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Policy Perspective

The unstudied barriers to widespread renewable energy deployment: Fossil fuel price responses

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ABSTRACT

Renewable energy policy focuses on supporting the deployment of renewable power generators so as to reduce their costs through scale economies and technological learning. It is expected that, once cost parity with fossil fuel generation is achieved, a transition towards renewable power should continue without the need for further renewable energy subsidies. However, this reasoning implicitly assumes that the cost of fossil fuel power generation does not respond to the large scale penetration of renewable power. In this paper we build a standard economic framework to test the validity of this assumption, particularly in the case of coal and gas fired power generation. We find that it is likely that the cost of fossil fuel power generation will respond to the large scale penetration of renewables, thus making the renewable energy transition slower or more costly than anticipated. More analysis is needed in order to be able to quantify this effect, the occurrence of which should be considered in the renewable energy discourse.

1. The energy transition and the flaw in policy architecture

In the 21st Century we are faced by two challenges that are highly dependent on the energy sector: sustainable economic development and global climate change. Addressing them is often being linked to the decarbonisation of today's energy system. Primary energy consumption is growing by approximately 2% per year, however this growing demand is heavily dependent on fossil fuels (GEA, 2012). Therefore, low carbon and renewable energy technologies are needed to mitigate the negative externalities associated with the fossil fuel sector. In particular, anthropogenic greenhouse gas emissions are increasing at a rapid rate and are very likely to be already causing changes to the global climate system (IPCC, 2014). According to BP (BP, 2014), without strong mitigation policies, emissions are set to increase by approximately 30% over the next 20 years. For this reason, future energy scenarios that are compatible with averting extreme impacts of climate change are characterised by strong penetration of low carbon technologies, including renewable energy (IPCC, 2014).

The pressing need for low carbon and renewable energy generation capacity has resulted in policy measures to support research, development and the rapid deployment of alternative technologies – thereby initiating the early stages of a low carbon energy transition. The power generation sector is arguably at the forefront of this transition and renewables in particular are increasingly competing with conventional fossil fuel plants that run predominantly on coal, natural gas, and to a lesser extent, oil. According to BP (BP, 2014), renewable generation capacity has grown at an average annual rate of 10.6% since 1990. BP expects renewable generation capacity to continue to grow at an average annual rate of 6.6% over the next two decades (BP, 2016). The penetration of renewables in the power generation sector is therefore the focus of this paper.

It is inevitable that the rapid emergence of new technologies is set to interact with the incumbent energy value chain in the power generation sector. The degree to which renewable energy can displace fossil fuels will conceivably be influenced by the following three issues.

The first is the extent to which fossil fuel backup generators are needed in order to balance electricity grids with medium to high levels of penetration of intermittent renewables, also considering the future role of storage and demand-side management; results of analysis differ depending on the geographical area and technology mix considered, see for example (EnerNex Corp., 2011; Pöyry, 2011; Strbac et al., 2012), hence no generally valid conclusions can be drawn.

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The second factor is the effect that the deployment of renewable technologies is already having on the profitability of fossil fuel generators and hence the decision to invest in new capacity. This is due to the fact that the deployment of renewables at a significant scale tends to decrease wholesale electricity prices[1] and, at the same time, increase their volatility,[2] as further discussed in Section 2. Moreover, renewables such as solar are displacing fossil fuel generation at daily peak times when wholesale electricity prices are higher (Channell et al., 2013). This is worsening the economic perspective of current investments, in particular for fossil fuel generators that do not benefit from the same level of public support of renewable generators. The relationship among renewable technologies, wholesale electricity prices and investment in new generation capacity is potentially another line of research.

