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RESEARCH

Green Electricity Prices

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Abstract
This paper examines the correlation between end-user electricity prices and the share of solar and wind energy in total electricity production in OECD countries. It is shown (i) that end-user prices in recent years (2020–2022) are positively correlated with the share of solar and wind and (ii) that the price of electricity in the majority of countries has risen with the solar and wind share since these types of energy came on the scene.

Keywords Electricity prices · Renewable energy · Energy transition

Introduction

For about 20 years, governments in most OECD member countries have been pursuing a transition from fossil fuels to solar and wind (S&W) power (Mearns and Sornette 2023). In the literature, there is a deluge of papers showing how S&W leads to reduced wholesale prices of electricity (Sensfuß et al. 2008; Benhmad and Percebois; 2018; Sapio 2019; Maciejowska 2020; Maniatis and Milonas 2022; to name a few). These price reductions seldom show up in reduced electricity bills for end users, be they households or industry. This is not an entirely unrecognized phenomenon. Cludius et al. (2014) point out that end-use prices in Germany have risen despite falling spot prices of electricity, owing to support schemes for green energy. Nevertheless, the connection between end-use prices of electricity and increasing S&W share seems a neglected area of research, to which this paper is meant to be a contribution. Klopcic et al. (2022) show that prices of electricity for households in the EU increased from 2011 to 2019, but their emphasis is on cross-border effects of increased competition.

This paper traces the development of end-user electricity prices in OECD countries and shows that in the majority of cases they have increased together with a rising share of S&W in the production of electricity, indicating that this energy transition imposes costs on end users that they might perhaps prefer to be without. Our sources of data are as follows: (1) Data on annual electricity prices are from the International Energy Agency, accessible at the OECD iLibrary. (2) Data on production of electricity, in total and by S&W, are from the Energy Institute Statistical Review of World Energy. (3) Data on consumer price indices, used to inflate electricity prices to 2022 price level, were taken from the IMF database.

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Analysis

The Present Situation

Figure 1 shows the average price of electricity in 30 OECD countries, in US dollars, versus the share of S&W in the total production of energy 2020–2022, together with a regression line. It is obvious that the price of energy tends to increase with the share of S&W. The price of electricity for industry is generally much lower than for households, which typically pay twice as much as industry or more. The spread across countries is greater for industry than for households. Denmark has the highest price for households and the highest share of S&W, almost 60 percent, tightly followed by Germany and Belgium. Korea and Turkey have the lowest price for households, about a quarter of what it is in Denmark. Korea has an exceptionally low S&W share, less than 5 percent. The highest price for industry is in Italy and the lowest in the United States, with Denmark about half-way in between despite its high S&W share.

There is a wide spread in the S&W share in the production of electricity. The countries with the smallest share are the Czech Republic, Korea, Slovakia, Slovenia, and

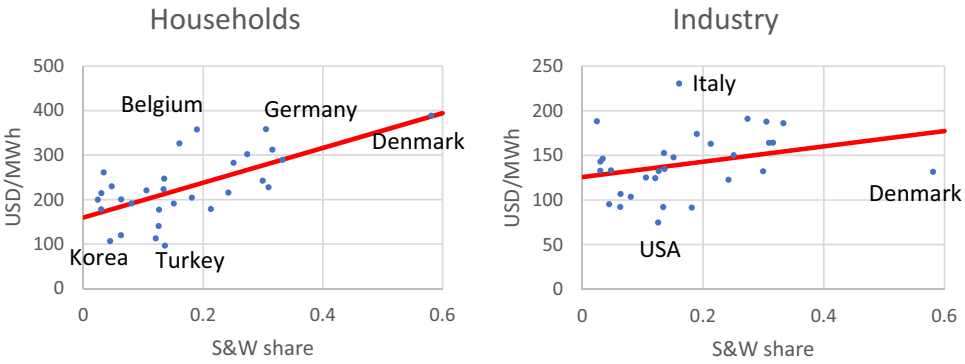

Fig. 1 Average price of electricity, in US dollars, versus share of solar and wind (S&W) in total production of energy 2020–2022

Switzerland, with a share of less than 5 percent. Denmark has a share of 60 percent and is a clear outlier. Germany, Greece, Ireland, and Spain all have a share of over 30 percent. The numbers are averages for 2020–2022.

