Does economic growth eat up environmental improvements? Electricity production and fossil fuel emission in OECD countries 1980–2014

By

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ABSTRACT

We analyze to what extent electricity production by non-fossil fuel replaces fossil fueled electricity production in 27 OECD-countries 1980–2014. Depending on model specification, the long run replacement coefficient is in the range of minus 0.4–1.0, which is considerably larger than found in other studies. This means that an increase in non-fossil fuel based electricity production by 10 kWh/capita replaces fossil fuel based production in the range 4–10 kWh/capita. Over all the estimated replacement is not sufficient to prevent economic growth from increasing fossil based electricity production, thus eating up environmental improvements. However, we identify two important exceptions to this. First, countries with a 'low' level of fossil based production have an Environmental Kuznets Curve (EKC) relationship when we allow for separate effects of the economic downturn after the Great Recession 2008–2009. Second, results for the EU countries indicate that the EU Emission Trading System, and possibly EU country specific policy instruments, have influenced the mix of electricity production in the intended direction.

Keywords: electricity production; OECD-countries; replacement pattern

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1. Introduction

An implicit assumption of the Intergovernmental Panel on Climate Change (IPCC) and the climate policy in many countries is that energy production and consumption by non-fossil fuel sources must replace energy production from fossil fuel (see, e.g., IPPC 2011). This paper analyzes the replacement pattern for electricity production in 27 OECD-countries 1980–2014. We find that replacement takes place but also that production based on fossil fuel grows during the same period. As economic growth is an important driving factor behind total electricity production and consumption, the consequence is that economic growth dominates the replacement gain. An important finding from our study is therefore that economic growth to a large extent eats up the replacement effect in the (mostly rich) OECD countries over the considered period of time. During the last few years the amount of electricity production based on fossils have declined somewhat, possibly indicating that the economic growth effect has been weakened. This may be related to The Great Recession (December 2007 – June 2009)[1] and subsequent years of economic downturn. However, the effects of policy instruments such as the EU Emission Trading System (EU ETS) and country specific instruments may have played a role as well.

Our finding of the direct replacement pattern is in line with previous studies from other samples of countries and use of other estimating methods and model specifications (York 2012, Hu and Cheng 2017). However, there are also important differences. York studied the short run replacement effect for a large sample of rich and poor countries (altogether 130 countries) over the period 1960–2009. He found that the replacement coefficient was about minus 0.08–0.09; that is, to replace 10 kWh/capita electricity produced by fossil fuel about 110-120 kWh/capita electricity from non-fossil fuel is needed. Hu end Cheng studied the replacement pattern for China both nationwide and in the six national grids over the period 1995–2014. Their main finding was that replacement is about the double of the finding in York (2012), but they also only considered short run effects. Both non-fossil

[1] See, e.g., https://www.federalreservehistory.org/essays/great_recession_of_200709

and fossil fuel based electricity production are serially correlated, which is reasonable due to large adjustment costs. In contrast to these studies, our focus is therefore on long run replacement, and we find that the estimated long run effects are much larger than the short run effects.

York (2012) and Hu and Cheng (2017) introduce GDP/capita to control for demand. York's model specifications allow for nonlinear relationships between fossil fueled electricity production and GDP/capita. Both include other control variables, such as degree of urbanization and demographic factors. We also control for GDP/capita, but analyze more explicitly how economic growth may influence the outcome. To do this we relate our modelling and findings to the large, and growing, literature on the Environmental Kuznets Curve (EKC) relationship which hypothesizes an inverted U-relationship between the environmental impact, here per capita production of electricity based on fossil fuel, and economic activity, here GDP/capita (see, e.g., World Bank 1992, Arrow et al. 1995, Uchiyama 2016). We are also controlling for time effects more directly as well as downturn in the aftermath of the recession 2008–09. Except from six relatively new OECD member countries from which we lack consistently collected data,[2] and Norway and Iceland, all OECD countries are included in our study. Norway and Iceland are excluded as close to 100 percent of their electricity production in the whole post WW2 period has been based on hydropower. Therefore, our sample of OECD countries includes 27 countries, denoted OECD27 hereafter. Our data on electricity production is based World Bank (2017), the same source as York (2012).

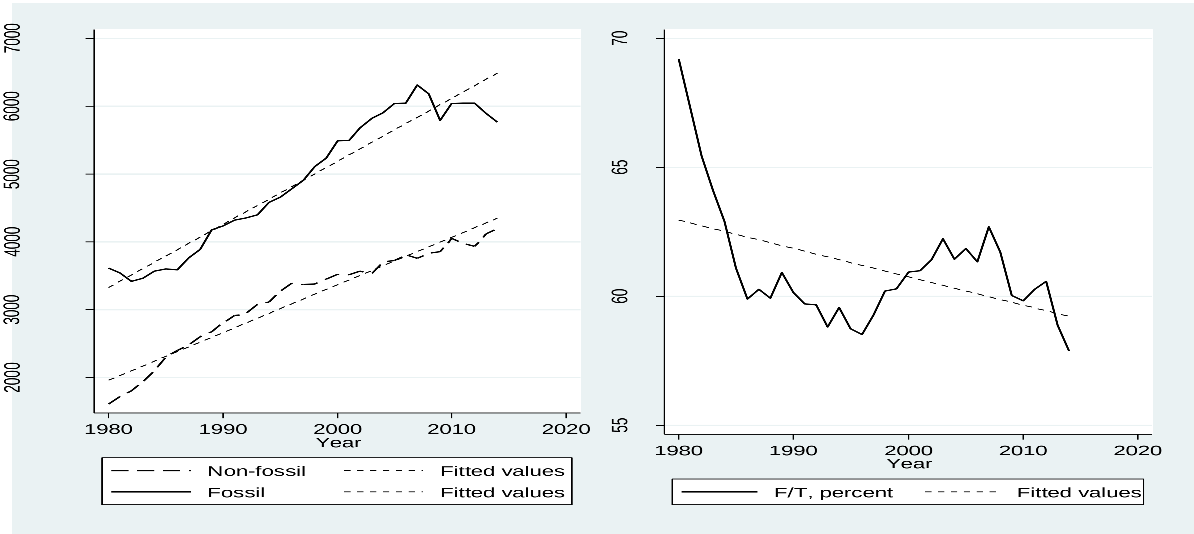
2. Changing pattern of electricity production

