC. Growth in energy consumption far outpaces growth in GDP in all sectors, except perhaps for transport. This points to the importance of the 'growth hypothesis' in the GCC where energy consumption plays an important role in economic development. This is in contrast to our OECD group where economic growth has been accompanied by relatively slower or even declining energy consumption in recent years. In this context, the evidence suggests the 'conservation hypothesis' holds which is where reductions in energy consumption can be achieved with little or no adverse impact on economic growth. While there is some variation between countries in each group (as can be seen in appendix A) these general results are quite strong and hold even for the resource rich OECD economies, such as the United States, Australia and Canada.

This strong link between economic development and energy consumption in the GCC is likely to be driven primarily by domestic energy prices which are among the lowest in the world. Low energy prices are likely to have significantly discouraged energy efficiency investments and prudent consumption of energy among households and industry alike.

Furthermore, low energy prices are likely to have also favored the expansion of energy intensive industry in the GCC over other sectors. While it is reasonable to expect that a region blessed with access to an abundance of low-cost energy to have a competitive advantage in energy intensive industries, subsidizing domestic users far below international benchmark prices is also likely to have distorted patterns of investment to be overly focused on the production of energy intensive basic commodities.

The region faces two broad strategic choices regarding the nature of diversification strategies which will shape the outlook for future domestic energy consumption. These are clearly exemplified by Saudi Arabia's Nationally Determined Contribution, under the Paris Accord climate change agreement [29]:

- A development pathway involving accelerated industrialization in energy intensive sectors such as petrochemicals, steel, aluminum and cement based on access to low-cost energy. This would bring about rising domestic energy consumption and downwards pressure on oil exports.
- A development pathway involving substantial diversification into non-energy sectors, such as financial services, medical services, tourism, education, renewable energy and energy efficiency. With this model, domestic energy consumption would be moderated and continued strong energy exports can be channeled into investment in these high value-added sectors.

This strategic decision will be determined by the extent of governments' resolve across most of the GCC to increase domestic energy prices to be more in line with international benchmarks, e.g., [8]. Accompanying such energy price reforms is the related need for clear industrial strategy which builds on the region's competitive advantages of access to relatively low-cost oil and gas but does not leave the region beholden to them by allowing other sectors to develop. Such an industrial strategy can aim to promote a competitive and strong energy intensive industrial sector by carefully sequencing price reforms with improvements to industrial productivity such as through enhanced support for energy efficiency and increasing the coverage and stringency of energy efficiency standards. At the same time, increased focus can be given to develop the energy services sector and down-stream higher value-added sectors as a richer source of employment opportunity for the local citizens. A key element for such industrial strategy to succeed is thus coordinating with appropriate education and training opportunities.

At the strategic policy level, setting national energy productivity or energy intensity targets could also serve as a powerful driver to help achieve the desired transition. At the sector level energy efficiency benchmarking, particularly in the energy intensive industrial sub-sectors, along with the phasing out outdated capacity and incentivizing improved energy management could also play an important role. For the transport and buildings sector improved energy efficiency labelling and standard setting are also important.

The development pathways taken within the GCC have been and will be unique. This reflects a particular set of socio-political constraints and the region's singular dependence on oil and gas and oil purchased imports. However, recent strategies to transition to economies less reliant on the sale and use of fossil fuels have gained substantial momentum and have the potential to reshape the energy-economic growth relationship.

As this paper has focused on a GCC level, it has been necessary to limit detail and discussion of how each individual country's development path has played out and may play out in the future on energy consumption. Recent reform plans across the GCC, such as Saudi Vision 2030 [18], will have profound implications on the balance between energy consumption and growth. Similarly, technological shifts, including the diffusion of electrical vehicles, nuclear and renewable energy, have the potential to realign the relationships between growth and energy demand at the sector level. Investigating such country-specific and technological shifts offers an important avenue for future research.

