World Economic and Financial Surveys

World Economic Outlook

Challenges to Steady Growth

Online Annexes: Chapter 1

OCT 18

INTERNATIONAL MONETARY FUND

Global Energy Demand: Additional Facts

Over the past decades, the increase in demand for electricity has led to higher usage of primary energy sources by the power sector. Electricity, in fact, is not a primary energy supply, given that it is generated from fossil fuels, mainly from coal and natural gas, nuclear, hydro, solar photovoltaic, wind, geothermal, biomass and waste, and a few other sources. Coal and natural gas contributed the most to satisfy the significant increase of electricity consumption from 1971 to 2015 (Annex Table 1.SF.1.1).

Contrary to all other primary energy sources, oil is mostly used in the transport sector and not in the power generation. The share of oil-fueled power plants has, in fact, declined dramatically over the past decades (Annex Table 1.SF.1.2).

Annex Table 1.SF.1.1. Contribution to Electrification, 1971–2015

(Percent, contribution to growth)

Coal	136
Oil	0
Gas	71
Nuclear	45
Hydro	16
Other renewables and other fuels	27
Total electricity growth (1971–2015)	296

Source: International Energy Agency, *World Energy Balances*; and IMF staff calculations.

Note: Individual contributions to electrification sum up to total electricity growth (1971–2015).

Annex Table 1.SF.1.2. World Energy Usage, 2015 and 1971

(Millions tonnes of oil equivalent)

Year = 2015 Unit: MTOE	Coal	Oil	Gas	Nuclear	Renewables and Other	Total	Percent of Total
Power Generation	2,680	307	1,232	671	754	5,643	41
Industry	826	308	530	0	193	1,858	14
Transport	3	2,491	98	0	76	2,667	20
Residential and Commercial	110	296	601	0	806	1,813	13
Non-Energy Use	61	615	160	0	-	836	6
Total Primary Energy Demand	3,836	4,334	2,944	671	1,858	13,643	100

Year = 1971 Unit: Mtoe	Coal	Oil	Gas	Nuclear	Renewables and Other	Total	Percent of Total
Power Generation	739	302	217	29	138	1,425	26
Industry	346	406	314	0	81	1,148	21
Transport	35	901	18	0	0	954	17
Residential and Commercial	209	341	204	0	463	1,217	22
Non-Energy Use	6	216	14	0	0	236	4
Total Primary Energy Demand	1,437	2,438	893	29	725	5,523	100

Source: International Energy Agency, *World Energy Balances*; and IMF staff calculations.

Note: Because of statistical discrepancies, individual data in each column do not sum exactly to total primary energy demand. Lighter color represents smaller share in total primary energy demand.

Energy and Income: The Econometric Specification

To test for the presence of an S-shaped relationship between energy demand and per capita income, the Special Feature uses an unbalanced panel of 136 countries, controlling for the size of the country (that is, population and land area) and fossil fuel abundance. Time fixed effects are used to capture worldwide gains in energy efficiency and fluctuations in global economic activity and energy prices. The sample is annual and spans 1971–2015, covering two major energy price cycles. Specifically, the exercise estimates the following specification relating (log) total energy demand E to (log) population, pop; a third-order polynomial in (log) income per capita, gdp; and a vector of control variables, X:[3]

$$E_{it} = \beta_0 + \beta_1 pop_{it} + \beta_2 gdp_{it} + \beta_3 (gdp_{it})^2 + \beta_4 (gdp_{it})^3 + \beta_5 \times X_{it} + \lambda_t + \varepsilon_{it} \quad (1.2)$$

in which λ_t are year fixed effects, while X_{it} includes a time-varying energy-export and coal producer dummy, distance from the equator, and the log of land area; the indices *i* and *t* refer to countries and years, respectively. An oil exporter is defined as having oil production exceeding consumption. A similar definition is used for natural gas and coal exporters. A coal producer is defined as having production able to satisfy between 60 percent and 100 percent of the country's coal consumption. Distance from equator is the absolute value of latitude.