We classify total electricity production (*T)* into two broad categories; non-fossil energy *NF* and fossil energy *F*, such that $T \equiv NF + F$. *NF* includes hydropower, nuclear, geothermal, solar, wind, tidal and wave energy, combustible renewables and waste, while *F* includes oil, gas and coal (see World Bank 2017 for details). For all the 27 OECD countries taken together, OECD27, the proportion *F/T* decreased sharply from somewhat below 70 % in 1980 to 60 % in 1986. Since then the proportion

[2] These six countries are: The Czech Republic (1995), Estonia (2010), Israel (2010), Latvia (2016), the Slovak republic (2000) and Slovenia (2010). Date of start membership in parentheses.

has stayed between 58.5 and 62.7 %. However, after 2007 it has fallen steadily to below 58 % in 2014 (Figure 1, right panel). During the same period, total electricity production in these countries, *T*, increased from about 5,200 TWh in 1980 to about 10,000 in 2014 (Figure 1, left panel). While fossil based electricity production overall has changed relatively less than non-fossil production from 1980 to 2014, the fitted regression lines indicate that the average annual growth has been larger for fossil based than non-fossil based production.

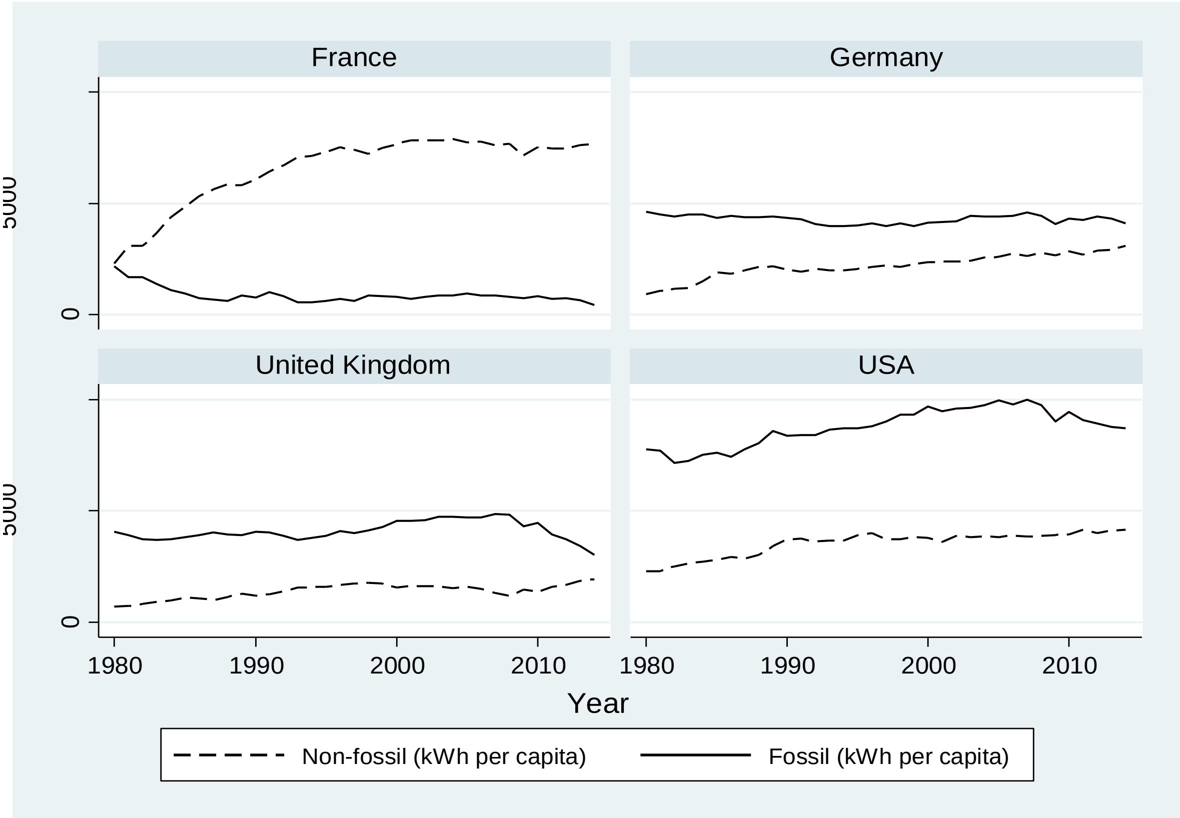
Figure 1. *Fossil (F) and non-fossil (NF) based electricity production OECD27 1980-2014. Absolute production in TWh (left panel) and fossil fraction (F/T) in % (right panel)*