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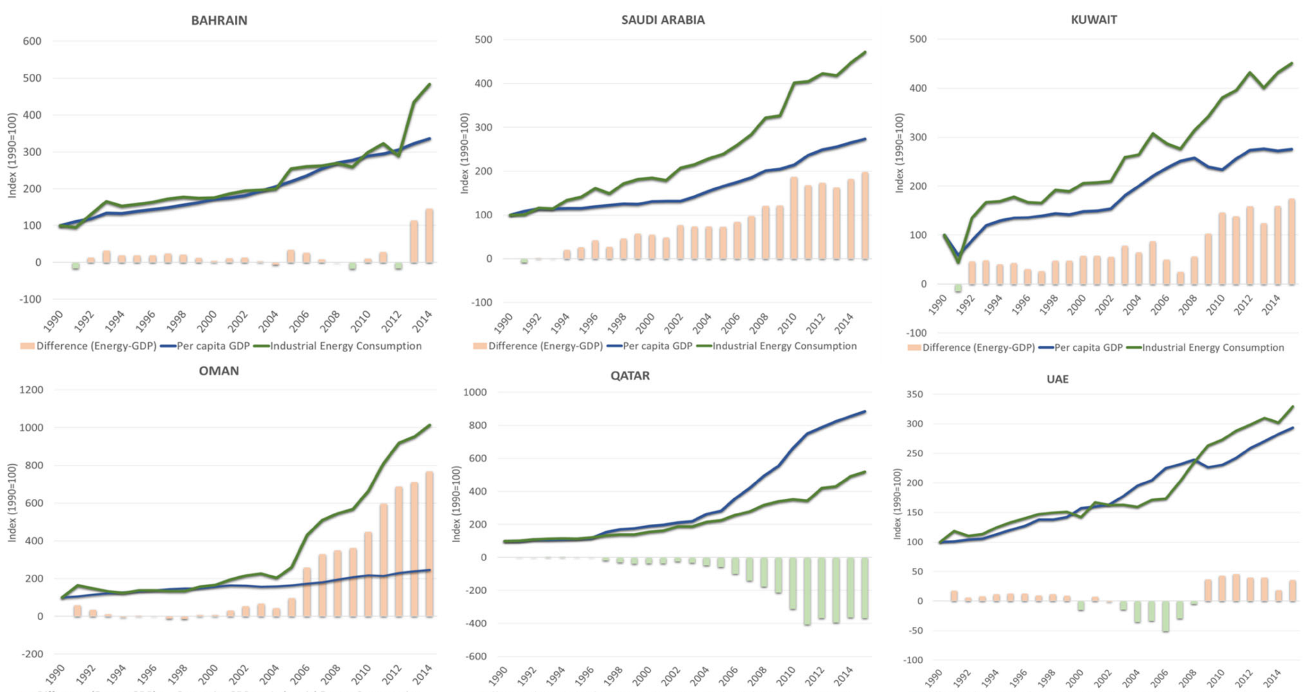
Compliance with ethical standards

Conflict of interest The authors are employees of KAPSARC which is one of the sponsoring organizations of Energy Transitions. The peer review process was blind to eliminate any conflict of interest.

