The EU *Energy Union*'s transition to a low-carbon zero subsidy electricity system - lessons from the UK's *Electricity Market Reform*

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HIGHLIGHTS

- The EU Energy Union package proposes market-responsive renewables support
- This implies Premium Feed-in tariffs, which need long-term hedge contracts
- Auctions in UK's Electricity Market Reform reduced renewables costs
- Zero-subsidy low-carbon generation requires a different auction design
- R&D requires a new form of funding

ABSTRACT

The 2015 EU *Energy Union* Package proposes integrating renewables into the market, just as the UK has moved away from Premium Feed-in Tariffs (FiTs) for renewable electricity supply (RES-E) to something closer to the standard FiT, which, when auctioned, demonstrated a 3% real fall in the weighted average cost of capital (WACC). The UK, which has experimented with nearly all forms of RES-E support, offers the evidence base for designing the *Energy Union*'s RES-E support. Cost calculations show that the carbon price needed for a post-2020 zero-subsidy technology-neutral low carbon electricity sector are highly sensitive to gas prices, technology costs and the WACC, implying the need for long-term capacity contracts and emissions standards.

Key words:
Renewable electricity
Support mechanisms
contract design
Future energy scenarios

1. Introduction

The 2015 EU *Energy Union Package* (EC, 2015b) proposes integrating renewable energy supply from electricity (RES-E) into the market. This aims to move away from the unresponsive standard Feed-in Tariffs (FiTs), replacing them by Premium FiTs (PFiTs), which pay a premium on the market price but require generators to take responsibility for selling and balancing their power. The UK, in its *Energy Act 2013* (HC, 2013), launched its Electricity Market Reform designed to accelerate the delivery of low-carbon and renewable energy supply (RES), to meet the EU RES and climate change targets at lower cost while maintaining reliability. In contrast to the *Energy Union Package* it aims to replace PFiTs with Contracts-for Differences with FiTs (CfDs for short) for RES-E, closer to the classic FiT, as the way to lower the cost of RES-E support.

This paper draws on the evidence of the effectiveness of various support mechanisms in the UK to identify good and bad policy instruments intended to guide the transition to a low-carbon zero-subsidy electricity system. Its main contribution is to quantify the impact of the recent Electricity Market Reform in lowering the cost of supporting RES-E. It further contributes by examining the impact of current public finance constraints on the UK's transition to the low-carbon future, and suggests better ways of reconciling climate change objectives with fiscal constraints. This analysis informs proposals for suitable instruments to meet the requirements of the *Energy Union Package* which has been criticized for raising the cost of RES-E support. It also addresses another key *Energy Union* of how to finance Research and Innovation to drive down the cost of less mature low-carbon energy technologies.

The UK electricity supply industry (ESI) has experienced substantial changes to its low-carbon support policies since the industry was privatized in 1990. From being the model for early EU Electricity and Gas Directives, the UK has increasingly had to adapt to externally driven European energy policies, usefully reviewed by (Kanellakis, et al., 2013). The UK has a long history of climate change policies (Lipp, 2007; Anandarajah and Strachan, 2010; Wood and Dow, 2011; Newbery, 2012b; Pollitt and Haney, 2013; Jamasb and Pollitt, 2015) with an emphasis on decarbonizing the economy, and particularly the ESI. The UK, home of the first commercial nuclear reactor, has been a proponent of nuclear power, although with growing concerns over its cost. In contrast, the EU has always found the issue of nuclear power highly divisive and has instead emphasized renewable energy.

Consequently, the UK has come under increasing pressure to broaden its climate change policies to embrace RES from the *Renewables Directive* (EC, 2009) that sets country-specific targets. Its aim is to support near-mature RES to become competitive with fossil fuels from 2020. The *Energy Union Package* endorse that aim, set out clear principles for support, and recognised that removing subsidies requires reforming the EU Emissions Trading System (ETS). The UK is similarly anxious to reduce inefficient subsidies, concerned at their impact on consumer affordability.

The *Energy Union Package* sets an EU target of a 40% reduction in greenhouse gas (GHG) emissions by 2030 (relative to 1990) with binding national commitments, and an EU-wide renewables target of 27% of energy consumption (with no specific national commitments). As such, it is less stringent than that mandated by the UK *Climate Change Act 2008* (HC, 2008), which requires reducing GHG emissions by 50% by 2025 and by 80% by 2050 (compared to 1990).