The third factor, which we address in this paper, is the cost competitiveness of renewables relative to fossil fuel generators. Exactly how this should be measured is also somewhat controversial, particularly with regard to whether or not grid integration costs of renewables should be accounted for (Ueckerdt et al., 2013) and how they should be estimated (Hirth, 2013). However, taking levelised cost of electricity (LCOE) as a metric, cost estimate studies suggest that the competitiveness of renewable power generators is strongly dependent on endogenous technological learning (Gross et al., 2013), while that of fossil fuel generators is mainly determined by the price of the fuel itself, i.e. coal and gas (Gross et al., 2013; IEA, 2007; Tidball et al., 2010; US EIA, 2016). In particular, according to (US EIA, 2016), operating and maintenance costs (of which fuel is a very significant part) of a conventional combined cycle gas turbine represent 74% of the total LCOE, while these cost only represent 26% in the case of onshore wind. This example suggests that fuel prices are critical to assessing the economic competitiveness of fossil fuel generators. Here it is argued that the penetration of renewable energy into the power market, by reducing the demand for fossil fuel generation, can directly result in a price response of fossil fuels which in turn affects the relative competitiveness of renewable power, potentially hindering their further penetration. As will be discussed in Section 2, this has not been directly addressed by the literature investigating the interaction between renewables and fossil fuels.

Since the existence of a fossil fuel price response to the introduction of renewables has not been tested yet, it has not been taken into consideration by policymakers. Renewable energy policy addresses the cost of renewable energy technologies in order to enhance their competitiveness and support their uptake. However, it largely ignores the value chain of fossil fuel generation and its possible reaction to the uptake of renewables. In this paper we seek to advance the understanding of the response of fossil fuel value chains to renewable technology market penetration. The question we pose is whether and to what extent overlooking this response leads to a slower than anticipated rate of the renewable energy adoption or a higher cost of the policy support measures required to achieve it.

The current literature on potential interactions between renewable technology penetration and fossil fuel value chains is critically reviewed in Section 2. Section 3 presents an initial analysis of the hypothesised price response mechanism, where we develop a framework based on standard economic theory of supply and demand and we apply it to the fossil fuel markets considered. In Section 4 we summarise our initial findings on the price response mechanism and formulate recommendations for further research.

2. The interaction between renewables and fossil fuels in the literature

We have reviewed the limited literature on the response of fossil fuel value chains to renewable energy penetration, and identified two main theories: the Green Paradox and Carbon Leakage. The Green Paradox theory (Sinn, 2008) is based on the idea that, by decreasing future demand for fossil fuels, climate change policy may accelerate their current rate of extraction and may therefore result in higher overall carbon emissions. The Carbon Leakage theory (Tirole, 2012), on the other hand, postulates that in the absence of globally coordinated climate change policy, production of goods and services based on fossil fuels will move to countries with less stringent environmental regulation therefore offsetting the carbon emission savings realised in countries where climate change policy is in place. One key difference between the two is that the Green Paradox describes an upstream, supply-side response of fossil fuels while the Carbon Leakage essentially describes a downstream, demand-side response. Both theories imply market changes (van der Ploeg and Withagen, 2015), either on the supply or demand side, which ultimately impact fossil fuel prices. However, the theories focus on better understanding the possible future effects of climate change policy, particularly carbon pricing, on global carbon emissions and therefore neither of them specifically addresses the possible effect of the deployment of renewables on the price of fossil fuels. The two theories are summarised in Table 1, together with their strengths and current limitations as discussed in the most recent literature (Jensen et al., 2015; Long, 2015; Sinn, 2015; van der Ploeg and Withagen, 2015).

Aside from the above-mentioned theories, renewables also interact with fossil fuel value chains through the effect that their penetration has on electricity markets. A review of the literature (Browne et al., 2015; Clò et al., 2015; De Vos, 2015; Dillig et al., 2016; Paraschiv et al., 2014; Pöyry, 2010; Würzburg et al., 2013) shows that, thanks to its low marginal cost, the deployment of this type of renewable generators tends to reduce electricity wholesale spot prices and to displace either coal or gas fired power generation due to its effect on the merit order curve. Finally, other studies address the interaction between fossil fuel and renewable generation technology from the perspective of technological improvements of the former as a result of competition with the latter; this is known as the 'Sailing Ship' effect (Pearson and Foxon, 2012). However, neither of these literature strands addresses the direct effect that the large scale introduction of renewable power generation can have on the price of fossil fuels and its potential hindrance to the further penetration of renewables.