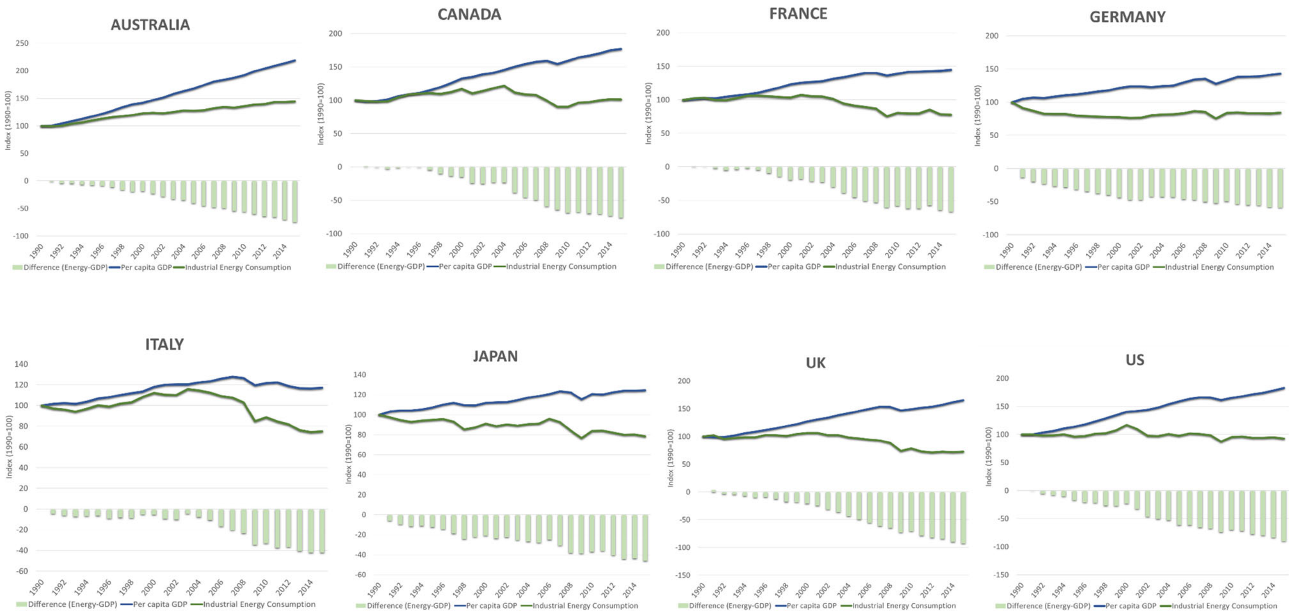
Appendix A1

Evidence of decoupling industrial sector: GCC countries. Source: KAPSARC analysis based on IEA data



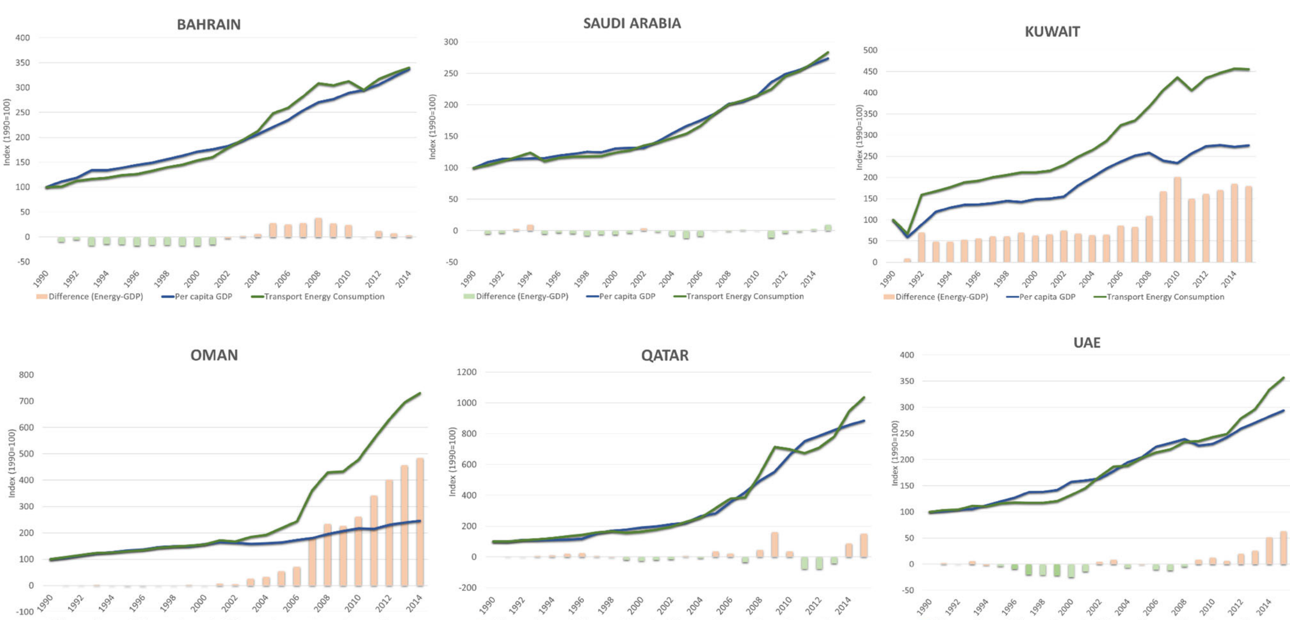
Appendix A2

Evidence of decoupling industrial sector: OECD reference group. Source: KAPSARC analysis based on IEA data