Source: Own calculations based on World Bank (2017)

The per capita electricity production varies considerably among these OECD countries. Figure 2 shows the development of both fossil (*F*) and non-fossil production (*NF*) for the four large countries France, Germany, United Kingdom and USA. France and USA have both a very high per capita level of electricity production, but the composition is quite different. While the electricity production in the USA mainly is based on fossil fuels, the mixture in France is very much the opposite because the high production from nuclear power. In Germany, the fossil fuel based production per capita has stayed more or less constant during the last 35 years while the non-fossil production has increased slowly, but steadily. However, the non-fossil production is still considerably lower than the fossil electricity production. In the UK, fossil production has decreased significantly during the very last years, due to reduction of the coal based electricity production. The detailed World Bank (2017) data shows that more wind based electricity production explains the increased production from non-fossil fuels here in recent years.

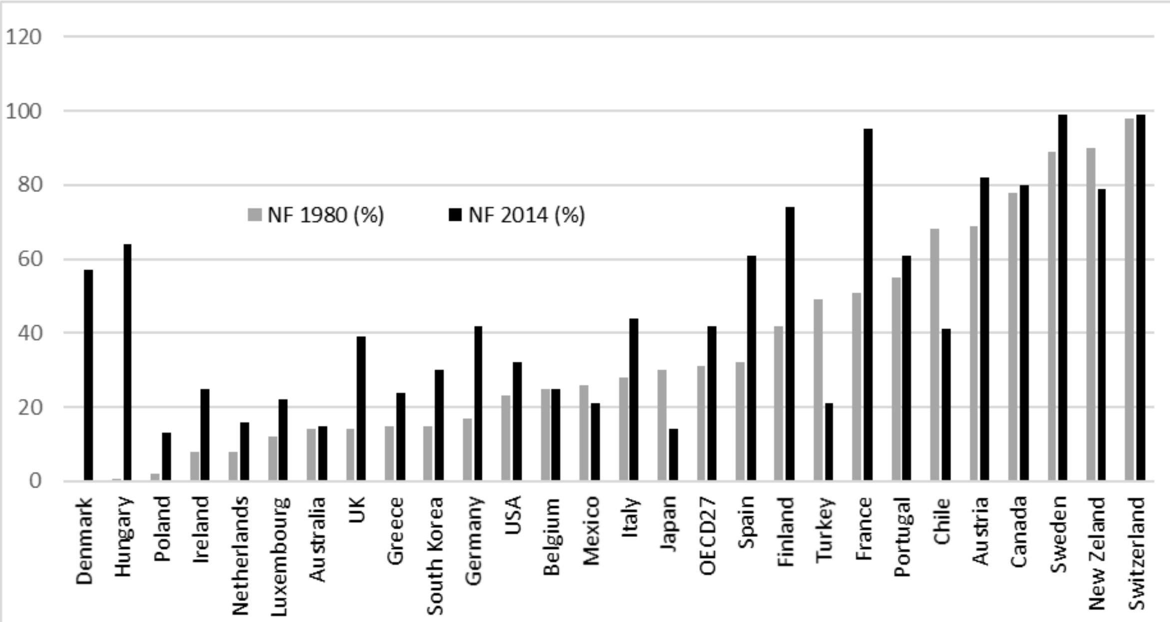
Figure 2. *Fossil (F) and non-fossil (NF) based electricity production per capita (kWh/capita) selected large countries 1980-2014*



Source: Own calculations based on World Bank (2017)

Figure 3 shows the non-fossil production fraction (*NF/T*) in 1980 and 2014 for all countries included in our study together with the OECD (weighted) average (OECD27). The countries are sorted by their *NF/T* fraction in 1980. Most countries have a higher fraction of non-fossil fuel production in 2014 than in 1980. Notable exceptions are Japan, Turkey and Chile. We also observe that the *NF/T* fraction has increased particularly much in Denmark, Hungary and France, but the causes are quite different. While France has expanded production based on nuclear power, increased windmill production is the reason in Denmark.

Figure 3. *Non-fossil electricity production fraction (NF/T), 27 OECD countries and OECD average 1980 and 2014*



Source: Own calculations based on World Bank (2017)

3. Models and main results

Figures 1 and 2 indicate that *F* and *NF* are serially correlated, which is not surprising because it is time consuming and costly to adjust electricity production (see, e.g., Hu and Cheng 2017). Formal unit root tests of the *F* and *NF* series show non-stationarity, thus one could argue for applying Equilibrium-Correction Mechanism (EqCM) models. However, in our empirical setting it is highly unclear how a long run equilibrium relation should be as there is no theoretical guidance. We tried different dynamic specifications with the following partial adjustment model, implying gradual adjustments toward some unspecific desired level of fossil based electricity production, as the base model: [3]

$$(1) \quad F_{i,t} = \beta_0 + \beta_1 F_{i,t-1} + \beta_2 NF_{i,t} + \beta_3 GDPC_{i,t} + \beta_4 GDPC_{i,t}^2 + \beta_5 GDPC_{i,t}^3 + \beta_6 Kyoto$$

$$+\beta_7 D_{2008-14} + Country\ FE + Year\ FE + error\ term,$$

where subscript i = 1, …, 27 denotes country and subscript t = 1980, …,2014 denotes year. Both $F_{i,t}$ and $NF_{i,t}$ are measured as per capita (kWh/capita). $NF_{i,t}$ is treated as an exogenous variable justified by the huge amount of subsidies and policy instruments implemented to increase electricity