The ESI is the natural starting point to decarbonize the economy, as it can be done at lower cost and with less behavioral and structural change than in other sectors. Decarbonizing the fuel mix does not require changing the final product, electricity, nor the massive past investments in the delivery infrastructure (transmission, distribution, metering and systems operation) and so requires no behavioral change, although demand response will become increasingly valuable with growing intermittent generation. The aim of the UK Electricity Market Reform (EMR) was to accelerate the delivery of low-carbon and RES-E, to meet emissions and RES targets at lower cost while maintaining reliability.

The UK represents one of the most interesting case studies of supporting RES-E, as she has tried almost every policy at least once before switching, often maintaining two policies in parallel. The UK therefore offers a model for comparing and contrasting alternative approaches to supporting RES-E (Lipp 2007). This is now urgent as the *Energy Union Package* has proposed a radical departure from the previously preferred European model of Feed-in Tariffs (FiTs), to which the UK had finally aligned itself with the EMR.

2. Methods

The recent history of UK's climate change and energy policies is examined to assess the strengths and weaknesses of different RES-E support policies. The costs of different forms of support in the UK are estimated from auction results and the evidence base for the EMR. The evidence thus obtained from the past ESI experience, the recent impact of EMR and the experience of other countries allows an assessment of the aims of the *Energy Union Package* and how they may best be met.

3. The UK's climate change and energy policies

Newbery (2012b; 2013) recounts the history of the UK's climate change and energy policies since *This Common Inheritance: Britain's Environmental Strategy* (HMSO, 1990) that set the UK's first carbon target. That history demonstrates the difficulty of maintaining consistency in energy policy. The now standard trilemma of reliability, sustainability and affordability in practice means reliability always trumps in the ESI, leaving politicians to fight over the relative weight to give to sustainability and affordability, widened to include competitiveness. That said, there has been, and still is, considerable cross-party support for commitments to reducing GHG emissions, reflected in the *Climate Change Act 2008* (HC, 2008) that provides a legal framework for delivering GHG commitments.

When the ESI was privatized by the Conservative Government in 1989, the nuclear power stations needed support to finance decommissioning. The Fossil Fuel Levy imposed on fossil generation raised the required revenue but DG COMP insisted that this be made available to all zero-carbon generation, including renewables. A Non-Fossil Fuel Obligation (NFFO) was placed on electricity supply companies in the 1989 *Electricity Act*, requiring them to buy a certain amount of nuclear or renewable electricity at a premium price. Support for renewables was provided through NFFO auctions for effectively Feed-in Tariffs (FiTs) (Mitchell, 2000).

The early NFFO auctions led to dramatic falls in the cost of renewables, but also to an increasing shortfall in the delivery of winning projects. Non-delivery was not penalized so developers bid for many sites to find at least one successful in gaining planning approval. Wood & Dow (2011) criticized the NFFO scheme for only delivering 19% of the contracted wind capacity.

After the 1997 change to a Labour Government, this failure to deliver led to the *Utilities Act* 2000, which placed an obligation on electricity suppliers to secure a specified proportion of their sales from renewables, which would be given Premium FiTs, called Renewables Obligation Certificates (ROCs). The amount is set out each year in the *Renewables Obligation Order*, which also sets the buy-out price for failure to buy a sufficient number of ROCs. Demand and supply for ROCs sets their price which is added to the wholesale price, and the revenue from the buyout fund is distributed to those issuing the ROCs in proportion to their sales, enhancing their value. Figure 1 shows that the revenue to wind farms is made up of a volatile wholesale price (measured here by annual moving average of the reference price in the day-ahead market, RPD), and the value of 1 ROC, which is more stable but still vulnerable to changes in the future requirement placed on supply companies relative to the supply of renewables. (Wood and Dow, 2011) argued that the RO raised "internal risk" by adding price and volume risk, and "external failures" from the ending of central dispatch and the move to the energy-only NETA/BETTA markets. "By the end of 2009, under a stable feed-in tariff mechanism, Germany had over 25 GW of wind installed in comparison to just over 4GW in the UK, and around 16% share of Electricity in comparison to 6.6% in the UK."