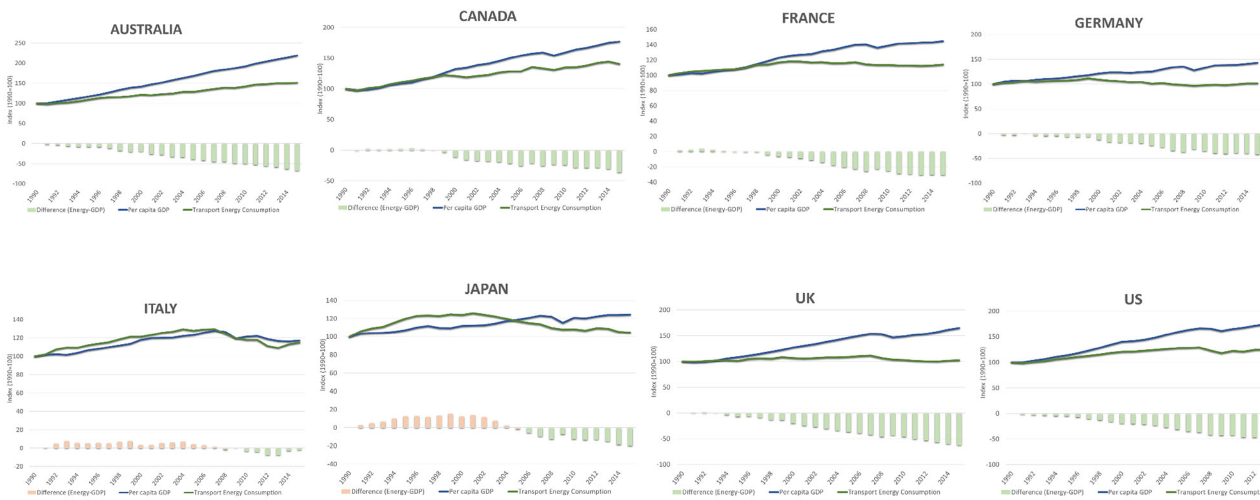
Appendix B1

Evidence of decoupling transport sector: GCC countries. Source: KAPSARC analysis based on IEA data