[3] There is a large literature on dynamic econometric models. Doornik and Hendry (2013) p. 143, give a brief overview of different types of models, and further references to this literature.

production based on non-fossil sources (see, e.g., Nicolini and Tavoni 2017). $GDPC_{i,t}$ is gross real domestic product per capita (in 1,000 US$, PPP adjusted), included to capture how economic activity affects fossil based electricity production. The estimation of a third order degree polynomial tests for possible EKC relationships.[4] The dummy variable $Kyoto$ which equals 1 for the countries that have signed the Kyoto protocol and 0 for the four countries that have not signed (Austria, Canada, Turkey and USA), is included to test if the Kyoto-countries differ from the other countries. $D_{2008-14}$ is a dummy variable (with 1 from 2008 to 2014, otherwise 0) included to control to what extent the Great Recession 2008–09 and the subsequent years economic adjustments influenced production of electricity. In addition, country and year fixed effects (FE) are included. Based on Eq. (1) our main parameter of interest is the long run effect of increased non-fossil energy electricity production, $\beta_2/(1-\beta_1)$. Additionally, the growth effect parameters, β_3, β_4 and β_5 are of great interest, particularly related to possible EKCs.

Table 1 presents results from altogether seven models. Model 1 is a static model with both country and year fixed effects (FE), similar to the models in York (2012) and Hu and Cheng (2017). The same static model without year FE (not shown in Table 1) yields parameter estimates almost identical to those of Model 1, and the same explanatory power (within R^2=0.62). Tests of the error terms from the static models clearly indicate serious serial correlation and thus model misspecification. The parameter estimates from the two first partial adjustment models (models 2 and 3), which are also estimated on the whole sample, are qualitatively similar irrespective of the inclusion of year FE, and have the same explanatory power measured by R^2. Compared to the static models, the partial

[4] It should be noted that the term 'Environmental Kuznets Curve' relationship (EKC relationship) has taken several dimensions. Some authors use it only to refer to an inverted U-shape (i.e., a second order degree polynomial), while others use the term more generally. When it comes to testing EKC relationships, using a third degree polynomial has been a common approach, see, e.g., Uchiyama (2016). A model with only a second order degree polynomial is too restrictive. If we exclude $GDPC^3_{i,t}$, none of the estimated long run replacement coefficients are changed qualitatively. In most of the estimated models presented in Tables 1 and 2, the relationship between $F_{i,t}$ and $GDPC_{i,t}$ changes from concave-convex relationships to concave when $GDPC^3_{i,t}$ is excluded from the model. In a few specifications no relationships, or concave-convex relationships, change to positive, even convex relationships, when $GDPC^3_{i,t}$ is excluded. These results clearly indicate that models without the third order polynomial are too restrictive for testing EKC relationships. All these results can be obtained from the authors upon request.

adjustment models have considerably higher explanatory power, and the estimated short run replacement coefficient β_2 in Eq. (1) is only about one third of those from the static models. All the other estimated coefficients in the partial adjustment models differ from the static models as well. Moreover, serially correlated error terms are absent, indicating that dynamic specification is important. On this background, the empirical results in the following are obtained from the partial adjustment models.

Table 1. *Parameter estimates from 27 OECD countries, 1980-2014. Dependent variable: fossil-fuel production per capita ($F_{i,t}$). Robust standard errors in parentheses.*

