Appendix A: Summary of existing policies to support investment in industrial electrification

Domain	Policy	Sector	Policy Start	Policy End	Budget	Description
Measures to directly support investment in electrification	Transforming Foundation Industries (TFI)	Foundation industries (Cement, Metals, Glass, Paper, Ceramics, Chemicals)	2020	2025 (Closed to new applicants)	£66 million (government) + £83 million (industry)	Aims to bring together businesses from different Foundation Industries to work on common resource and energy efficiency opportunities through collaborative initiatives. Must be cross-industry and cannot fund company-specific energy efficiency or decarbonisation.
	Industrial Decarbonisation Challenge (IDC)	Multiple	2019	2024	£170 million	Research-focused fund which aims to accelerate the cost-effectiveness of decarbonisation across heavy and energy-intensive industries. It operates through funding the uptake of engineering plans, business plans, the demonstration of cost-effective technologies and processes, and enabling deployment of core infrastructure. One of its goals is to create four low-carbon industrial clusters by 2030 and at least one net zero cluster by 2040.
	Industrial Energy Transformation Fund (IETF)	Multiple	2020	2024 (Closed to new applicants)	£315 million	Aims to help businesses with high energy use, including energy intensive industries, to invest in energy efficiency and low carbon technologies to reduce carbon emissions and energy bills. It covers feasibility and engineering studies and a proportion of the investment cost.
	Clean Steel Fund	Steel	2023 (proposed)	Unknown	£250 million	Aims to enable the transition to lower carbon iron and steel production. It considers funding in projects aiming at switching to lower carbon fuels, such as biomass, hydrogen and electricity, and including CCUS.
	PRISM	Steel	2020	2024	£22 million	Research focused fund which aims to increase the competitiveness of the steel sector in the UK by fostering the innovation in decarbonisation, digital technologies and circular economy. It funds research within the Material Process Institute, and funds services provided by the MPI in 50% for collaborative projects and 25% for individual initiatives.

Appendix B: Tables of existing policy proposals in the literature

Table 3: Summary of existing proposals to support investment in electrification.

Policy	Description	Proposed by
Increase funding for clean technologies	Increase funding for low-carbon production methods such as electrification, matching the ambition of other nations to avoid the UK losing further ground in the green transition/market share.	(Whitwham et al., 2022) (UK Steel, 2022)
Demonstrator projects in key areas of industrial production	Establishment of demonstrator projects in key areas of industrial production, such as a large-scale green steel pilot.	(Whitwham et al., 2022) (UK Steel, 2022)
Improve sequentiality between funding programmes	Programmes that fund engineering projects and those that fund project implementation should run sequentially taking into account that the lead time between project identification and an investment decision.	(BEIS, 2020)
Carbon Contracts for Difference (CCfDs)	Project-based guarantees of a fixed carbon price to decrease the risk of investing in new low-emission technologies.	(Frontier, 2021)

Table 4: Summary of proposed measures to reduce the price of industrial electricity.

Policy	Description	Proposed by
Implement network cost reductions	Re-examine network charging arrangements (transmission and distribution) to reduce cost to industries.	(UK Steel, 2021) (Grubb and Drummond., 2018, 2021) (UK Steel, 2022)
Shift policy cost from electricity to gas bill	Shift some policy costs from the electricity bills of industrial producers onto industrial gas bills.	(Frontier, 2021) (Drummond et al., 2021).
Increase the level of renewable levy exemptions	Increase the relief from 85% aid intensity, to closer to the level of reliefs applied in Germany, where companies achieving the necessary electro-intensity thresholds pay a maximum of 0.5% of their GVA	(UK Steel, 2021) (UK Steel, 2022)
Increase compensation for the indirect costs of the UK ETS	Expand 100% compensation for the Carbon Price Support's indirect costs to all EIIS.	(UK Steel, 2021)
Exemption from Capacity Market costs	Provide an exemption from Capacity Market costs.	(UK Steel, 2021) (UK Steel, 2022)

Table 5: Proposed measures to promote the adoption of low-carbon industrial products.