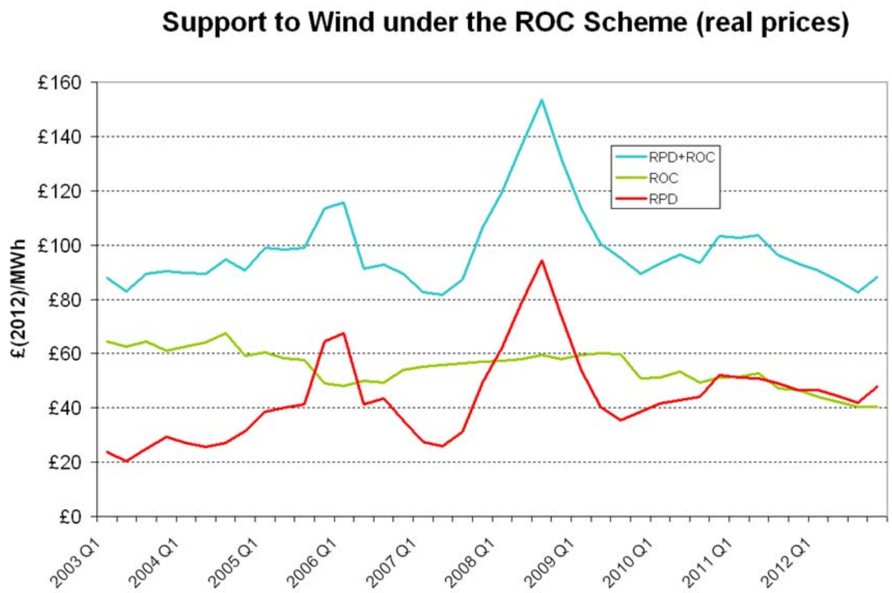

Figure 1 The revenue received per MWh of on-shore wind under the RO scheme
Sources: RPD from APX, ROC prices from Ofgem[1]

This lagging performance from a country with the best wind resource in Europe might not have mattered, given the *Climate Change Act 2008* (HC, 2008) with its ambitious carbon targets, the latest of which, the fourth carbon budget (2023-27) commits the UK to reduce emissions by 50% from 1990, except for the *Renewables Directive* (EC, 2009). That Directive increased the share of EU energy (not electricity) that must be generated from RES by 2020 from 12.5% to 20%. The share of RES-E was expected to be 34% by 2020, and had reached 24% by 2015, of which 10% was variable (wind and solar) (EC, 2015c). Surprisingly, the UK Labour Government accepted one of the most challenging RES targets (relative to its initial position) of 15%, and promised to source 40% of electricity from low carbon sources and around 30% of electricity from renewables by 2020 (DECC, 2009). These ambitious targets undermined confidence that there would be any support for conventional generation, much of which was due to retire as a result of the EU *Large Combustion Plant Directive* and *Industrial Emissions Directive*.

Faced with concerns over security of supply, the regulator, Ofgem, launched *Project Discovery*, which recommended "far reaching energy market reforms to consumers, industry and government" and concluded that "The unprecedented combination of the global financial crisis, tough environmental targets, increasing gas import dependency and the closure of ageing power stations has combined to cast

[1] At https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-ro-buy-out-price-%C2%A344.33-and-mutualisation-ceilings-2015-16 accessed 20/7/15

reasonable doubt over whether the current energy arrangements will deliver secure and sustainable energy supplies." (Ofgem, 2010).

The Department of Energy and Climate Change (DECC, 2010) came to the diagnosis - the carbon price was too low to support unsubsidized nuclear power, while the wholesale electricity price was set by fossil fuel prices (and the ETS). Fossil generators enjoyed a natural hedge as the difference between the electricity sales price and the cost of fuel is reasonably stable, while that for non-fossil generation is very volatile, as shown in figure 1, as their variable costs are low and constant (Roques et al. 2006; 2008). Looking forward, non-fossil generation faces volatile carbon prices that are too low and sensitive to political intervention, thus undermining their future credibility. DECC (2010) agreed that security of supply was becoming an issue, and that the market was not delivering the required volume of renewables.

Labour lost the 2010 election and was replaced by a Conservative–led coalition with Lib-Dem support, more favourable to nuclear power but less well disposed to the European Project, arguing that GHG reductions matter, not the manner of delivery (RES).

This reflects an EU failure to provide convincing reasons for RES support, and the suspicion that it has more to do with Germany's hostility to nuclear power and the implication that the cost of switching to RES should be "fairly" shared to protect German competitiveness. The stated reasons often include the economically doubtful arguments that it enhances energy independence, stimulates new industries and creates employment. Given that most PV and many wind turbines are now made in China, that the cost per job created in these new industries is higher than in the rest of the economy and so reallocating funds actually reduces employment per public €, and that oil and gas imports are rising as a share of final energy demand, these arguments miss the central and only legitimate defence for RES support.