Development of Prices and the S&W Share

Has the price of electricity risen in tandem with the S&W share in the production of electricity? To examine this, we regressed the price of electricity on the S&W share. S&W share has developed at different pace in different countries. Denmark was an early starter; the S&W share exceeded 2 percent as early as 1990 and was about 60 percent in 2020–2022. It makes little sense to run this regression with a negligible S&W share; hence, we do this only for years after and including the year when S&W exceeded 1 percent for the first time, which makes for a rather short time series for some countries. We have excluded countries where the share of S&W was less than 4 percent in 2022, which excludes a number of OECD member countries, such as Slovenia and Slovakia. Norway is excluded because of a very short time series for S&W, and Australia because of a long gap in the price series (Australia will be commented upon later). This leaves us with 28 OECD countries, which are listed in an appendix.

The price series we use is prices in domestic currency inflated by the consumer price index to the 2022 price level. The results for regression for individual countries are summarized in Table A1 in the Appendix. For the household sector, we get a significantly positive coefficient for the majority of countries (15 of 28), not significant for 9, and significantly negative for 4. The results for industry are similar, a significantly positive coefficient for 14 countries, insignificant for 12, and significantly negative for 2.

The magnitude of the regression coefficient of the S&W share depends, of course, on which currency the price is measured in. To get a better measure of what a higher share of wind and solar might mean in terms of higher prices across countries, a price index for each country was constructed and set at 1 for the year in which the solar and wind share exceeded 1 percent for the first time. This indexing procedure puts all countries on a comparable basis so that correction for different price levels across countries by country dummies is not necessary.

We then regressed this price index on the S&W share for all countries. The result is shown in Table 1. Both estimates of the regression coefficient are similar and close to 1.3, which means that a one percent point's increase in the S&W share will increase the price of electricity by 1.3 percent points on average across countries, both for households and industry, but the absolute increase in household prices will of course be greater because household prices are higher. In several countries, prices have risen much more than that, particularly in countries with a high S&W share. In Germany, the share of S&W reached 30 percent in 2020–22 while the price for households was 75 percent higher than when the S&W share was only 1 percent. In the United Kingdom, the S&W share exceeded 25 percent in 2020–22 while the price for households was almost twice as high as when the S&W share began its ascendance from 1 percent (see Figs. 4 and 5 in a later section); in 2022, it was three times as high.

There are reasons to expect that the relationship between electricity prices and the S&W share is nonlinear. Integrating S&W into the electricity system becomes increasingly challenging as its share of total electricity production increases (Kroposki 2017; Guerra et al. 2022). This could raise prices at an increasing rate as the S&W share rises further. On the other hand, the costs of S&W could be highest to begin with as these types of installations are introduced, due to learning effects and technological progress. This could lead to slower price increase as the S&W share rises further, and prices might even fall. To investigate this further, a threshold regression was performed, where the

Table 1 Results for the regression price index = $a + b$*S&W share

Household sector		Industry sector	
a	b	a	b
1.0128 (0.0141)	1.2620 (0.0959)	1.0044 (0.0209)	1.3237 (0.1404)

Standard deviation in parentheses

Table 2 Results for a threshold regression price index = $a + b$*S&W share

Household sector				Industry sector			
S&W < 0.3563		S&W > 0.3563		S&W < 0.3291		S&W > 0.3291	
a	*b*	*a*	*b*	*a*	*b*	*a*	*b*
0.9826 (0.0144)	1.6366 (0.1155)	1.9095 (0.5239)	− 0.9648 (1.0493)	0.9423 (0.0201)	2.0857 (0.1643)	2.4094 (0.6823)	− 2.3723 (1.4791)