Policy	Description	Proposed by
Voluntary/Mandatory product Labelling	Accredits products with lower embodied emissions than a benchmark by government.	(BEIS, 2022b)
Mandatory products standards	Sets an upper limit on the embodied/lifecycle emissions for industrial products placed on the market.	(Frontier, 2021) (Whitwham et al., 2022) (UK Steel, 2022)
Low-carbon public procurement	Favours the purchase of low emission products in contracts for public projects. Maximum threshold for the embodied and lifecycle emissions of goods and services procured.	(MPA, 2020) (BEIS, 2020) (Frontier, 2021) (BEIS, 2022b) (Whitwham et al., 2022) (UK Steel, 2022)
Private procurement	Government supports the purchase of low emission products by the private sector, for example through facilitating the formation of voluntary buyers' alliances.	(UK Steel, 2022) (Whitwham et al., 2022)
Carbon Border Adjustment Mechanism	Mechanism to tax imports into the UK mirroring the carbon cost on local producers imposed by the UK ETS.	(BEIS, 2020) (Frontier, 2021) (Whitwham et al., 2022) (Viisainen et al., 2022) (UK Steel, 2022)

Appendix C: Current policies for alleviating industrial electricity prices

Domain	Policy	Sector	Policy Start	Policy End	Budget	Description
Existing measures to moderate electricity prices	Compensation for indirect carbon costs	Electricity-intensive industries (at risk of carbon leakage)	2013	2025	£51 million (2019; EU ETS compen-sation only)	Direct compensation of carbon costs from UK ETS and Carbon Price Floor on electricity consumed (75% of calculated costs, up to 1.5% Gross Value-Added).
	Renewable levy exemptions (CfDs, FiTs, RO)	Electricity-intensive industries (at risk of carbon leakage)	2017	Not specified	N/A	Exemption of up to 100% of the levy costs of the contracts-for-difference (CfDs), small scale Feed-in Tariffs (FiTs) and Renewable Obligation (RO).
	Energy Bill Relief Scheme*	Non-domestic electricity & gas consumers	Oct 2022	March 2023	£18.5bn (Autumn statement) contingent upon wholesale prices	Cap on wholesale element of non-domestic electricity prices at £211/MWh and gas prices at £75/MWh, between October 2022 and March 2023. Network and other costs still apply.
	Energy Bill Discount Scheme*	Non-domestic electricity & gas consumers	Apr 2023	March 2024	£5.5bn (cap based on estimated volumes)	A per unit discount on the wholesale element of non-domestic electricity prices of £19.61/MWh over a price threshold of £302/MWh. For gas prices the discount is at £6.97/MWh over a price threshold of £107/MWh. A higher level of support is available for EIIs with a discount on electricity prices of £89/MWh over a price threshold of £185/MWh, and a discount on gas prices of £40/MWh over a price threshold of £99/MWh. These discounts only apply to 70% of energy volumes. Network and other costs still apply.
Other relevant mechanisms	Climate Change Levy (CCL) exemptions	Energy-intensive industries	2001	Not specified	-	Levy on industrial consumption of electricity and fossil fuels. Industries entering into a Climate Change Agreement (CCA), with specified carbon or energy targets, may receive a 93% discount on standard CCL rates (until 2025). From 2014, taxable commodities used in mineralogical or metallurgical processes also receive an exemption.
	UK ETS	Energy-intensive industries	2021	Not specified	-	UK ETS replaced the EU ETS to price GHG emissions from the power and energy-intensive industry sectors. Permits freely allocated, via sector-specific benchmarks, to energy-intensive companies considered at risk of carbon leakage due.

**Added after interviews took place*

Appendix D: A 'Green Power Pool' options for design and implementation

In 2018, in the context of work examining the drivers behind the high electricity prices faced by UK industry compared to key European competitors[1], we first outlined an approach which would enable consumers to access cheap renewable energy through a 'Green Power Pool' (GPP). This can most generally be conceived as a combined volume of electricity from many renewable generators, made available to consumers directly rather than through the current wholesale market. This approach would establish a 'dual market' system, with the wholesale market operating in parallel to the GPP, and interacting with it in ways described below. A Green Power Pool emerged as key option for wholesale market reform under the government's REMA consultation launched in July 2022.