RES targets should be viewed as a policy designed to create demand-pull that will induce learning-by-doing and achieve the dynamic economies of scale to drive down costs and make these low-carbon options attractive to the rest of the world (Berglund & Söderholm, 2006; Kobos, Erickson, & Drennen, 2006; Laleman & Albrecht, 2014; Rivers & Jaccard, 2006; Sagar & van der Zwaan, 2006; Weyant, 2011). Only if that happens will other countries be willing to sign up to the massive decarbonisation that global climate change mitigation requires. The *Renewables Directive* ensures that the club good of financing this innovation goal is equitably shared, although its failure to address the underlying market failure of an inadequate carbon price through the EU ETS and the conflict between the ETS and the *Renewables Directive* (which lowers the price of emission allowances, EUAs) further undermine trust in the coherence of EU Climate Change strategy.

4. Electricity Market Reform

The 2011 estimated cost of meeting the Government's carbon and renewables targets by 2020 in electricity alone amounted to £110 billion, or over £12 billion per year compared with less than £5 billion in 2008, itself nearly 80% above the previous decade average (DECC, 2011). This considerably exceeded the financial capacity of the major utilities, requiring new sources of finance. Given the high capital cost of most low-carbon options, anything to de-risk investments and lower the Weighted Average Cost of Capital (WACC) would lower support costs. A reduction in risk that reduced the WACC by each 1% would reduce interest costs by £1.2 billion each year by 2020, or nearly £45/year per household, compared with current domestic electricity bills of £450/yr.

The consultation proposed a Carbon Price Support (CPS) - a tax to bring the carbon price to a level that would ensure the commercial viability of nuclear power. The 2011 Budget (HMT, 2011) set the support price of CO_2 at £(2009)16/tonne in April 2013, projected to rise to £(2009)70/tonne by 2030. Any carbon tax adversely impacting competitiveness would not be credible, and indeed the 2014 Budget froze its price.

The solution to the credibility problem was to offer long-term 15-year contracts for low-carbon generation, Contracts-for-Differences with FiTs (CfDs for short). The CfD specifies a strike price and pays or receives the strike price less the market price (if the market price exceeds the strike price the holder pays back the excess). While similar to a standard FiT, the CfD holder is responsible for selling output and managing imbalances while the standard FiT pays on metered output.

CfDs with FiTs differ from standard CfDs in that they only pay if the plant generates. A standard CfD is a financial contract that pays or receives $(s - p)$ per MWh (where s is the strike price and p is the wholesale price), regardless whether the plant operates. The holder will only dispatch plant if $p > c$, avoidable cost. The contract makes operating profit $(s - p) + \text{Max}(p - c, 0) = s - \text{Min}(p, c)$, and a fully hedged plant will bid to sell at c (D. M. Newbery 1995), setting the price if at the margin. In contrast, the holder of a CfD/FiT would be willing to generate if $p > c - s$, and could set a negative price.

The final EMR component was an annual Capacity Auction to secure adequate flexible plant for reliability, starting in December 2014 for delivery four years hence (the first for winter 2018/19).

4.1 The power of auctions

DECC, the EMR delivery ministry, delegated the tasks of advising on the CfD strike prices and the procurement capacity in the auction to National Grid, and appointed an independent Panel of Technical Experts (PTE) to advise on National Grid's analysis. DECC published the draft CfD strike prices in July (DECC, 2013a) with the PTE's first report (DECC, 2013b). The PTE criticized the methods for setting strike prices, arguing that the hurdle rate (the Weighted Average Cost of Capital, WACC) was too high, given the de-risking the contracts provided (15 years duration, indexed to the price level) and argued that auctions were superior (DECC, 2013b, para 79). Although CfDs had been announced before the 2012 ROC re-banding, the RO system would run in parallel with the CfDs until 2017. A successful CfD scheme therefore had to compete with ROCs and offer a uniform country-wide price. Germany in contrast offered lower support in windier places, avoiding overcompensating well-endowed sites and also sets nominal prices, The UK offers indexed (real) prices, criticized by the NAO (2015) as unnecessary when bond finance is normally nominal, helpfully front-end loading payments.

The PTE criticized the capacity auction for ignoring interconnectors and for excessively valuing the cost of System Operator actions to mitigate loss of load events (Newbery and Grubb 2015). The auction produced a clearing price 60% below that estimated by DECC, demonstrating the power of auctions to reveal information and the danger of setting an administrative price.

DG COMP, noting the PTE's report, criticized the omission of interconnectors and so DECC included them in the 2015 auction. DG COMP criticized the failure to market test the state aids offered by CfDs. In response the Government announced a CfD auction (DECC, 2014b) with three separate pots for different technologies, limited by the Levy Control Framework.[2] Developers submit sealed bids, which are capped at the administratively set strike prices. The results of the first CfD auction, held in February 2015, are presented in Table 1. The 27 successful projects receive subsidies of £315 million per year by 2020/21. The solar bid of £50 for 2015/16 was not registered, so receives no CfD.