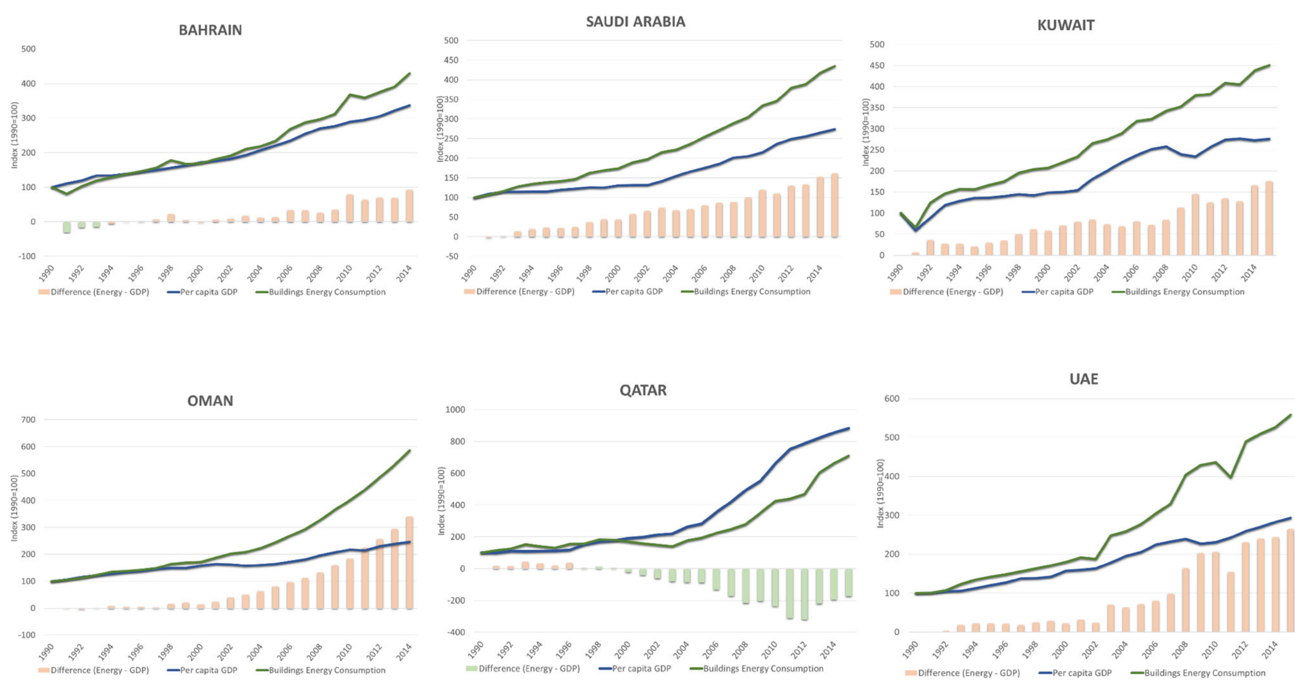
Appendix B2

Evidence of decoupling transport sector: OECD reference group of countries. Source: KAPSARC analysis based on IEA data



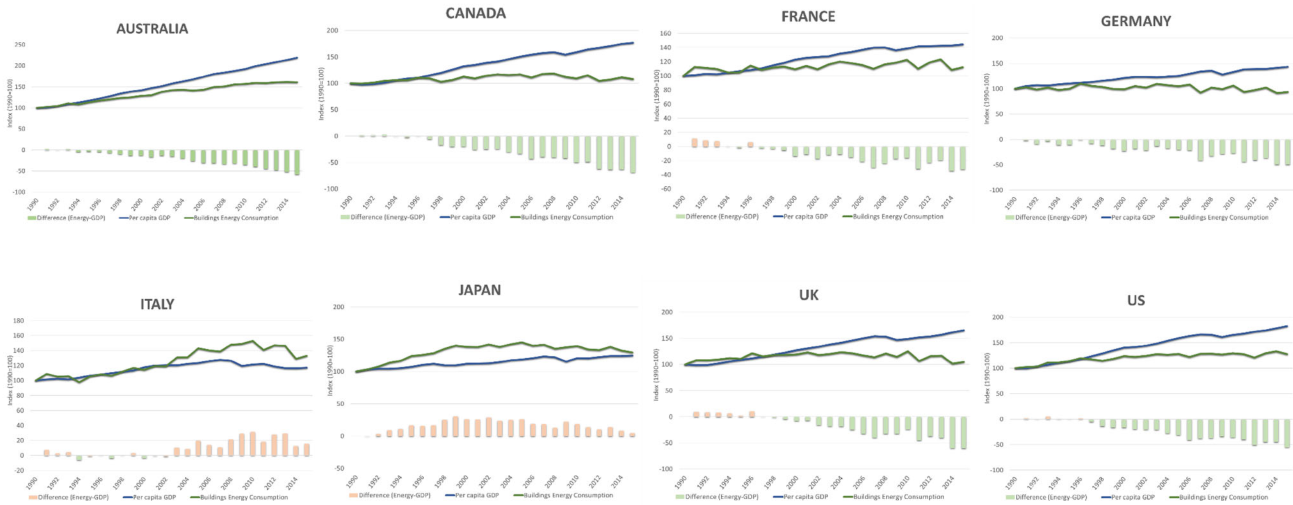
Appendix C1

Evidence of decoupling buildings sector: GCC Countries. Source: KAPSARC analysis based on IEA data