In November 2022, we published a working paper that develops specific options for the design and implementation of a GPP in Great Britain[2]. It also outlines how a GPP could potentially address some suggested guiding principles for market reform outlined in Box 2, whilst preserving security of supply and enhancing conditions for low-carbon investment and efficient operation of an expanding electricity system.

In principle, there could be many variations on the idea of consumers gaining access to bulk renewables without going through the wholesale market. Indeed, some already do, through direct Power Purchase Agreements (PPAs) – direct contracts between a given purchaser (which could be an industrial consumer, or a supply company) and specific renewable energy sources. Some of the renewables built with support of Renewable Obligation Certificates are sold through PPAs. We return to consider the strengths and limitations of PPAs later.

Box 2: Five guiding principles for assessing market reform

1. The growing prevalence of lower-cost renewables is not an aberration in electricity markets but a fundamental feature, and offers opportunities for responses to the energy crisis that align short- and longer-term needs by:

    a. Making better use of existing low-carbon generation in the context of the energy crisis

    b. Recognising that the most rapid and extensive progress has been due to investment based on long-term contracts, which have been mostly outside the current wholesale market

    The implication is that seizing opportunities requires substantial developments in electricity market design to support the move beyond a fossil-fuel-led system.

2. Structural solutions are required to separate the average price of electricity from the short-run marginal-gas cost and risk-based premium pricing of current wholesale markets.

3. Governments need to consider whether vulnerable groups – in both households and business – can or should be priority beneficiaries of the revolution in cheap, clean electricity.

4. Seizing the opportunity of low-cost renewables ultimately requires market structures which apportion backup and balancing costs appropriately and proportionately.

5. Along with supporting infrastructure, pursuing the energy transition will require new policy approaches and institutional structures to engage consumers across all energy uses, to enhance investment in energy efficiency, innovation, and electrification with flexibility.

1: (Grubb and Drummond, 2018)
2: (Grubb et al., 2022)

A GREEN POWER POOL BASED ON CONTRACTS-FOR-DIFFERENCE

To clarify essential features, our paper focused on one, quite specific form of Green Power Pool: one based on the output of renewables supported under the UK's Contracts for Difference. For purposes of exposition and clarity around the economics, this has the major advantages of transparency in cost and volume (as set out in Figure 2 for offshore wind), as well as legitimacy for government to influence how electricity supported by such government underwriting is deployed in the context of a major national energy crisis.

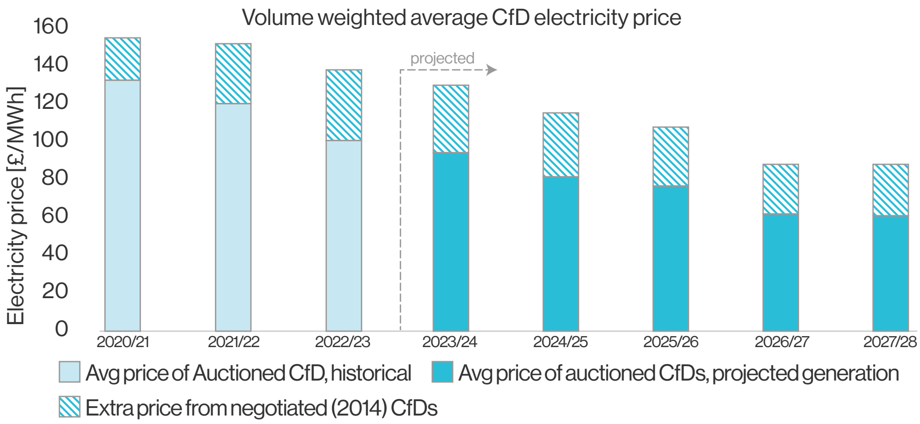
For the most part, consumers cannot directly access this generation at or near their costs. Generators with CfD contracts still currently sell into the wholesale market, followed by a complex process of recycling surplus generator income, which limits the ability to address the principles 3–5.