[2] https://lowcarboncontracts.uk/system/files/round_2_operational_plan_v2.pdf

Table 1 CfD Auction Allocation: Round 1

Technology		admin price	lowest clearing price	2015/16	2016/17	2017/18	2018/19	Total Capacity (MW)
Advanced Conversion	£/MWh	£140	£114.39			£119.89	£114.39	
Technologies	MW					36	26	62
Energy from Waste with	£/MWh	£80	£80				£80.00	
Combined Heat and Power	MW						94.75	94.75
Offshore wind	£/MWh	£140	£114.39			£119.89	£114.39	
	MW					714	448	1162
Onshore wind	£/MWh	£95	£79.23		£79.23	£79.99	£82.50	
	MW				45	77.5	626.05	748.55
Solar PV	£/MWh	£120	£50.00	£50.00	£79.23			
	MW			32.88	36.67			69.55

Source: DECC (2015a)

4.2 Estimating the excess cost of administered support prices

Table 1 shows the clearing prices were often substantially below the administered prices (now price caps). The excess level of the WACC can be computed from Table 1 using cost estimates (National Grid, 2013) and price forecasts (DECC, 2014d). The differences in the internal rate of return for on-shore wind for varying values of the capacity factor (CF), capital cost (capex), and opex are shown in table 2 as "IRR delta", where changes in assumptions are italicized.

Table 2 Differences in the internal rate of return for on-shore wind

CF	capex £/kW	fixed opex £kWyr	var opex £/MWh	IRR delta
25%	£1,600	£30	£5	3.30%
25%	*£1,800*	£30	£5	3.10%
28%	£1,600	£30	£5	3.40%
25%	£1,600	*£45*	£5	3.50%
25%	£1,600	*£20*	£5	3.20%
25%	£1,600	£30	*£2*	3.20%

Source: own calculations

The differences from varying the technology assumptions are small, suggesting that the lowering of the WACC of some 3% real per year is robust. This is material as DECC (2013c) estimated that the WACC for on-shore wind might fall from 8.3% under the RO scheme to 7.9% with a CfD, or by 0.4% (all real). If the implied WACC is reduced by 3.3% through auctions then the saving on generation investment of £75 billion up to 2020 (DECC, 2011) would be £2.5 billion per year by 2020, continuing for 15 years. The contrary view that the RO provides a better hedge than CfDs for (Bunn and Yusupov 2015) might be true for portfolio utilities but the EMR was intended to encourage new sources of finance and appears successful, consistent with the experience elsewhere (Criscuolo and Menon 2015).

The potential savings may be under-estimated as unsuccessful bidders could fall back on the RO Scheme until 2017. Had the RO scheme ended when CfDs began, there would have been no fall-back, no need to ensure equality between CfDs and ROCs, and hence lower prices in the CfD auction and even larger savings. Thus the end of 25 years of designing supports for renewables brought us back to the original NFFO tender auctions, but this time paying (slightly) more attention to penalties for non-delivery (DECC, 2015b).

In May 2015 the Conservatives unexpectedly won the election and immediately distanced itself from previous coalition agreements. In June the Government announced the end of ROCs for on-shore wind.[3] If ending the RO scheme implies relying on CfD auctions, that would be a sensible if over-due policy change. If it was to end all on-shore wind support to pacify rural Conservative voters, it was unnecessary as veto planning powers are devolved to local authorities. Clearly one over-riding concern is that current support levels risk breaching the Levy Control Framework (LCF) that caps subsidies at £7.5 billion/yr by 2020. CfDs make subsidies rise as wholesale prices fall, so excessive capacity procurement did not help (Newbery and Grubb, 2015). Closing the RO scheme for the cheapest large-scale renewable option but not the far more expensive off-shore wind and tidal lagoons makes no sense given the constraint of the LCF.

5. Analysis of renewables support

The EMR phased the replacement of ROCs by CfDs, reducing risk and lowering cost but still confronting generators with marketing and balancing risk (D. Newbery 2012a). Just after the first CfD auction the *Energy Union Package* was launched (COM(2015) 80), stating that:

> "… renewable production needs to be supported through market-based schemes that address market failures, ensure cost-effectiveness and avoid overcompensation or distortion. Low-cost financing for capital intensive renewables depends on having a stable investment framework that reduces regulatory risk." (EC, 2015)

Action Point 5 reiterated the aim of "integrating renewables in the market …" and proposing "a new European electricity market design in 2015, which will be followed by legislative proposals in 2016." This Commission proposal would seem to reverse the logic, painfully learned in the UK, of moving from PFiTs to FiTs with their revenue guarantee and hence reduced risk and WACC. German, Danish Spanish and Italian case studies (Criscuolo and Menon 2015; Laleman and Albrecht 2014; Lipp 2007) all demonstrate that a well-designed FiT can be cost-effective (with suitable degression

[3] See http://www.parliament.uk/business/publications/written-questions-answers-statements/written-statement/Commons/2015-06-18/HCWS40/ last accessed 20/7/15

tracking falling costs),[4] can deliver rapid deployment, and encourage the cost reductions that are the logic behind the *Renewables Directive*, as figure 2 shows. Why then abandon what seems to be an effective instrument?