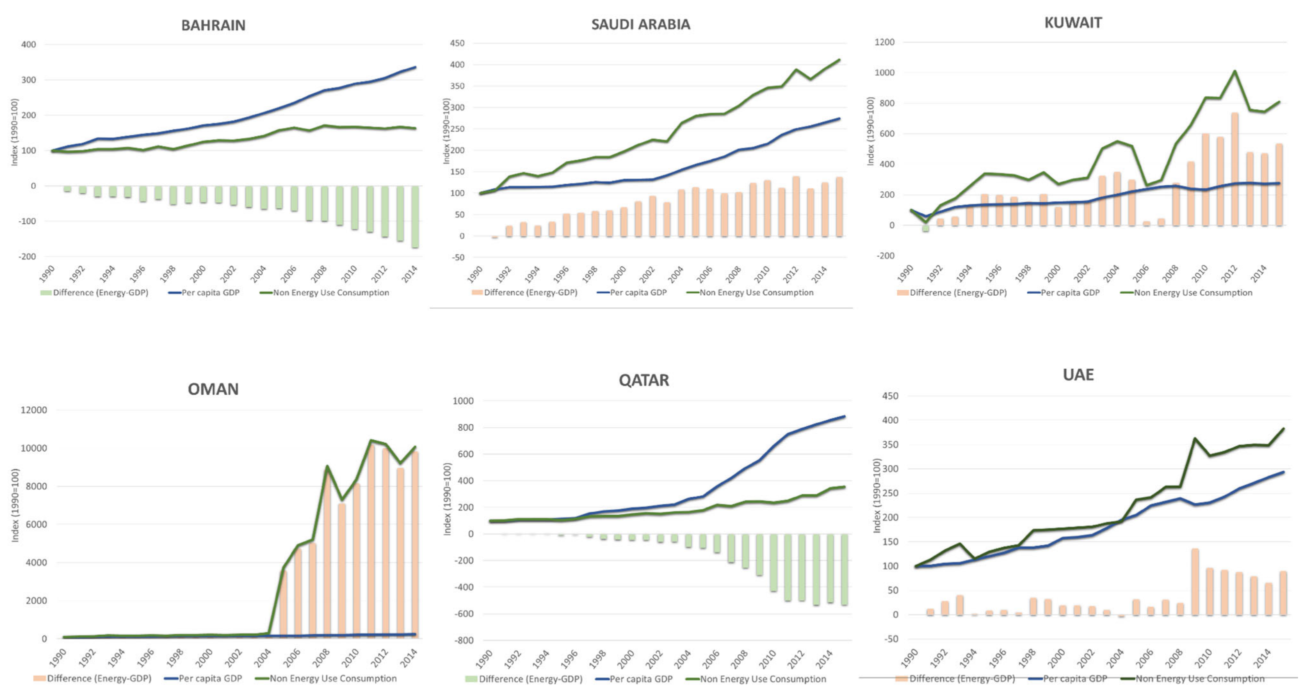
Appendix C2

Evidence of decoupling buildings sector: OECD reference group of countries. Source: KAPSARC analysis based on IEA data