This empirical specification generalizes earlier contributions to the literature on energy demand, including Medlock and Soligo (2001) and van Benthem (2015), and follows the seminal work of Grossman and Krueger (1995), who study turning points in the relationship between income and environmental quality by introducing a cubic per capita income term.[4] Similarly, this specification potentially allows for an S-shaped relationship between income and energy demand ($\beta_4 < 0$). The special case of $\beta_3 = \beta_4 = 0$ and $\beta_1 = \beta_2$ corresponds to the case in which energy demand increases proportionally to GDP.

Results for the baseline specification, column (5), and robustness checks are reported in Annex Table 1.SF.1.3. Not surprisingly, the analysis finds that energy demand moves in lockstep with population. Point estimates suggest that having a sizable land area coupled with being a coal exporter (producer) increases energy demand by about 45 (33) percent. Given that coal is expensive to transport, coal prices tend to be relatively low in coal producer countries, thus attracting energy-intensive industries, while a large land area may require more travelling and may proxy for hydropower potential. Both factors increase energy demand given population size and other country characteristics.

[3]Energy demand (in million tons of oil equivalent) is the sum of electricity and primary energy supply (that is, coal, oil, natural gas, hydropower, nuclear energy, and renewables). Energy data are from the International Energy Agency; data on population, GDP per capita (in 2011 US dollars), and country area size (in square kilometers) come from the World Bank's World Development Indicators. Latitude is from the GeoDist database by Centre d'Etudes Prospectives et d'Informations Internationales.

[4]Energy is consumed to produce energy services. These are defined as "those functions performed using energy which are means to obtain or facilitate desired end services or states" (Fell 2017). Familiar examples are heating, cooling, lighting, refrigeration, and transport. The non-energy demand for fossil fuels stems mainly from the petrochemical industry, representing about 6 percent of total primary energy demand.

Annex Table 1.SF.1.3. Total Demand Determinants by Different Specifications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Population	1.005***	1.009***	1.000***	1.079***	0.965***	0.959***	1.161***
	(0.0272)	(0.0246)	(0.0245)	(0.0312)	(0.0472)	(0.0390)	(0.148)
GDP per Capita	0.783***	-1.048**	-8.415***	-7.103*	-8.676**	-5.068*	-6.889***
	(0.0357)	(0.327)	(1.834)	(3.568)	(2.744)	(2.442)	(1.922)
(GDP per Capita)^2		0.104***	0.956***	0.843*	1.044**	0.639*	0.865***
		(0.0182)	(0.212)	(0.426)	(0.331)	(0.296)	(0.238)
(GDP per Capita)^3			-0.0324***	-0.0293	-0.0378**	-0.0231	-0.0330***
			(0.00805)	(0.0165)	(0.0130)	(0.0116)	(0.00976)
Area					0.0798	0.0953*	
					(0.0416)	(0.0364)	
Oil Exporter					-0.0173	0.00523	
					(0.0947)	(0.0748)	
Gas Exporter					0.0483	-0.0478	
					(0.0847)	(0.0703)	
Coal Exporter					0.378**	0.315**	
					(0.118)	(0.0955)	
Coal Producer					0.251*	0.132	
					(0.115)	(0.0881)	
Latitude						0.0138***	
						(0.0031)	
Constant	-13.43***	-5.650***	15.34**	9.517	14.23	3.341	7.445
	(0.546)	(1.435)	(5.331)	(9.864)	(7.524)	(6.480)	(6.957)
Observations	5,095	5,095	5,095	5,095	2,794	2,773	5,095
Number of Countries	136	136	136	136	88	87	136
Graduation from Biomass			770	520	562	321	464
Static Saturation Point			454,186	401,087	179,389	323,516	82,921
Dynamic Saturation Point (1% eff. gain)			154,556	127,286	63,590	74,050	17,831
Dynamic Saturation Point (spec. eff. gain)			173,333	33,576	38,410	41,298	25,281
Inflection Point			18,698	14,447	10,039	10,184	6,204
Max Elasticity			0.9892	0.9723	0.9416	0.8280	0.6660
Average Elasticity			0.9845	0.9721	0.9233	0.8177	0.5888
R^2	0.91	0.92	0.93	0.95	0.96	0.97	1.00
Model	OLS	OLS	OLS	WLS	WLS	WLS	WLS