3. A perspective on the price response of fossil fuels to the deployment of renewables

Given the lack of analysis of a possible price response of fossil fuels to the deployment of renewables, we set out to build a hypothetical price response mechanism based on standard economic theory and to test it based on the available evidence. Our approach is based on supply-demand analysis, the use of which can also be found in past studies explaining determinants of oil prices (Hamilton, 2008; Horn, 2004; Stevens, 1995). Since according to standard economic theory, prices and quantities in a particular market are the result of the balance between supply and demand, in the next paragraphs we will analyse possible shifts in the demand and supply curves of fossil fuels as a result of the introduction of renewables.[3] This will allow us to draw conclusions on the plausibility of the hypothesised price response mechanism, also taking into consideration factors that are specific to the fuel markets considered. Although demand and supply curve shifts in reality may occur simultaneously, here we will discuss them in turn for the sake of illustration.

[1] Liberalized spot electricity markets have a marginal approach, implying that the price of electricity equals its marginal cost of production. The reason for this evolution of prices is that renewable technology has very low marginal costs.

[2] This is linked to the intermittent nature of renewable power generation.

[3] It is worth noting that a partial equilibrium analysis of the kind we conduct does not capture the interactions with all other markets in the economy.

Table 1
Theories found in the literature on the interaction between renewable energy technology penetration and fossil fuel value chains.

	Theory	Evidence of occurrence and limitations
The Green Paradox	Change in time period of supply – *temporal supply response.* Sinn (2008) theorized that the extraction and supply of fossil fuels would accelerate, or be brought forward in time, in anticipation of a future reduction in fossil fuel resource rents as a result of incoming carbon pricing. Otherwise stated, leaving carbon-based resources in situ would give rise to an opportunity cost as their future rents may decrease because of carbon policies.	Modelling by van der Ploeg and Withagen (2015) indicates that this mechanism can occur. Its validity however suffers from the following limitations: • It is based on Hotelling's Rule, which ignores sunk investments and production constraints, both of which are important factors that determine the supply side response of fossil fuel value chains; • It disregards the effect of alternative technologies themselves and argues that they are imperfect substitutes to the incumbent; • The theory assumes perfect market competition for energy carriers on a global scale, which does not hold for the natural gas and coal markets; The latest studies have sought to address some of these limitations (van der Ploeg and Withagen, 2015; Jensen et al., 2015; Long, 2015; Sinn, 2015). However, the results of modelling studies are sensitive to the assumptions made and the empirical evidence to support them remains limited and contrasting (van der Ploeg and Withagen, 2015; Jensen et al., 2015).
Carbon Leakage	Change in geographical location of energy-intensive activities – *spatial demand response.* Tirole (2012) establishes that carbon leakage can arise from two possible scenarios. Firstly, countries not cooperating in climate policy may be considered to have a competitive advantage due to energy prices to consumers being cheaper. Energy intensive businesses may opt to move to these countries, thereby potentially offsetting emission savings otherwise realised. The other scenario is that a drop in aggregate demand for carbon based fuels decreases the price of energy globally, thus allowing for economies with less stringent environmental policies to take advantage of this and boost output and therefore emissions.	Currently occurs in non-Annex 1 parties of the United Nations Framework Convention on Climate Change, especially China, India, and other growing Asian economies. Estimates of carbon leakage rates due to the Kyoto Protocol range from 5% to 20% (Babiker, 2005). The change in prices associated with this geographical shift is unclear, and the extent to which fossil fuel suppliers can realistically increase their output is also omitted.