	Model 1	**Model 2**	**Model 3**	**Model 4** $F_{i,t}$>3,400	**Model 5** $F_{i,t}$>3,400	**Model 6** $F_{i,t}$<3,000	**Model 7** $F_{i,t}$<3,000
$F_{i,t-1}$	---	0.79***	0.78***	0.75***	0.72***	0.69***	0.68**
		(0.056)	(0.052)	(0.061)	(0.049)	(0.087)	(0.099)
$NF_{i,t}$	-0.35***	-0.13**	-0.11**	-0.20**	-0.28***	-0.11*	-0.13**
	(0.129)	(0.054)	(0.050)	(0.092)	(0.103)	(0.069)	(0.067)
$GDPC_{i,t}$	436.65***	110.35***	124.07***	91.62	33.28	150.29***	119.66
	(114.28)	(39.79)	(34.011)	(57.69)	(42.64)	(46.82)	(36.17)
$GDPC_{i,t}^2$	-7.02***	-1.73***	-1.87***	-1.10	-0.61	-2.45***	-2.01***
	(1.85)	(0.612)	(0.567)	(0.914)	(0.751)	(0.819)	(0.717)
$GDPC_{i,t}^3$	0.039***	0.009***	0.010***	0.006	0.004	0.014***	0.011**
	(0.010)	(0.003)	(0.003)	(0.005)	(0.004)	(0.005)	(0.004)
$Kyoto$	-3,251.76***	-745.60***	-716.70***	-762.12***	-1,092.83***	-1,185.50***	-645.77**
	(253.34)	(203.75)	(154.57)	(181.05)	(185.78)	(312.79)	(274.61)
$D_{2008-14}$	-687.08	-113.11	-257.26***	-334.41***	483.90*	-183.62***	-27.16
	(570.83)	(192.71)	(51.37)	(81.86)	(253.28)	(49.74)	(155.32)
Long run replacement	---	***-0.60******	***-0.53******	***-0.80*****	**-0.99*****	***-0.37*****	***-0.41******
		(0.165)	***(0.170)***	***(0.315)***	**(0.317)**	***(0.155)***	***(0.131)***
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	No	No	Yes	No	Yes
N	945[1]	918[1]	918	408[2]	408	408[3]	408
R^2 *(within)*	0.630	0.861	0.856	0.813	0.843	0.861	0.881
R^2 *(overall)*	0.930	0.974	0.973	0.942	0.951	0.954	0.961
AR(1)[4]	3.459***	-0.1842	-0.147	-0.160	-0.160	0.282	1.244
[p-value]	[0.001]	[0.854]	[0.883]	[0.873]	[0.873]	[0.778]	[0.213]
AR(2)[4]	3.369***	1.281	1.525	1.473	1.461	1.207	1.647
[p-value]	[0.001]	[0.200]	[0.127]	[0.141]	[0.144]	[0.228]	[0.100]

[1] Full sample; [2] 12 countries with average $F_{i,t}$ > 3,400 kWh/capita; [3] 12 countries with average $F_{i,t}$ < 3,000 kWh/capita, see Table A1 in Appendix; [4] N(0,1) distributed tests for first and second order serial correlation in the error terms.
*** p < 0.01, ** p < 0.05, * p < 0.1. Statistical analysis: STATA 14.0 and OxMatrix 7.0.

The variation in sources of electricity production is large between the OECD countries, and it is interesting that the long run replacement effect on average is much higher for countries with a 'high' level, than for countries with a 'low' level of fossil fuel based production. This is evident from comparing the parameters of Model 4 and Model 5 with those of Model 6 and Model 7 in Table 1. The models 4 and 5 are estimated on data from the 12 countries with an average of *more than* 3,400 kWh/capita of fossil fuel based production over the period 1980-2014, while the models 6 and 7 are estimated on data from the 12 countries with a similar average *below* 3,000 kWh/capita.[5] Notably, except from the models 4 and 5, the parameters of the *GDPC* terms are statistically significant in all specifications, and qualitatively similar in the pair of models 4 and 5, and models 6 and 7. The same applies regarding the long run replacement effects in these two model pairs. The dummy variable *Kyoto* has statistically significant effects in all specifications saying that fossil fuel based production is lower in the Kyoto agreement countries, although the size of the effect depends on whether or not Year FE are included. The qualitative impact of the dummy variable $D_{2008-14}$ depends on the inclusion of Year FE or not. Including Year FE changes the $D_{2008-14}$ parameters qualitatively as one becomes positive though marginally on statistical grounds (Model 5), and the other far from statistically significant. This is not surprising, as the Year FE capture time specific effects in these years.[6]

The start of the Great Recession coincides with the start of the second phase of the EU emissions trading system (EU ETS).[7] As this phase represented enforcement of the quota system and a lower cap on allowances, the decline in fossil fuel based electricity production in the last part of the estimation period could be due to a change in the environmental policy. To account for this, we separate the data set into EU and non-EU countries. The estimated long run replacement coefficients for the EU countries are -0.37 and -0.45 (without and with Year FE, respectively), and -1.00 and -1.25

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[5] See Table A1 in the Appendix which countries are included in these two sub-samples. For the whole sample, the average F is 3,204 kWh/capita. In order to get two samples that clearly differ w.r.t. this average, Italy (F=3,184), Poland (F=3,343) and the Republic of Korea (F=3,203) are not included. Including Italy and the Republic of Korea in a F<3,204 group changes the long run replacement coefficient from -0.37 (Model 6) to -0.43, whereas including Poland in a F>3,204 group does not change the coefficient at all. There are also small changes in the other parameters, but qualitatively not at all. All these estimates can be obtained from the authors upon request.

[6] If we drop $D_{2008-14}$ in Model 5, the Year FE for the years 2008-14 are all positive and most of them statistically different from zero at the five percent level of significance. When we do the same for Model 7, none of the year effects in the period 2008-14 are statistically different from zero.

[7] https://ec.europa.eu/clima/policies/ets_en

(without and with Year FE, respectively) for the non-EU countries. See Table 2. The negative shift in fossil based electricity production possibly due to the downturn in the wake of the Great Recession ($D_{2008-14}$) is about twice as large for the EU countries as compared to the non-EU countries (-344 kWh per capita *versus* -182) in the models without Year FE. However, when including *Year FE* the parameters become statistically insignificant for both groups of countries.