A natural starting point for establishing a GPP could therefore be to re-direct the sales of electricity already produced by generators with CfDs. This could be achieved without significant changes to the financial terms of CfD contracts that have so successfully supported the growth of large-scale renewables, hence maintaining investor confidence.

CfD-based generation volume, price and cost implications

By redirecting and aggregating CfD based generation in a GPP, a government-backed GPP aggregator – or 'Pool operator' – could offer contracts to consumers based on the average cost of this generation, reflected by the strike prices awarded to each individual generator. Figure 8 presents the actual and projected volume-weighted average strike price for electricity produced by generators with CfD contracts. Based on auctioned CfDs only,[3] the weighted-average strike price – dominated by offshore wind – is already below £100/MWh, and declining, remaining well below the forward electricity prices presented in Figure 3.

Figure 8: Average wholesale prices of electricity produced by existing and contracted CfDs.



Source: *Produced by the authors based on LCCC's forecast generation (Figure 9)*

Policy charges in a Green Power Pool

At present electricity prices, policy charges amount to less than 5% of electricity prices. If, and as, wholesale prices fall, they may again be seen as significant. However, a Green Power Pool based on CfDs would be paying directly for renewables – including some of the earlier, higher cost contracts. The pool would thus already carry these costs and since such a pool would not draw on other renewables, adding the support cost of ROC-based renewables would clearly be inappropriate.

Moreover, since renewables do not emit CO2 and the price of the pool would reflect the cost of renewables, nor would pool customers pay any carbon charge, thus eliminating much of the complexity around carbon charges (and partial compensatory payments for energy-intensive industries).

Volumes

To indicate the scale of CfDs, in the wider context of the GB's non-fossil generation, Figure 9 indicates the volume available from different low-carbon sources in receipt of government support in Great Britain, with projections to 2027/8. In 2022/23, generation from all CfD generators will amount to around 37 TWh – over 10% of all electricity generated in the UK.[4]

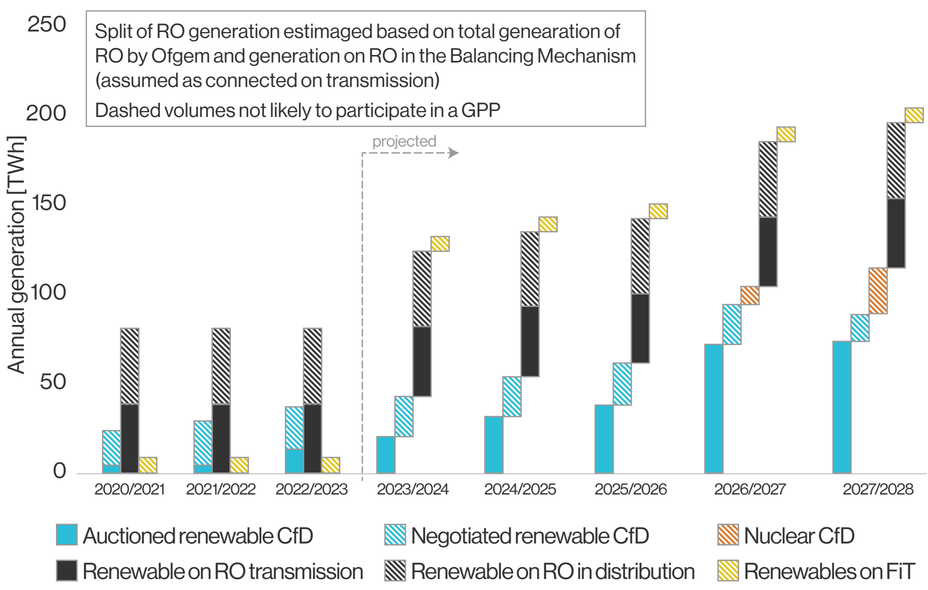
The generation from the four auctioned CfD rounds to date is growing fast and by 2027/28 would amount to about a quarter of current total UK generation. The projections indicate that if all CfDs so far contracted were combined with generation currently supported by Renewable Obligations, the total (over 150TWh/yr) would, within five years, amount to about half UK electricity generation.[5]

3: 25 I.e., if the more expensive 'negotiated' (pre-Round 1) contracts are not included. As well as expensive initial offshore wind contracts, the negotiated CfDs awarded in 2014 included significant volumes of biomass and the Hinkley Point C nuclear reactor; the subsequent auctioned CfDs are dominated by wind and some solar.