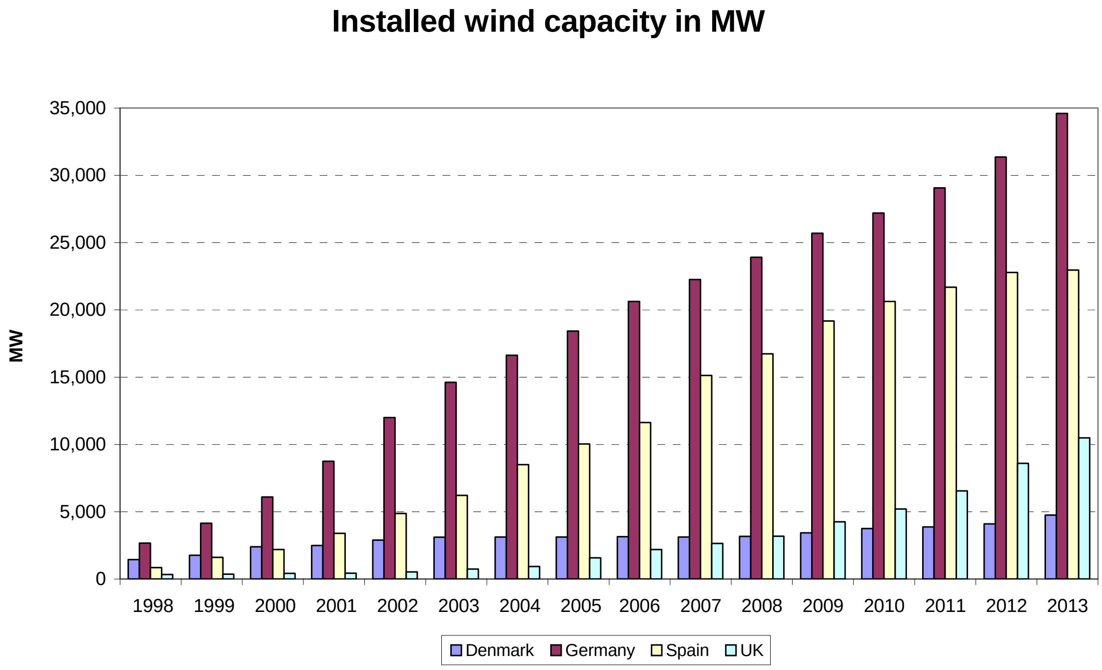

Figure 2 Progress with deploying wind 1998-2013
Sources: IEA to 2011, EWEA 2011-13

There are two good reasons for linking payments to wholesale prices and requiring RES-E to pay for balancing services. As the volume of a specific type of RES-E increases in a local market area (South German PV is an excellent example)[5] so the output in favourable conditions will increase, depressing wholesale prices in those hours (Green and Vasilakos 2010). This fall in prices should lead developers to choose better locations (higher local prices offsetting less sun or wind). A contract price independent of the spot price suppresses efficient signals, raising deployment costs. PV has a rapid afternoon fall-off, requiring rapid ramp rates from back-up plant.[6] High RES-E penetration requires new and costly ancillary services (ramping, frequency response, inertia) and needs to be reflected in support costs, logically by requiring operators to purchase them.

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[4] See also Mahalingam et al (2015) and references therein
[5] "Wholesale electricity costs in Germany decrease in 2012 vs. 2008 by a total of €6.145b driven by increased solar PV generation" according to Renewable Analytics at http://www.qualenergia.it/sites/default/files/articolo-doc/RA-January-2013_Germany-Wholesale-Power-Report-3.pdf
[6] See e.g. https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

The counter argument is that exposing RES-E to uncertain market conditions undermines the risk and cost reducing properties of the classic FiT, reallocating risk to those less able to bear it. It does, however, raise the question of how best to support RES-E. The logic of the *Renewables Directive* is to solve the club good problem of financing deployment to reap the dynamic economies of scale (learning-by-doing), which is primarily about the design, location and installation of the RES-E plant, and less about its operation (which, if it is mature enough to warrant mass deployment, should primarily depend on the resource, wind or sun). This would suggest paying for availability rather than output, per MW, not per MWh, with developers receiving the local, ideally nodal, price.