3.1. The fossil fuel demand shift

We start our analysis of the price response of fossil fuels to the deployment of renewables by assessing the extent to which the latter causes a reduction in demand of fossil fuels for power generation. Let us begin by considering the abstract case of a total annual demand for power that, in the absence of renewables, is constant over time. If power demand did not change as a result of the penetration of renewable energy into the market, renewables would replace an equivalent amount of fossil fuel power, which would result in a commensurate decrease in demand for coal and gas commodities as well. However, estimating the demand shift of fossil fuels solely on the basis of the renewable power capacity deployed and its capacity factor is incorrect, because demand for power is itself a function of its price. So should the introduction of renewable power result in a reduction in power prices, the overall power demand would increase. This can be expected as, in addition to the low marginal cost of renewables previously discussed, power prices are also sensitive to the price of fossil fuels used in power generation (IEA, 2014), which in turn will decrease as they are displaced by renewables. For this reason, the decrease in fossil fuel power demand will probably be smaller than the corresponding amount of renewable power generation introduced in the electricity sector. A qualitative graphic representation of this effect is provided in Fig. 1, where the gradual introduction of renewables is shown to increase total demand for power.

If we now take into account the fact that global power generation has increased by 3.1% annually in the last 20 years (BP, 2015), and under a business as usual scenario is projected to continue growing substantially (BP, 2014), it is clear that the scope for a reduction of fossil fuel demand following the introduction of renewables further decreases. Past energy transitions have shown that new fuels have not significantly displaced demand for the incumbent fuels but instead have mainly satisfied further energy demand growth (Fouquet, 2009). In the absence of strong, globally coordinated carbon policy, this same effect may in future be observed with fossil fuels when renewables are introduced: cheaper fossil fuels will likely spur growth in overall power

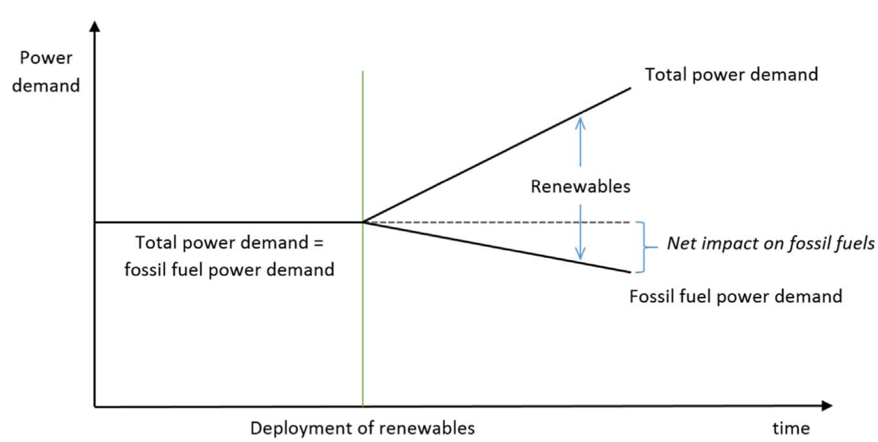

Fig. 1. Renewable power deployment and its impact on fossil fuel power demand.