Standard deviation in parentheses

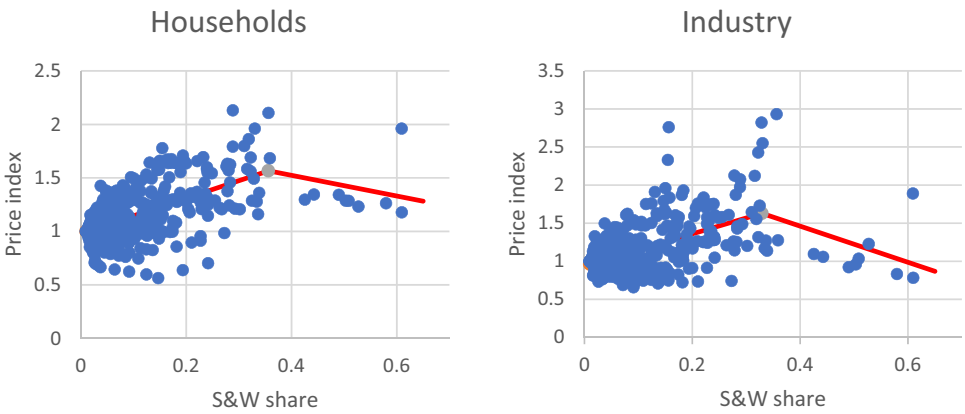

Fig. 2 Data points and regression lines for the results in Table 2

regression coefficients were postulated to be different below versus above a certain threshold value of the S&W share.[1] The threshold value was determined by minimizing the sum of squared error terms. The results are shown in Table 2. According to this, prices would fall and not rise as the S&W share rises beyond a threshold value of between 30 and 40 percent. This would be consistent with saying that the costs of solar and wind energy are the highest initially and might fall as the solar and wind share increases further.

There is, however, reason to take these results with due caution. Figure 2 shows the data points and the regression lines. The declining lines are produced by only a few observations, all of which come from Denmark, and the regression coefficient is not significantly different from zero. Denmark has by far the highest S&W share, and electricity prices in Denmark are lower than in some other countries with a high S&W share. These results might therefore not hold in general. Taking them nevertheless at face value, one could say that the greatest rise in electricity prices might be over as the S&W share reaches a level of about 30 percent and thereafter prices would stay high as the S&W share increases further. This would be consistent with the experience in Australia and Germany, to be discussed further in the following section. In both these countries, the price has not increased any further in recent years despite a continued rise in the S&W share.

[1] The calculations were performed in Solver, with regression lines constrained to cross at the point dividing the sample in two.

Select Countries: Australia, Germany, and the UK

It is instructive to look at the development over time of prices and the S&W share for individual countries. Doing so for both the household and the industry sector for all 28 countries would exceed any reasonable limits so we focus on the household sector in a few countries. Figure 3 shows what has happened in Australia. Unfortunately, there is a wide gap in the data for Australia, so it is not included in the regressions reported above. Nonetheless, it is clear that the price of electricity shot upwards from 2004 to 2013, from a rather stable level of about 200 Aus$ (in 2022 value of money) from 1990 to 2004 to 300–380 Aus$ in 2013 – 2021. This was accompanied by a moderate rise in the share of S&W in total energy production, from 0.4 percent in 2004 to 5.2 percent in 2013. Geroe (2022) cites evidence that about half of this was due to higher network charges, but mentions also decommissioning of coal fired power plants and political uncertainty about increased use of renewable energy. After 2013, the S&W share has risen steeply, and the price has stayed high and become more volatile than before S&W appeared on the scene, but with a slightly negative trend.

Figures 4 and 5 show the price development in Germany and the United Kingdom, together with the S&W share in electricity production. The price of electricity, in 2022 value of money, declined from 1990 to 2003 when S&W had just begun to appear. The price in the United Kingdom