Sources: International Energy Agency; World Bank World Development Indicators; and IMF staff calculations.

Note: Energy exporters and producers are derived from the International Energy Agency. Latitude is the absolute value of latitude in degrees for national capitals. Robust standard errors clustered at the country level in parentheses. Variables are in logarithmic scale. Column (7) uses fixed effects regression. Average elasticity is calculated at 15,000 2011 international US$. "eff. gain" is efficiency gain. "spec. eff. gain" is specific efficiency gain, and is calculated using each specification's average growth of time dummies. OLS = ordinary least squares. WLS = weighted least squares.

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Results are qualitatively robust to different specifications, including "distance from the equator" (column (6)) and "temperature" (not shown), which serve as proxies for intrinsic demand for cooling and heating energy services, reducing the significance of income. This is not surprising, however, as Hall and Jones (1999) and other scholars have used distance from the equator to instrument output per worker. Similarly, under country fixed effects, the estimate of the cubic terms is less significant when using OLS (not shown).[5] Pooling the sample, instead, allows for a better exploitation of income differences across countries to infer the form of the energy-income S-shaped relation. Finally, weighting countries by energy demand, reinforces the S-shaped relationship, reducing the saturation point, even with country fixed effects (specification 7). Further, a necessary and sufficient condition for having an S-shaped relationship is that $\beta_1<0$, $\beta_2>0$, and $\beta_3<0$. The estimated coefficients meet this condition, which is statistically significant and robust across most specifications.

The average energy efficiency gain over the sample is calculated by dividing the time dummy in 2015 (that is, the last data point) by 45 (the number of years in the sample).[6] Energy efficiency gains vary somewhat across specifications, with an average of about 1 percent a year.[7] In Annex Table 1.SF.3, the baseline dynamic saturation point, thus, is calculated assuming a 1 percent annual efficiency gain. Alternatively, the dynamic saturation point is calculated assuming the average efficiency gain calculated for each specification.[8] As even small differences in the assumed efficiency gains compound over time, the alternative calculation can lead to substantial differences in the estimated saturation point.

The Primary Energy Mix

To examine the primary energy mix, each primary energy share is regressed on a quadratic function of per capita income, as shown in Annex Table 1.SF.1.4. The same dataset of the energy demand analysis is used. The shares are calculated dividing the primary energy source to total energy by country over time. To control for the local relative abundance of a specific resource, either dummies or country fixed effects are used. In the energy source panel regression, country fixed effects are necessary to avoid omitted variable bias (for example, Malta uses no natural gas, given that no gas pipeline reaches the island). It is worth noting how having a relative abundance of a fossil fuel (that is, oil, natural gas, and coal) increases significantly its consumption share (that is, the exporter and coal producer dummies are significant), mostly at the expense of the other (relatively less abundant) fossil fuels. [9]

[5]Results for the specifications with country fixed effects estimated with ordinary least squares are available upon request.

[6]The time dummy in the first year of the sample, 1971, is normalized to 0.

[7]As for energy efficiency, there is long-standing debate in resource economics on whether energy efficiency implies a reduction in energy consumption. Jevons (1865) asserts: "[I]t is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth […] Every improvement of the engine when effected will only accelerate anew the consumption of coal." Most recent studies, however, do not find the Jevons' effect—instead, energy consumption declines, all else equal, as energy efficiency improves (Greening, Greene, and Difiglio 2000; Sorrell 2009). By example, the United States "graduated" from biomass in the last quarter of the 19th century when wood was replaced by coal as the primary resource (EIA 2018).