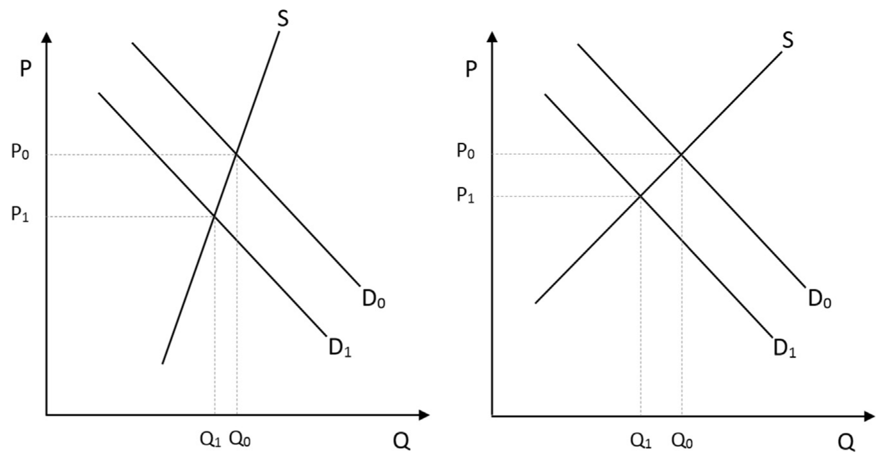

Fig. 2. Effect of supply elasticity on the price drop. For the same demand shift D_0 to D_1, a more inelastic supply (left) leads to a higher price drop (P_0 to P_1) than in the case of a more elastic supply (right).

generation. This chimes well with the projected continued growth of coal and gas particularly in non-OECD countries (BP, 2014; IEA, 2013) as also envisaged by the Carbon Leakage theory. If we also factor in the effect that a drop in fossil fuel prices has on their demand for other energy uses, i.e.: outside of power generation, it can be concluded that the substitution of fossil fuel demand brought by the penetration of renewables is going to be significantly smaller than the equivalent amount of renewable power introduced.

However, although the quantity of fossil fuel displaced by renewables may be small, the impact on fuel price could be high, depending on the price elasticity of supply and demand. In particular, the more inelastic demand and supply, the more substantial the price drop will be for a given reduction in fossil fuel demand. Fig. 2 illustrates this effect in the case of price elasticity of supply; we can see from the figure that for equal leftward shifts of the demand curve, a larger price drop is observed in the case of the more inelastic supply curve. Similarly, a more inelastic demand curve results in a higher price drop for the same leftward demand shift (not illustrated).

So if the demand and supply curves of fossil fuels were inelastic, a small amount of displaced fossil fuel could result in a significant drop in fossil fuel prices. Assessing the exact scale of the price drop though is problematic: not only is the demand shift difficult to accurately estimate, but the availability of supply and demand elasticity data is limited. In particular, supply cost data of coal and natural gas is commercially sensitive, therefore global cumulative capacity cost curves are difficult to construct as limited data is available in the public domain (BP, 2015; Haftendorn et al., 2010). In Fig. 3 we show a global cost curve for coal for the year 2006 based on data collected from a wide range of sources (Haftendorn et al., 2010). As can be seen from this example, the elasticity of supply is generally not constant along the curve. It is also worth noting that the profile of the curve can change substantially over time as a result of investment or disinvestment in production capacity.

Moreover, data on the elasticity of demand for coal and gas are particularly sparse. In the literature, there have been very few efforts to estimate elasticities due to the high complexity involved in this task. Bohi (1981) suggests that shifts in supply and demand occur too frequently in the markets for a single demand elasticity equation to be accurately traced for an extended period of time. However a recent study of the US Energy Information Administration (EIA, 2012), which updates previous similar studies, provides evidence that demand for both coal and gas in power generation is generally inelastic.

3.2. The fossil fuel supply shift

The discussion of the fossil fuel demand shift suggests that such shift could be small, and yet still lead to a substantial price response in the case of inelastic demand and supply. Since demand is likely to be inelastic, at least in the short term, the scale of the price response will depend on the elasticity of supply, which in turn is a function of the specific circumstances of the market considered. However, a further drop in price of fossil fuels may occur as producers seek to compete against renewables or among themselves for market share by reducing their supply cost, which corresponds to shifting the supply curve