4: The weighted-average strike price of this generation would be around £128/MWh; below the winter wholesale prices, but around double the historical average wholesale price. However, this includes expensive contracts awarded to generators in 2014 – mainly biomass and offshore wind, but also nuclear in the guise of Hinkley Point C, currently due to come online in 2026/7 – before an auction mechanism helped to rapidly reduce strike prices awarded in subsequent CfD allocation rounds. If electricity from these generators is excluded, the current weighted-average price is around £93/MWh.

5: Complications in this data include that only about half the RO generation reported by Ofgem participates in the national balancing mechanism, as indicated; Much of the rest may connect at distribution level, and some may be for own use, making it unclear how much might be available to participate in a national 'green power pool.'

Figure 9: Renewable energy and other CfD derived generation in UK, expected 2023 and projected 2027/28.



Source: *Produced by the authors based on LCCC's projected generation and the RO annual report 2020–2021. For comparison, total UK generation in 2021 was 308TWh.*[6]

Cost implications and safeguards

As noted, at present the CfD generators sell into the wholesale market and when their generation is cheaper than the 'reference price' (in the day ahead market), they pay back the surplus revenues to suppliers. The money flows of a targeted GPP would be very similar to that obtained if these revenues were paid directly to the participants in the pool (for a brief overview of the pros- and cons of different approaches to targeting support, see Table 6 below).

A distinct feature of a green power pool based on CfD renewables is that consumers outside the pool would no longer receive these repayments. At the total repayment level in the last six months of 2022 (£282m), and assuming that all the repayments in the current approach are being passed through to consumers, this would amount to about £20/year per UK household – about 50p per week, to enable clean electricity at CfD prices to be channelled to those most in need.

Projections are sensitive in particular to what happens to wholesale prices. As noted, the cost of CfD electricity looks set to remain well below wholesale prices. Should electricity wholesale prices collapse much faster and deeper (which seems unlikely due to forward contracting as noted), a simple safeguard would be to set the rules so that GPP consumers could revert to the standard market if the cost derived from the GPP pool should ever fall below the Ofgem retail price cap.

General principles and non-CfD renewables generation

The general principle of a GPP-pool is that renewables would sell power on the basis of contracted costs (reflecting investment, debt repayments, maintenance etc) – not on the basis of the short-run marginal system price – and this power would be aggregated through the pool which would sell on to its customers.

The aggregation of renewables input is particularly important given the variability of most renewables. Some researchers have suggested that renewable generators should individually be responsible for balancing and backup to provide firm power. This, however, would be extraordinarily inefficient since it would not take advantage of the dispersion of renewables of different types and regions. Indeed one look at Figure 6 indicates that this would result in a vastly excessive degree of backup, since the overall peak-output capacity of renewables by 2030 could substantially exceed total peak demand, and that capacity would be spread around the country taking advantage of the patterns of weather fronts moving across the country, and complementarity particularly of wind and solar generation.[7]

A green power pool can reflect the fact that it is overall output of renewables which needs balancing and backup to provide firm power, not individual sources. Whilst we use CfD-backed generation to illustrate the principles, the idea of a green power pool is generalisable to all renewables (and indeed, non-fossil sources), both existing and ongoing new investment. A key question remains around what should happen to renewable generators receiving other forms of government support, and particularly the Renewables Obligation – which account for the lion's share of renewable generation until around 2026/27, and which are now subject to the 'windfall' levy. This adds another layer of complexity, rather than tackling the fundamental structures that necessitated such an intervention in the first place, and we return to the wider dimensions later.