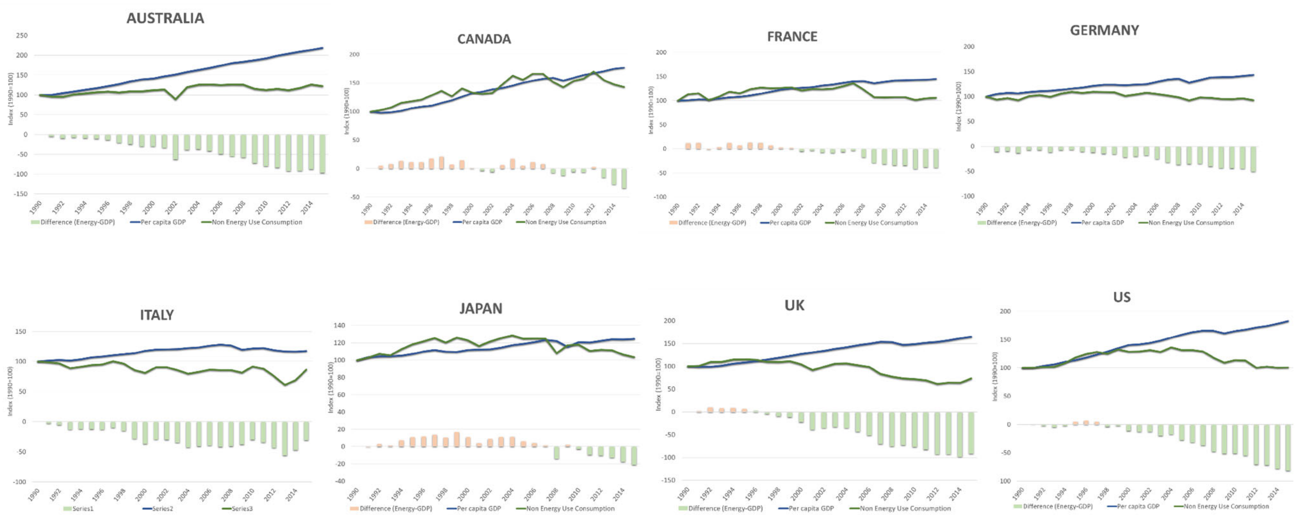
Appendix D1

Evidence of decoupling non-energy use sector: GCC countries. Source: KAPSARC analysis based on IEA data



Appendix D2

Evidence of decoupling Non-energy use sector: OECD reference group of countries. Source: KAPSARC analysis based on IEA data



Appendix E

Table E1 Detailed results: GCC

GCC	Industry		Transport		Buildings		Non energy	
	Cubic	Quadratic	Cubic	Quadratic	Cubic	Quadratic	Cubic	Quadratic
log(Y/P)	− 92,183	7,858	− 55,756	1,461	− 70,611	6,892	− 220,574	13,800
	− 1,692	*2,894*	*− 2,013*	*1,021*	*− 3,871*	*7,736*	*− 2,534*	*2,836*
[log(Y/P)]2	23,593	− 0,822	13,893	− 0,071	18,146	− 0,769	55,656	− 1,543
	1,801	*− 2,655*	*2,089*	*− 0,437*	*4,086*	*− 7,288*	*2,682*	*− 2,787*
[log(Y/P)]3	− 1,970		− 1,127		− 1,526		− 4615	
	− 1,886		*− 2,127*		*− 4,265*		*− 2,813*	
log(gas price)	− 0,129	− 0,117	− 0,148	− 0,141	− 0,032	− 0,022	− 0,234	− 0,206
	− 0,517	*− 0,557*	*− 1,180*	*− 1,307*	*− 0,413*	*− 0,280*	*− 0,527*	*− 0,535*
Adjusted R^2	0,758	0,747	0,860	0,851	0,917	0,897	0,739	0,723
F test	15,247	14,887	29,043	27,811	51,433	41,804	13,935	13,274
	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
No obs.	156	156	156	156	156	156	156	156

(1) Fixed effects estimation with country and time effects (not shown); (2) robust *t* statistics in round brackets: (3) *P* values in square brackets; (4) the *F* statistic tests the null hypothesis that all coefficients are equal to zero; (5) sample period 1990–2014; (6) the estimation model is given by expressions (4) and (6)

Table E2 Detailed results: OECD reference group

OECD reference group	Industry		Transport		Buildings		Non energy	
	Cubic	Quadratic	Cubic	Quadratic	Cubic	Quadratic	Cubic	Quadratic
log(Y/P)	− 99,323	− 2,371	0,699	− 3,364	180,657	− 1,445	− 365,803	− 9,354
	− 2,236	*− 1,349*	*0,034*	*− 3,858*	*4,769*	*− 1,199*	*− 6,535*	*− 3,591*
[log(Y/P)]2	27,371	0,407	− 0,605	0,525	− 50,511	0,136	100,454	1,317
	2,218	*1,659*	*− 0,105*	*4,312*	*− 4,777*	*0,824*	*6,487*	*3,666*
[log(Y/P)]3	− 2,497		0,105		4,691		− 9,182	
	− 2,187		*0,196*		*4,772*		*− 6,437*	
log(Gas Price)	− 0,103	− 0,179	− 0,218	− 0,215	− 0,448	− 0,306	− 0,022	− 0,299
	− 1,359	*− 3,021*	*− 6,608*	*− 7,946*	*− 7,797*	*− 5,594*	*− 0,259*	*− 4,028*
Adjusted R^2	0,967	0,967	0,995	0,995	0,977	0,974	0,967	0,961
F test	171,181	173,895	1.247,665	1.290,580	248,134	225,896	167,620	147,370
	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
No obs.	208	208	208	208	208	208	208	208

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