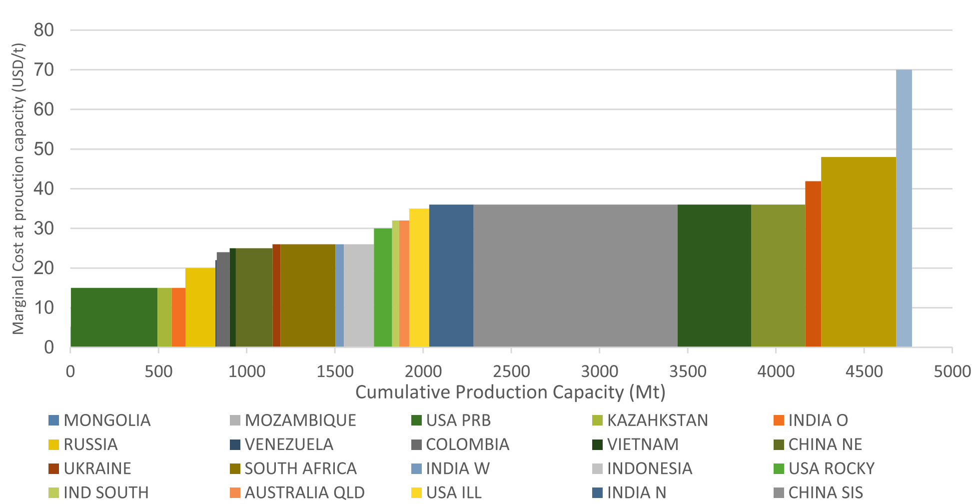

Fig. 3. Marginal cost vs cumulative production of major mining basins (adapted from Haftendorn et al., 2010).

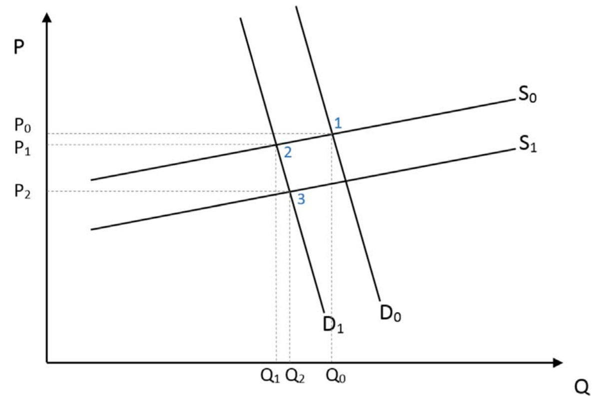

Fig. 4. Effect of a supply shift on the price drop. A demand shift (D_0 to D_1) along an elastic supply curve S_0 is followed by a supply shift (S_0 to S_1), leading to a price drop (P_0 to P_2) larger than in the case of the demand shift alone (P_0 to P_1).

downwards. This is illustrated in Fig. 4, where a leftward demand shift prompts a downward supply shift, resulting in a larger price drop than the demand shift alone would produce.

In a perfectly competitive market where price equals marginal cost, firms can only increase their competitiveness by means of cost reduction through technological development. However, fossil fuel markets in general cannot be regarded as perfect due to the presence of large players with some market power, which gives rise to rents. Indeed, there is evidence that some suppliers have the capability to sell coal or gas at or below the current market price, yet still equal to or above their supply cost (BP, 2015; Haftendorn et al., 2010). This means that fossil fuel producers potentially have the ability to behave strategically and boost their competitiveness by renouncing part of their rents. In doing so, they would be able to supply the market at a lower price and undercut competing low carbon energy sources such as renewables (Gerlagh and Liski, 2011).

The extent to which a supply response is possible depends on the particular fossil fuel considered, the particular field from which it is extracted, the type of ownership of extractive sector firms in the respective value chains and the pricing mechanism of the market within which the energy carrier is traded. These factors are here discussed in turn. Firstly, costs for coal basins globally vary by approximately a factor of 3 (Haftendorn et al., 2010), and for gas supplied to Europe specifically by a factor of 4 (BP, 2015; Lochner and Bothe, 2008). These large variations are a function of: geological and techno-economic factors (BGR, 2009); financial conditions, labour and capital structure (Rogner, 1997); and the lifetime of a mining basin (Haftendorn et al., 2010). The large discrepancies in marginal costs of extraction between different suppliers mean that some are in the advantageous position of having significant headroom before market prices reach extraction costs, adding flexibility to a fossil fuel supply curve to shift downwards towards lower prices in response to rising pressure from renewables.