6: (BEIS, 2022c)

7: A proposal from Prof Dieter Helm (Helm, 2017) that renewable generators should pay for the backup of their plants could (depending on whether it could be designed to include demand-side response) create a strong push for flexibility, but it would be a very inefficient and expensive way of doing so – in part because it would parcel out to numerous individual plants what is a collective need to balance output of renewables overall. Efficient backup and balancing is a system property, with enormous inefficiencies if parceled out to individual generators. A trivial example: we do not build capacity to ensure that every household could securely turn on all kettles (not to mention other appliances) at the same time. For renewables, both capacity backup and dynamic balancing costs are substantially reduced by geographical dispersion (e.g., as a wind system crosses the country) and even more by technological variety (wind + solar + ...), even more so if there is significant storage. Helm's proposal also does not clarify whether the level of 'backup' should be average output, average winter output, or peak capacity, of a wind farm – because there is no logical answer (except, the latter would be grossly inefficient, leading to tens of GW of completely redundant backup capacity). It is an excellent principle that backup and balancing costs should be both transparent, and ultimately paid for in the cost chain from variable power sources to consumers of that power – but only if the different variable inputs are aggregated, with backup and balancing recognized as a collective system property, with costs proportionately allocated.

To target or not to target?

"Targeting" – differentiating support or allocating costs between different groups – has become a defining challenge in the energy sector. The UK government attempt in Autumn 2022 to provide blanket fiscal support to all consumers (albeit, already differentiated between households and business) for two years proved ruinous and short-lived.[8]

As the UK Chancellor stated, the most obvious way to reduce costs is by targeting those most in need. The most obvious mechanism to do so is fiscal. However, as we have noted, raising revenue from the energy sector through windfall taxes on cheaper generators, and then deciding who should receive how much fiscal support of uncertain duration, against the inherent unpredictability of future electricity prices, is hardly a stable configuration for energy policy. Nor does it help to address the inflationary impact of energy price shocks.

Reforming the electricity market through Green Power Pools could help potentially in two very different ways. If most renewables sold power into the system more aligned to a "cost plus" basis, and this were fed through suppliers to final consumers, then the average electricity price would increasingly reflect this – it would no longer be wholly driven by the short-run marginal cost (the latter would still play a role, but increasingly in relation to handling variability, as discussed below).

However, if the price of electricity offered through the pool is significantly below that available from the wholesale market, demand would rapidly outstrip supply. If there were no constraints, the value of contracts would rise to that of supply contracts under the current wholesale market, largely defeating the objective. One option under active consideration would be to require electricity suppliers to purchase a proportionate share of renewables output at such cost, and to reflect this in the overall tariffs offered to consumers. The idea of an undifferentiated GPP could be particularly important if it engages all renewables, including the large volume current on ROCs, and future expansion. At present however, the terms and legal basis on which such renewables could enter a GPP are unclear (unlike CfDs).

The other option involves targeting particular groups. Table 6 compares three approaches to targeting support. Each has pros and cons. The most obvious benefit of targeting power from a CfD-based GPP is the stability, predictability, and transparency of the mechanism. In addition, compared to fiscal targeting, it would not be inflationary, since it would reduce electricity prices rather than pay some consumer groups to cope with higher prices. For international trading industry also, direct fiscal supports face greater risk of contravening World Trade Organisation (WTO) rules on subsidies, potentially stimulating legal action and countervailing measures.

Strategically, continuing direct government payments would simply act to 'patch' the distributional consequences of a market structure becoming increasingly unsuited to the nature of the system underpinning it. Instead, offering preferential access to a Green Power Pool to provide these consumers with direct access to renewable electricity, at prices at or near the long-run average cost of their generation, would represent a move towards changing market structures better aligned with the changing structure of UK generation.

Such targeting would be particularly relevant if a GPP were initiated on the basis of CfD-backed renewables for several reasons. The volume is limited, though growing as indicated. CfDs already return 'surplus' revenues to suppliers, so the financial impact on electricity prices of switching CfD generation to an untargeted GPP would be minimal. The biggest value of a GPP based purely on government-backed CfD generation would be if the output were targeted to those most in need, and for which such targeting could most contribute to overall welfare and national strategic goals, as current supports decline during 2023.