Table 2. *Parameter estimates from EU and non-EU countries, 1980-2014. Dependent variable: fossil-fuel production per capita ($F_{i,t}$). Robust standard errors in parentheses.*

	17 EU countries		**10 non-EU countries**	
	Model 8	**Model 9**	**Model 10**	**Model 11**
$F_{i,t-1}$	0.70*** (0.046)	0.69*** (0.042)	0.86*** (0.063)	0.89*** (0.064)
$NF_{i,t}$	-0.11** (0.053)	-0.14** (0.060)	-0.14** (0.063)	-0.14** (0.064)
$GDPC_{i,t}$	112.99*** (38.20)	74.72* (38.931)	130.50*** (0.507)	124.26*** (35.38)
$GDPC^2_{i,t}$	-1.65** (0.662)	-1.20* (0.656)	-2.05*** (0.507)	-1.99*** (0.571)
$GDPC^3_{i,t}$	0.009** (0.004)	0.007** (0.004)	0.011*** (0.003)	0.011*** (0.004)
$Kyoto$	---	---	-422.87 (1.01)	-211.43 (378.93)
$D_{2008-14}$	-344.40*** (59.44)	-50.51 (161.961)	-182*** (58.04)	-293.29 (197.86)
Long run replacement	***-0.37** (0.145)***	***-0.45*** (0.148)***	***-1.00*** (0.369)***	***-1.25*** (0.404)***
Country FE	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes
N	578	578	340	340
R^2 (within)	0.784	0.809	0.957	0.944
R^2 (overall)	0.925	0.934	0.995	0.996
AR(1) [p-value][1]	-0.043 [0.97]	-0.126 [0.90]	0.125 [0.90]	-0.235 [0.81]
AR(2) [p-value][1]	1.143 [0.25]	1.124 [0.26]	0.917 [0.36]	1.053 [0.29]

[1] N(0,1) distributed tests for first and second order serial correlation in the error terms.

4. Discussion

Our results give new knowledge on three aspects of the electricity production replacement process in the OECD countries. *First*, the implied long run replacement coefficients for the 27 OECD countries are much larger (in absolute value) than the short run coefficients reported in other studies (York 2012, Hu and Cheng 2017). In Model 2 and Model 3, 10 kWh/capita higher non-fossil based electricity production reduces the amount of fossil based electricity production by 5 – 6 kWh/capita in the long run. This is much higher than the size of replacement from the static models, and underlines the importance of dynamics to capture inertia due to adjustment costs when specifying the models.

The *second* important point is that the adjustment process seems to depend on the countries' level of fossil electricity production. Comparing the results from the models 4-7, countries with a 'high' level of fossil production have a long run replacement coefficient about twice the size of countries with a 'low' level (minus 0.80 – 0.99 *versus* minus 0.37 – 0.41). A possible explanation is that countries with a 'high' level of fossil electricity have a higher technological level, thus making it easier to accomplish replacement because of a larger technological opportunity set. Another possible explanation is political; the pressure for replacement may be more profound in countries with a 'high' level of fossil electricity production than in countries with a 'low' level.

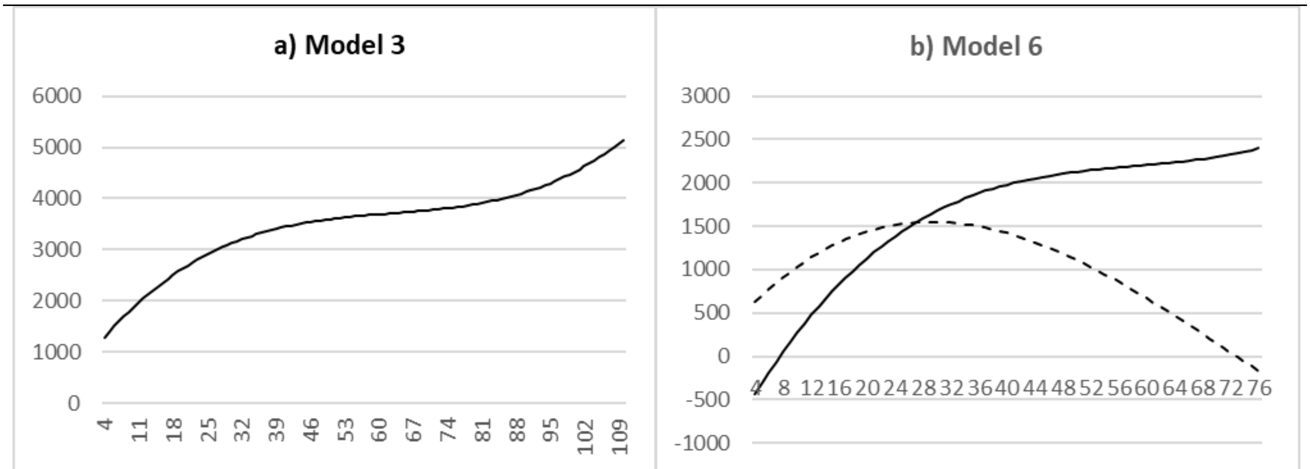
Third, economic growth has a direct effect on electricity consumption, and our maintained hypothesis is that higher economic activity increases electricity production based on fossil fuel. However, as indicated, an Environmental Kuznets Curve (EKC) may be present, dampening the *positive* relation between fossil electricity production and *GDPC*, eventually reaching a turning point and becoming negative as *GDPC* increases further. As the estimated values of the parameters of the three *GDPC* terms alternate in sign, with positive coefficients of the first and third order polynomials, there is no clear sign of any EKC relationship. Instead, we find that the estimated parameters indicate that higher economic activity increases electricity production based on fossil fuel. This applies to Model 2 and Model 3, which have very similar estimates and include all the 27 OECD countries.