With regard to firm ownership, private sector companies will be most responsive to managing and reducing prices in order to maintain competitiveness and market share (Weigelt and Camerer, 1988). However, state-owned extractive sector companies can also react to increased competition and lower prices by reducing their rents in order to sustain production and exploration. In particular, we note that governments of fossil fuel rich countries heavily tax national production. Taking the example of Latin America, in year 2008 the percent of total tax income from natural resources (mainly fossil fuels) was 13.9% in Venezuela, 10.8% in Bolivia, 8.8% in Ecuador, and 8.4% in Mexico (UNECLAC, 2008). These figures suggest that governments have room for reducing their fiscal rents on fossil fuels, thus making it more attractive for the industry to increase exploration in new fields and production in mature ones.

The discussion above suggests that, provided there are rents that can be renounced, a fossil fuel supply response is possible and even likely, especially in view of future carbon policy that may restrict the use of fossil fuels, thus magnifying the price effect of the demand shift previously discussed. However, the specific price formation mechanisms of the fossil fuels considered also need to be taken into account, as they can potentially undermine the validity of the price response hypothesis outlined so far.

In particular, only 43% of total world natural gas consumed in 2013 was priced based on gas on gas competition, whereas 19% was indexed to the price of oil and 33% was priced by governments based on certain criteria (IGU, 2014). However, it is important to note that in North America and Europe gas on gas competition is now prevalent, and oil price indexing is gradually reducing its share, which makes it possible for the price response mechanism we have postulated to occur in these markets. Moreover, in China and India, where prices of domestic natural gas are regulated, the pricing is now increasingly based on “cost of service”, which ensures an acceptable rate of return to the value chain firms, and prices are adjusted based on market developments when necessary. China and India also import growing quantities of liquefied natural gas (LNG), more than a quarter of which is priced according to gas on gas competition, so the price response mechanism hypothesised can also occur in these countries, although probably to a lesser extent than in regions such as North America and Europe.

As for the coal market, it is generally regarded as a globally competitive market with a relatively transparent spot pricing system. However the balanced geographical diversification of coal reserves means that only around 15% of coal consumed is traded internationally while the vast majority of coal produced is sold and consumed on regional markets (IEA, 2013). Despite this, the large number of players involved ensures that coal prices are largely determined by demand and supply dynamics (IEA, 2013). In particular, the low coal prices experienced since mid-2011 are due to strong oversupply in the international market. Given that under the current regime producers have had to drastically cut costs and some are selling below production cost, the scope for a further supply shift is very limited and will remain so until market conditions improve.

3.3. *Effect of fossil fuel price response on renewables*

Although our initial assessment of the price response mechanism did not allow us to quantitatively assess its likely future scale, it did suggest that a price response of both coal and gas to the large scale introduction of renewables is likely to occur. Based on the discussion so far we can therefore state that the hypothesised price response mechanism would impact the cost competitiveness of renewables against fossil fuel generators, making the deployment of renewables more expensive than anticipated and increasing their need for financial