The UK capacity auction secured capacity at only 40% of the bureaucratically estimated Cost of New Entry, the preferred way of setting capacity payments in markets such as that in the island of Ireland.[7] That suggests the most cost-effective way of supporting mature renewables is through a similar capacity auction. Its aim would be to identify the “missing money” needed to justify deployment, while providing a long-term contract for availability that addresses the “missing (futures) market” problem (Newbery, 1989; 2015c). Successful bidders would receive a nominal payment per MW of capacity available for some period, and be responsible for selling power at the spot price, avoiding the location distortion that high RES-E prices cause (Newbery, 2011). Such auctions would remove the risk that future support payments would breach the LCF (although capping support risks breaching the RES target).

This might seem to recreate the risk of the PFiT, although the contractual guarantee of capacity payments should allow a higher fraction of debt finance that the less predictable ROC value. To reduce risk further, balancing and other ancillary services could be procured competitively by the System Operator and offered in a cost-reflective contract, whose cost would be factored into the auction for capacity availability. Other aggregators or supply companies could offer PPAs for the metered output, based on a prediction of the local wholesale price, further reducing transaction costs and risks. Finally, RES-E (and indeed all generation) should pay the deep connection charge amortized over a suitable period to ensure efficient location and exit decisions (Newbery, 2011).

6. The transition to the zero subsidy future

The *Energy Union Package* implies the need for an efficient, credible and durable carbon price delivered through a reformed ETS. Mature renewables should be supported by that carbon price alone, and immature renewables will be supported together with other Strategic Energy Technologies (SET) in a revamped Research and Innovation (R&I) Plan (Ruester et al. 2014):

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[7] See e.g. http://www.allislandproject.org/en/homepage.aspx

> "… the new European energy R&I approach[8] should accelerate energy system transformation. This should build on Horizon 2020 and involve all Member States, stakeholders and the Commission." (EC, 2015b).

The required carbon price for low-carbon electricity is hard to estimate as it is so sensitive to the price of fossil fuels and future technology costs (Newbery, 2015d). This is readily appreciated by noting that if the carbon intensity of the fossil fuel used in setting the wholesale price is γ tonnes CO_2/MWh_{th} (subscript th refers to the fuel's energy content, not of the electricity produced) then if the price of fuel falls by €1/MWh_{th} the price of CO_2 must rise by €1/γ to compensate. For pipeline gas, the most likely competitive fuel (allowing for losses in pumping etc. of 3%) is 0.19,[9] so the multiplier for the CO_2 price is 5.24. The difference between DECC's (2014e) High and Low gas price projections for 2020 is £(2014)16 (€19.84)/MWh_{th} so the uncertainty about the required carbon price to support mature RES-E is €104/tonne CO_2. Newbery (2015d) shows that the required carbon price is also very sensitive to the WACC and technology costs, which may be one reason for preferring either an emissions intensity for new power plant (tonnes/MWyear), or a cap-and-trade system in which the volume of allowances is adjusted to support a carbon price high enough to make mature low-carbon generation commercially viable. Even with such mechanisms in place the absent futures markets for power and carbon make auctioned contracts attractive for reducing costs.

6.1 Efficient innovation funding

An efficient path to a low-carbon future must deliver adequate Research, Development, Demonstration and Deployment (RDD&D), all of which form part of the Energy Technology Innovation System (Gallagher, et al. 2012) and all of which will require carefully designed policies (Bointner 2014; Hervás et al., 2011; Jamasb and Pollitt 2015; Mercure et al. 2014; Popp and Newell 2012) and public support (Aalbers, Shestalova, and Kocsis 2013). The *Energy Union Package* correctly identifies R&I as critical to decarbonization, but is silent on how the new R&I approach may be funded. (Laleman and Albrecht 2014) note that "for each Euro spent on R&D to develop future technologies, 35 to 41 Euros are spent on the deployment of existing technologies." Jamasb and Pollitt (2015) have noted the adverse impact of liberalization on energy R&D, while Jamasb (2007) and Nordhaus (2014) note the danger of attributing too high a share of cost reductions to learning-by-doing and hence undervaluing R&D.

A lesson can be learned from the way the *Renewables Directive* ensured equitable Member State (MS) support. The targets for RES were allocated between MSs on the basis of resource and wealth. The main problem was that the targets were set in shares of final energy, rather than as a share of GDP. As a result it is hard to efficiently trade RES

[8] This should comprise an updated Strategic Energy Technology Plan and a strategic transport R&I agenda.