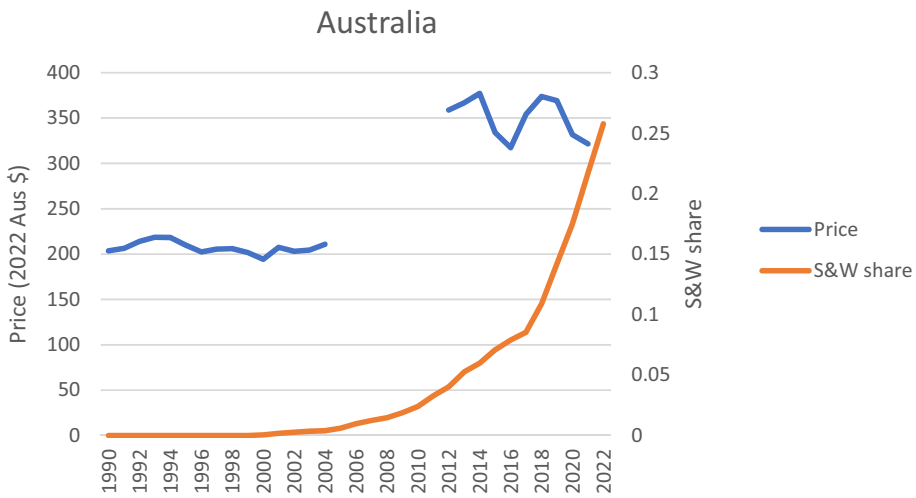

Fig. 3 Price of electricity for households in Australia and the S&W share in production of electricity

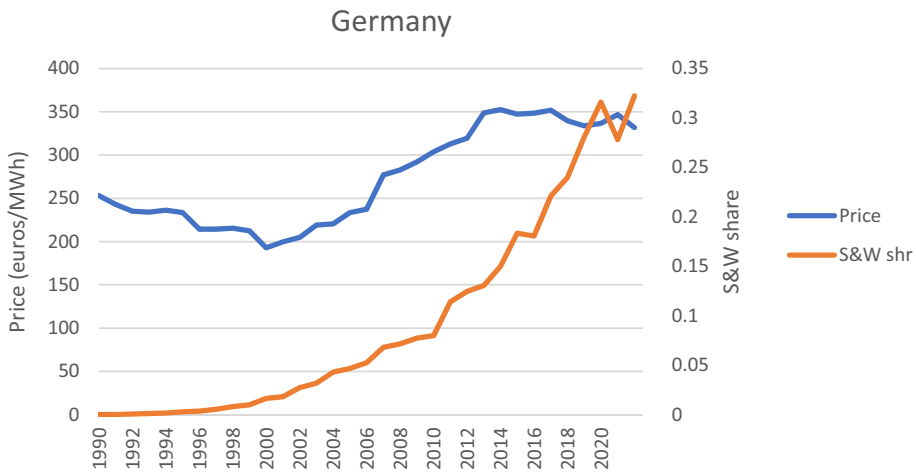

Fig. 4 Price of electricity for households in Germany and the S&W share in production of electricity

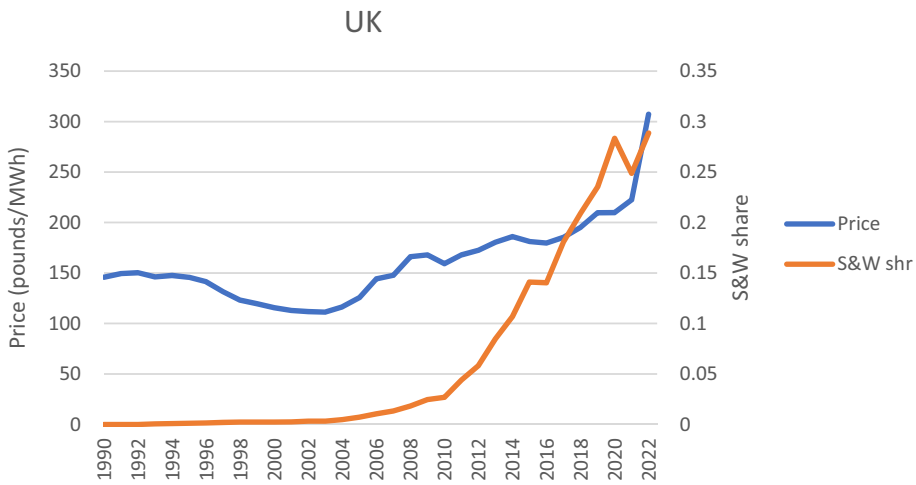

Fig. 5 Price of electricity for households in the United Kingdom and the S&W share in production of electricity

has continued to rise from that point almost without interruption while, in Germany, the price has become stabilized after 2013 at 70–75 percent above the 2000 level.