The relation between *F* and *GDPC* based on the parameters from Model 3 is depicted in Figure 4 a), and shows an increasing concave-convex relationship.[8] The same applies to Model 6, which includes countries with a 'low' level of fossil based electricity production, see Figure 4b), solid line. The

[8] The levels of the curves in Figure 4 of course depend on the values of the other variables in the equations. We have not used some specific values of these variables to depict the curves, but simply forced them to go through the average values of *F* and *GDPC* of the respective samples. Choice of 'levels variables' does not influence the shape of the curves, only the levels.

interpretation from these two models is that economic growth, measured by *GDPC*, eats up environmental improvements. This is also consistent with replacement coefficients less than 1 in absolute value. On the other hand, none of the estimated *GDPC* parameters of Model 4 and Model 5 are statistically different from zero, indicating that economic growth does not affect fossil based production in countries with a 'high' level of fossil based electricity production.

Figure 4. *Estimated relationships between GDP per capita (GDPC) (horizontal axis) and fossil based electricity production (F) (vertical axis)from* ***a) Model 3****, and* ***b) Model 6*** *with (dotted line) and without (solid line) interaction terms of Recession and GDPC.*



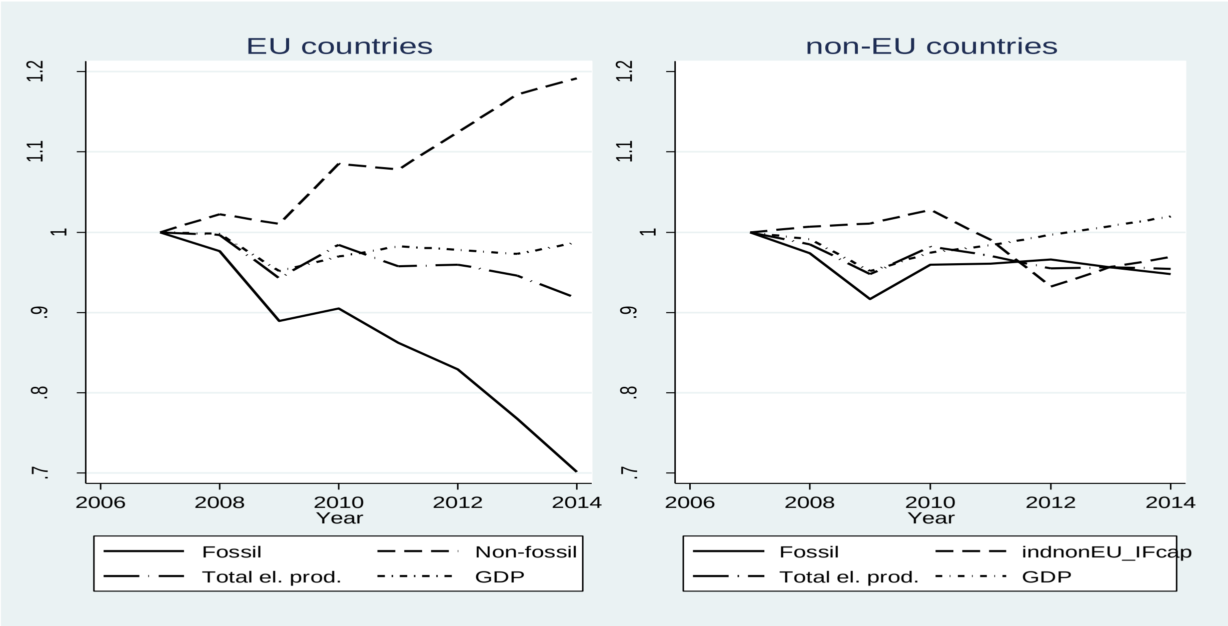
a) Model 3 is estimated on *GDPC* ∈[4;110]. The graph of the relationship between *GDPC* and *F* is depicted such that it crosses the sample averages of *F* (=3,204) and *GDPC* (=32).
b) Model 6 is estimated on *GDPC* ∈[4;76]. The *solid line* is the graph of the relationship between *GDPC* and *F* based on the parameter estimates given in Table 1. The *dotted line* is based on the parameter estimates from the model with interaction terms of the dummy variable *Finance* and *GDPC*. Both graphs are depicted so they cross the sample averages of *F* (=1,543) and *GDPC* (=27).

The dummy variable $D_{2008-14}$ is included to control for possible effects related to the economic downturn, and the subsequent years' economic adjustments, after the Great Recession. In all specifications without Year FE, fossil fuel based electricity production is reduced in these years taken together. However, a crucial question is whether this reduction is a (short run) shift possibly due to a lower level of economic activity, or whether it may represent changing behavior by re-establishing economic activity through investment in more environmental friendly new capital equipment.