[8]This is labelled "spec. eff. gain" in Annex Table 1.SF.1.3.

[9]There is a positive correlation between the natural gas and oil exporter dummies, given that about half of natural gas exporters are also oil exporters. This relation is much weaker, instead, for coal.

Annex Table 1.SF.1.4. Primary Energy and Electricity Share Determinants

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Share of Fossil Fuel		Share of Oil		Share of Natural Gas		Share of Coal		Share of Renewable		Share of Electricity	
GDP per Capita	0.594***	0.798***	0.460***	0.466***	-0.124	0.165	0.258***	0.158	-0.395***	-0.729***	-0.0567***	-0.0468
	(0.1120)	(0.1900)	(0.0925)	(0.1210)	(0.1360)	(0.1270)	(0.0751)	(0.1480)	(0.0857)	(0.1790)	(0.0082)	(0.0709)
$(\text{GDP per Capita})^2$	-0.0327***	-0.0395***	-0.0290***	-0.0237**	0.00927	-0.00792	-0.0129**	-0.00759	0.0195***	0.0343***	0.00565***	0.00387
	(0.0065)	(0.0108)	(0.0060)	(0.0070)	(0.0086)	(0.0075)	(0.0048)	(0.0081)	(0.0048)	(0.0100)	(0.0005)	(0.0039)
Oil Exporter		0.046		0.0747*		0.0681*		-0.0901**		-0.0268		-0.02
		(0.0414)		(0.0319)		(0.0322)		(0.0271)		(0.0407)		(0.0140)
Gas Exporter		0.00155		-0.0646**		0.113**		-0.0406		0.0279		-0.00231
		(0.0371)		(0.0199)		(0.0407)		(0.0251)		(0.0349)		(0.0122)
Coal Exporter		-0.00387		-0.135***		-0.0627*		0.186***		0.0181		-0.00854
		(0.0348)		(0.0282)		(0.0282)		(0.0465)		(0.0331)		(0.0086)
Coal Producer		0.0359		-0.0704*		-0.0092		0.103***		-0.038		-0.00468
		(0.0264)		(0.0318)		(0.0319)		(0.0257)		(0.0245)		(0.0103)
Constant	-1.759***	-3.213***	-1.219***	-1.821***	0.528	-0.661	-1.067***	-0.677	2.041***	3.975***	0.0935**	0.22
	(0.456)	(0.830)	(0.315)	(0.514)	(0.476)	(0.524)	(0.264)	(0.674)	(0.376)	(0.791)	(0.028)	(0.320)
Observations	5,095	2,794	5,095	2,794	5,095	2,794	5,095	2,794	5,095	2,794	5,095	2,794
Number of Countries	136	88	136	88	136	88	136	88	136	88	136	88
Share Peak	8,930	24,310	2,755	18,455	NA	NA	22,377	NA	NA	NA	NA	NA
R^2	0.94	0.33	0.9	0.23	0.92	0.16	0.97	0.27	0.97	0.45	0.95	0.19

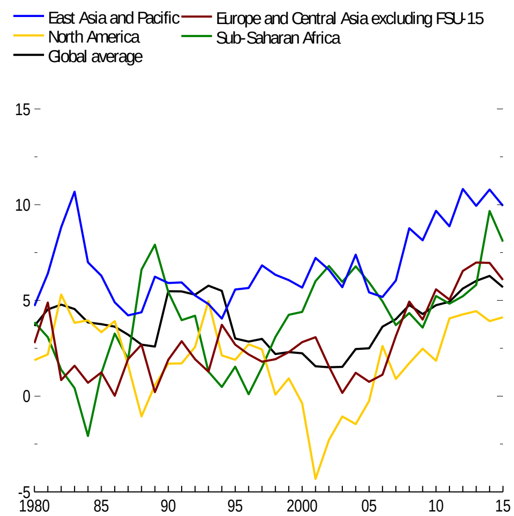
Sources: International Energy Agency; Wold Bank World Development Indicators; and IMF staff calculations.