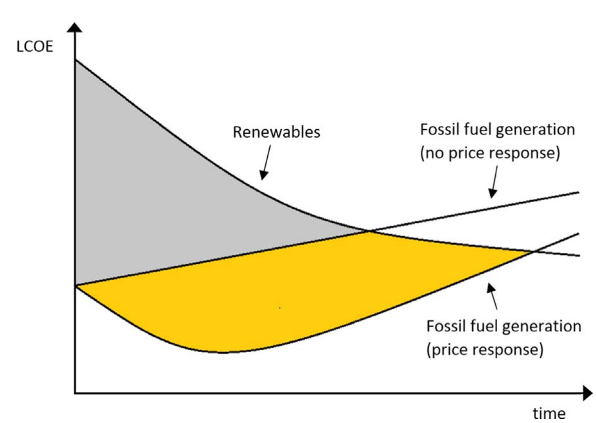

Fig. 5. Effect of the fossil fuel price response on the cost competitiveness of renewables, in terms of the levelised cost of energy (LCOE) of renewable and fossil fuel power generators. Grey and yellow areas express the cumulative financial support needed per unit of renewable power generated.

support. This idea is qualitatively illustrated in Fig. 5, where we suggest that in the presence of a fossil fuel price response, the LCOE of fossil fuel generators could stay below the expected path for a certain period of time, thus increasing the need for cumulative financial support to renewables (yellow area) above and beyond that expected (grey area) should there be no fossil fuel price response. The magnitude and duration of this effect will depend upon a number of specific market conditions and policy variables, also including the introduction of strong carbon pricing.

4. Conclusions

This paper critically discussed the possible occurrence of a price response of fossil fuels to the penetration of low carbon and renewable energy, which could hinder the transition to low carbon energy or make it more costly to achieve than anticipated by increasing the cost competitiveness of fossil fuel power generation. Analysing the existing literature we have identified two relevant theories: the Green Paradox and Carbon Leakage. These theories, which respectively postulate a time effect and a geographic effect of the penetration of renewables on the extraction and use of fossil fuels, have generated useful insights in the field of climate change policy. However, while implying a price response of fossil fuels, they do not address this potentially important mechanism directly.

In order to assess the likely occurrence and estimate the magnitude of a possible feedback loop between renewable penetration and competitiveness of fossil fuel power generators, we first propose an analytical framework based on supply-demand analysis, and then further discuss the root causes of the mechanism based on the specific characteristics of the fossil fuel markets considered.

The preliminary analysis conducted has led us to the following conclusions:

- A reduction in demand of coal and gas may occur due to the large-scale penetration of renewables. However, due to the fact that power demand is itself a function of price, that a reduction in fossil fuel prices reflect on the price of power, and that both coal and gas have energy uses outside of power generation, it is likely that the demand reduction will be significantly smaller than the corresponding amount of renewable capacity deployed.
- Despite this, even small reductions in demand for fossil fuels could potentially lead to a large price response, especially considering the fact that demand for coal and gas for power generation appears to be generally inelastic, at least in the short term.
- The price elasticity of supply of both coal and gas however is more uncertain, depending on the particular conditions of the market considered, and can significantly change over time.
- In the case of elastic supply, the price response to a reduction in demand for fossil fuel is small, however an additional price drop can occur if, as a result of the introduction of renewables, the producers of fossil fuels are able to increase their competitiveness in order to recover part of the market share lost, or in other words shift the supply curve downwards.
- In a regime of perfect competition, such shift can only be achieved by introducing technological improvements. However, in imperfect markets the firms and governments benefit from supernormal profits in the form of resource rents; both could be reduced in order to increase competitiveness.
- There is evidence to suggest that a supply shift is possible, however the extent to which this may happen is somewhat constrained by the structure and current state of the markets on which coal and gas are traded.

Based on our analysis, we conclude that a more detailed assessment of the price response of fossil fuels to the introduction of renewables would require performing case studies that are specific to particular fuels and markets, where all the key aspects of the problem we have identified could be researched in sufficient detail so as to enable quantitative estimation of price drops, the timeframe over which they would occur and their effect on the competitiveness of renewables. Interactions with all other market in the economy should be considered, as well as the impact of carbon taxation and other relevant energy security, climate change and industrial policy measures.

Our initial findings also indicate that the price response theory is tenable, which in turn has strong implications for the design of policy aimed at delivering the global renewable energy transition. We therefore believe it important that research in this field continues.

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