[9] http://www.carbonindependent.org/sources_home_energy.htm

across borders as the cost of supporting each technology varies. If instead the target had been set as a percent of GDP, then MSs could meet their target either by supporting the deployment various renewables (benchmarked on a value per MW of available capacity) or on Research, Development or Demonstration plants (RD&D). It would then be possible for MSs to meet their obligations by financing RES in some other location (even, and more sensibly, in developing countries) or on competitively tendered RD&D projects (Sagar and van der Zwaan, 2006) and (Baker et al., 2015).

Given a funding stream for RD&D, the only (but large) question to address is how these funds should be allocated. The spirit of funding through an EU commitment is that the resulting funds, although collected at Member State level, should be competitively allocated to the best proposals. This is in line with the evidence from the literature on innovation funding, which also stresses the need for stability and predictability in the funds available, sadly lacking over the past decades `(Anadón, 2012; Mowery et al., 2010). The UK Ofgem's Low Carbon Network Fund[10] is an excellent model of how competition can be used to allocate funds to regulated network utilities to overcome the barriers they face in adopting innovations, for they fear that if successful regulation will claw back the gains, but if unsuccessful they will bear the full cost. The competition has the dual effect of motivating the companies who will have to install successful innovations, while ensuring that the best prospects are brought to light. Olmos et al (2011 and references therein) elaborate the international evidence on this at greater length and show how it can be extended to a wider group of potential innovators, and how to allocate different pots for projects at different stages of maturity. This paper does not seek

7. Conclusions

Britain experimented with NFFO tender auctions for RES-E in the 1990s. They were successful in driving down prices but less successful in achieving high take-up. They were replaced by ROCs – effectively PFiTs – but the financing risk raised their cost and the UK fell behind Germany with less impressive wind resources (figure 2). The *Energy Act 2013* changed RES-E support closer to a FiT, but requiring operators to arrange marketing and balancing. Auctions delivered considerable cost savings compared to administratively set prices. This paper estimates a reduction in the WACC of 3% real, and potential savings of € billions. NAO (2014) argued that large amounts of money were poorly spent in the transitional (FIDeR) contracts paying these strike prices, confirming that although FiTs can be cheap, there must be some mechanism to link the support price to the actual cost – and auctions would appear the best way.

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[10] https://www.ofgem.gov.uk/electricity/distribution-networks/network-innovation/low-carbon-networks-fund

The *Energy Union Package* appears to argue for PFiTs to confront developers with market signals, as otherwise there is no guarantee that RES-E will choose the right technology, time of entry or location efficiently. This intention is sound but needs to be reconciled with a sufficiently stable investment climate that allocates risks to those best placed to bear them, while still providing incentives for efficiency. This paper argues that capacity auctions, hedged if desired with suitable PPAs and contracts for ancillary and balancing services (all reflecting efficient market value) are the logical solution. These would provide the most financially efficient form of support, would avoid the vexed problem of deciding what is the right carbon price, and would allow progress to a zero subsidy regime for mature RES-E post 2020. It also reduces uncertainty about fiscal exposure, revealed by the exhaustion of the UK LCF.

Finally, climate change policies must ensure adequate and efficiently allocated funding for RD&D to bring the less mature technologies (CCS, off-shore wind, Generation 4 nuclear power, etc.) to the point that they are demonstrably viable or should be abandoned. Changing the obligation from energy shares to GDP shares is the logical solution to the club good problem of financing this public good, which can then be efficiently allocated by competitive processes.

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Glossary

CCC	Committee on Climate Change
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CF	capacity factor
CfD	Contract for Difference
CO_2	carbon di-oxide
CPF	Carbon price floor
DECC	Department of Energy and Climate Change
EMR	Electricity market reform
ESI	electricity supply industry
ETS	Emissions Trading Scheme
EU	European Union
FES	Future energy scenario
FiT	Feed-in Tariff
GDP	Gross domestic product
GHG	Greenhouse gas
MS	Member State (of the EU)
NFFO	Non-fossil fuel obligation
PFiT	Premium FiT
PTE	Panel of technical experts (to advise DECC on delivery of EMR)
PPA	Power purchase agreement
PV	(solar) photo-voltaic generation
R&I	research and innovation
R&D	research and development
RD&D	research, development and demonstration
RES	Renewable energy supply
RES-E	Renewable energy supply from electricity
RO(C)	Renewable Obligation (Certificate)
WACC	Weighted average cost of capaity