Conclusion

It has been shown that the price of electricity tends to be higher in countries with a high share of S&W in the

production of electricity. It has also been shown that a rising S&W share has coincided with a rising price of electricity. It is difficult to see any other explanation than higher cost of electricity from S&W. This is due to two factors: (i) high investment costs of this type of energy and (ii) high cost of back-up facilities when S&W are not available. It appears that these costs have been unloaded on households' energy bills to a greater extent than on industry, but the prices paid by industry have also risen together with the S&W share.

This may not tell the whole story of the cost disadvantage of S&W. This type of energy has been subsidized in all countries, but in various ways. All these subsidies have not necessarily been recovered through higher prices for users, but taxpayers do ultimately have to pay for these outlays. Investigating to what extent subsidies to S&W energy have been recovered through higher electricity bills is a major task awaiting investigation, but outside the scope of this paper.

Appendix

See Table 3.

Table 3 Summary of results from regressing the price of electricity in domestic currency, at 2022 price level, on the share of S&W in the total production of electricity

	Household prices			Industry prices		
	Positive	Not significant	Negative	Positive	Not significant	Negative
Austria 2004–2022		0.0605 (0.4210)			0.3731 (0.9985)	
Belgium 2009–2022	2.3289 (0.5624)				0.5744 (0.5974)	
Canada 2009–2022	6.6368 (0.5602)			5.6486 (1.3342)		
Chile 2014–2022		0.7214 (0.5359)		2.6772 (0.7938)		
Denmark 1990–2022	0.4961 (0.1211)				0.1815 (0.1593)	
Estonia 2008–2022	2.5398 (0.7583)			3.6470 (1.4184)		
Finland 2013–2022	1.9621 (0.2149)				1.2870 (0.8020)	
France 2008–2022	4.5781 (0.4498)			2.4237 (0.5929)		
Germany 1999–2022	2.1599 (0.3463)			3.9877 (0.4511)		
Greece 2001–2005, 2008–2022	2.9972 (0.2470)			3.4024 (0.6052)		
Hungary 2010–2022			− 2.3068 (0.6509)		2.7118 (1.7259)	
Ireland 2001–2022	2.0341 (0.2077)			1.5178 (0.5149)		
Israel 2014–2019, 2020 industry		− 2.9414 (3.1778) 2014–2019			− 2.4893 (2.1810)	
Italy 2007–2020, 2022	1.4006 (0.4714)				0.3225 (0.6774)	
Japan 2012–2021		0.5314 (0.5387)			− 0.6285 (0.6462)	
Korea (S) 2015–2022			− 3.1327 (1.5178)			− 1.2401 (0.5807)
Luxembourg 2005–2022		− 0.1900 (0.1709)			− 0.1627 (0.6866)	
Mexico 2012–2018			− 5.5414 (0.6722)		− 4.9197 (3.1833)	
Netherlands 2003–2022		0.8234 (0.7028)		1.2884 (0.5305)		
New Zealand 2005–2022	3.3425 (0.6973)			3.7842 (1.5204)		
Poland 2010–2022		− 0.0911 (0.2268)		2.2051 (1.0394)		
Portugal 2003–2022	1.1096 (0.2319)			0.9069 (0.1204)		
Spain 1999–2022	1.9835 (0.2230)			3.4658 (0.4832)		
Sweden 2008–2020, 2022		0.4520 (0.3423)			0.9257 (0.9233)	
Switzerland 2014–2022	2.2243 (0.5089)				0.7251 (1.1064)	
Turkey 2010–2022		− 0.2760 (0.3367)		6.9805 (2.4645)		
UK 2006–2022	2.1517 (0.3778)			1.8790 (0.3621)		
USA 2008–2022			− 0.2982 (0.0881)			− 1.1575 (0.2383)

Significance level: 5%

Author contributions There is only one author of this paper

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Data Availability Data will be made available upon request.

Declarations

Competing interests The authors declare no competing interests.

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