Note: Fixed effects regression. Robust standard errors clustered at the country level in parentheses. Share is in percentage. GDP per capita is in logarithmic scale. NA = not applicable.

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

The Demand for and Supply of Renewable Energy: Additional Information

Annex Figure 1.SF.1.1. Renewable Total Primary Energy Supply Growth, by Select Regions
(percent, five-year year moving average)



Source: International Energy Agency; and IMF staff calculations
Note: Renewable total primary energy supply includes hydropower, geothermal, and solar, wind, and other. FSU-15 is former Soviet Union, consisting of 15 countries. Global average includes FSU-15, Latin America and the Caribbean, Middle East and North Africa, and South Asia.

As discussed in Box 1.SF.1, renewable energy has grown rapidly in recent years. Annex Figure 1.SF.1.1 visualizes renewable energy growth between 1980–2015 by region using five-year moving averages.

To explain the demand and outlook for renewable energy, Box 1.SF.1 proposes a simpler version of the main specification used in the Special Feature: [17]

$$RE_{it} = \exp(\beta_0 + \beta_1 gdp_{it} + \beta_2 pop_{it} + \beta_5 X_i + \beta_6 year_t) + \varepsilon_{it} \qquad (1.3),$$

in which RE_{it} measures the renewable energy capacity for electricity generation; gdp_{it} and pop_{it} are log income and log population, respectively; X_i is a set of controls including distance from the equator and the logarithm of land area; and $year_t$ is a trend term capturing global trends in technology. The renewable energy capacity for electricity generation (in gigawatts [GW]) includes hydropower, solar, wind, and geothermal (except biofuels) covering 177 countries over 1990–2015 (using data from the US Energy Information Administration).

Given that the focus in Box 1.SF.1 is on forecasting the demand for renewable energy, the above equation is estimated in levels using a weighted nonlinear least squares estimator, which is identical to Poisson pseudo-maximum likelihood (PPML) as in Silva and Tenreyro (2006). An estimation of the log-log form of equation (1) using weighted ordinary least squares (with RE_{it} as weight) gives very similar out-of-sample predictions, but the within-sample predictions of weighted nonlinear least squares appear superior.[18]

For the out-of-sample prediction presented in Box 1.SF.1, OECD (2014) long-term forecasts for GDP per capita and population size are used. The Organisation for Economic Co-operation and Development (OECD) publishes GDP and population forecasts for 45 major economies, including all OECD and Group of Twenty countries. For the remaining group of countries, the average sample growth rates are used. Given that most renewable energy capacity is installed in the 45 countries covered by the OECD, the forecasts are not sensitive to these assumptions.

To calculate how much energy the increase in renewable energy capacity can deliver to the electricity grid under the conservative and baseline scenarios shown in Figure 1.SF.1.1 of Box 1.SF.1, it is assumed that renewable energy capacity has a utilization rate of 35 percent, on average. Furthermore, to calculate how much fossil-fuel-based electricity generation can potentially be replaced by this new renewable energy capacity, total demand for fossil fuels by the electricity sector is calculated by summing over the categories coal, oil and gas in the "Power Generation" row of Annex Table 1.SF.1.2 for the year 2015. To account for the loss of energy that occurs during conversion from chemical energy to electricity in thermal power plants, it is assumed that the conversion efficiency of primary fossil fuels is 35 percent, on average.

[17]The shorter time span used here makes it difficult to fit an S-curved relationship between renewable energy capacity and income, necessitating a simpler specification.

[18]For the several advantages of PPML relative to ordinary least squares for estimating nonlinear relationships, see Silva and Tenreyro (2006).