To investigate this, the models 3, 4 and 6 were re-estimated with interaction terms between $D_{2008-14}$, and the variables $F_{i,t-1}$, $NF_{i,t}$ and $GDPC_{i,t}$. The finding is that in none of these specifications the long run replacement coefficients changed in any substantial way, and the estimates of the economic activity coefficients β_3, β_4 and β_5 are qualitatively similar to those reported in Table 1. The interaction term parameters of $GDPC_{i,t}$ in this version of Model 4 are very far from being statistically significant. In these specifications of models 3 and 6 the level of significance is considerably lower, but only the $D_{2008-14} \times GDPC_{i,t}$ parameter in this version of Model 6 is statistically different from zero (p=0.07). These results imply that the growth effect in these models only changes for Model 6, illustrated by the dotted line in Figure 4b). The interesting point is that the positively sloped and mostly concave relationship from Model 6 [solid line in Figure 4b)] becomes an EKC with a turning point at GDPC≈30 when we allow economic development to affect fossil based electricity production during the years 2008-14 differently as compared to the years before. Possibly, this indicates changed behavior.

The Great Recession coincides with the start of the second phase of the EU emissions trading system (EU ETS), with lower cap on allowances. Our results for EU *versus* non-EU countries (Table 2) raise the question if the observed difference in the parameter estimates of the dummy variable $D_{2008-14}$ is due to changes in environmental policy, or a result of an economic downturn, or a mix of both. Looking at the development of total, fossil and non-fossil electricity production and GDP per capita in the group of EU countries and the group of non-EU countries separately in the period 2007-2014, we find an interesting picture shown in Figure 5.

Figure 5. *GDP per capita, total electricity production, and electricity production based on fossil and on non-fossil fuel in 17 EU countries (left) and non-EU countries (right), 2007-2014. Indices (2007=1)*



Source: Own calculations based on World Bank (2017)

For the EU countries, GDP per capita has stayed almost constant and total electricity production has fallen by 8 percent. Moreover, fossil fuel based electricity production is in the same period *reduced* by 29 percent while non-fossil production is *increased* by 17 percent. Notably, the change in the composition of the electricity production is very trend like, indicating that it may be a policy based, planned development. The picture for the non-EU countries is very different as there are no trend like developments. Moreover, the fluctuations are within a narrow band of ten percentage points.

5. Conclusion and policy implications

For the 27 OECD countries altogether we find that electricity production by non-fossil fuel in varying degree has replaced fossil fueled production in the years 1980–2014. Depending on model specification, the long run replacement coefficient is in the range of minus 0.4–1,0, which is considerably larger in absolute value than the short run (static) coefficients found in other studies. Consistent with this result, economic growth seems to eat up the environmental improvement, and the evidence of Environmental Kuznets Curve relationships is accordingly weak. Additionally, we find that for countries with on average a ‘high’ level of fossil based electricity production the relation between fossil based production and GDP is absent (models 4 and 5). During the last few years the amount of fossil fuel based production have declined somewhat. This may be related to economic stagnation after the Great Recession, but it may also indicate impact of policy changes so that the economic growth effect is weakened. This may have happened in countries with a 'low' level of fossil fuel production, but not in the other countries.

It seems reasonable to interpret the results for the non-EU countries as adjustments due to unanticipated changes, such as the Great Recession, whereas the results for the EU countries point at changed behavior due to policy adjustments, and where the EU ETS seems to have influenced the mix of the electricity production. However, EU ETS is only one set of policy instruments. Additionally, a huge amount of subsidies have been channeled to increase electricity production based on non-fossil sources during the last 10 – 15 years in many EU countries. This 'carrot' policy has possibly promoted renewable electricity production in many of the EU countries (Nicolini and Tavoni 2017), and best known is probably the 'Energiwende' policy in Germany.

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Appendix

Table A1. *Country specific descriptive statistics. EU countries in italics.*

	Country	Average fossil based electricity production *F* (kWh/capita)	Average non-fossil electricity production *NF* (kWh/capita)	Average GDP per capita *GDPC* (in 1,000 USD PPP adjusted)	F > 3,400	F < 3,000
1	Australia	8236	912	41.3	**x**	
2	*Austria*	1992	4810	38.4		**x**
3	*Belgium*	2799	4009	36.9		**x**
4	Canada	4094	13551	40.6	**x**	
5	Chile	1055	1237	8.9		**x**
6	*Denmark*	4993	916	50.3	**x**	
7	*Finland*	3449	7423	37.0	**x**	
8	*France*	874	6545	35.3		**x**
9	*Germany*	4284	2187	35.4	**x**	
10	*Greece*	3419	425	22.3	**x**	
11	*Hungary*	1760	1149	10.7		**x**
12	*Ireland*	3870	423	34.7	**x**	
13	*Italy*	3184	935	32.5	***	
14	Japan	4431	2519	39.0	**x**	
15	*Luxembourg*	3913	630	76.8	**x**	
16	Mexico	1298	384	8.1		**x**
17	*The Netherlands*	4717	479	41.0	**x**	
18	New Zealand	2327	6954	28.9		**x**
19	*Poland*	3343	110	8.2	***	
20	*Portugal*	2063	1279	18.5		**x**
21	Republic of Korea	3203	1826	13.5	***	
22	*Spain*	2487	2176	25.3		**x**
23	*Sweden*	578	15012	42.1		**x**
24	Switzerland	128	8297	65.0		**x**
25	Turkey	1157	494	7.6		**x**
26	*United Kingdom*	4101	1377	32.3	**x**	
27	USA	8750	3533	40.8	**x**	

*** Italy, Poland and the Republic of Korea have values between 3,000 and 3,400, and are not included in these analyses. Source: Own calculations based on World Bank (2017).

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