8: The cost of this support, initially intended to last two years for domestic consumers, alongside tax cuts and other measures in the September 2022 'mini-Budget', contributed to the subsequent financial and political turmoil. A few weeks later, the new Chancellor Jeremy Hunt rescinded the two-year coverage, stating that, "(B)eyond [April] it would not be responsible to continue exposing public finances to unlimited volatility in international gas prices", pledging instead to, "(D)esign a new approach that will cost the taxpayer significantly less than planned", by targeting those in the most need. (Thomas, 2022)

Table 6: Comparison of different targeting approaches

	Direct payments	CfD indirect	Direct – Targeted Green Power Pool
Description	Government direct payments to priority groups	Focus CfD recycling payments to priority groups	Give priority groups access to cheaper electricity through a Green Power Pool
Complexity of initial implementation	**Low** (for households), if based upon existing benefit systems	**Medium*** (more complex for industrial consumers)	**Medium to High** depending upon contract complexity
Stability of mechanism	**Low** contingent upon general budgetary decision-making	**Medium** consumers (or their suppliers) pay wholesale prices, later receive compensation	**High** Long-term contracts with assured prices reflecting cost of CfD contracts
Predictability of benefit to targeted group (assuming policy stability)	**High**	**Medium** Level uncertain and payment timing misaligned to high cost periods	**High** Assured price component has low variability
Predictability of liability (assuming policy stability)	**Medium** Depends on government decisions in relation to evolution of energy prices	**Low but transitional** Degree depends on underlying energy price volatility	**High** Generator prices fixed; consumer assured price has low range
Transparency in system costs for balancing renewables variability	**Low / Medium**** No change	**Low / Medium**** No change	**High** (assuming implemented with GPP balancing from wholesale market)
Contribution to development of low-carbon system	No change	No change	**High** (depending on contract design)
Wider economic and legal risks	Potential WTO challenges for industrial support; government bears cost; potentially inflationary	Unclear WTO compatibility for industry support; no cost to government; not inflationary	Likely WTO compatible; no cost to government **If based on CfDs only:** Not inflationary **If RO generators brought into GPP:** potentially deflationary, depending on strike prices & time horizon

** Targeting recycling of CfD revenues introduces new complexities as the current mechanism is based on a common cap to the tariff*

*** Current system involves 'constraint payments' and Capacity Market, but does not transparently identify other costs associated with providing 'firm power' complementary to variable renewables output*

PRIORITIES FOR TARGETING THROUGH GPP-BASED ELECTRICITY CONTRACTS

Although establishing a GPP would be initially more complex than other options for targeted support, a range of unique benefits could result. As it would not draw on government budgets and would instead be largely based on fixed CfD strike prices, it would hold greater stability and predictability for recipients. Access by electro-intensive industries would also likely comply with WTO rules, as although they would receive electricity at prices significantly lower than supply available through the wholesale market, it would be unsubsidised (and in legal terms could be largely akin to such consumers being party to a Power Purchase Agreement – PPA). Such GPP targeting may offer a more economically sustainable and robust way to protect vulnerable groups from high electricity prices than other means of support yet adopted or proposed.

However, all approaches to targeting involve political choices, drawing on consideration of which groups should benefit and why. Two priority groups stand out for initial priority access to the GPP for exceptional political, economic and welfare concerns. The first priority group could be 'fuel poor' domestic consumers already targeted for previous government supports, or otherwise defined for this purpose. Another priority group could be electro-intensive industry.

In Great Britain, one potential definition of priority industries could be those already eligible for compensation for the indirect costs of the UK Emissions Trading Scheme (UK ETS) applied to electricity generation. This group used between 3 to 4 TWh of electricity in 2021, close to 15% of the electricity generated under CfDs that year. An alternative definition could consider the larger set of industries that are eligible for the Energy Intensive Industries Exemption Scheme.[9] The amount of electricity generated from CfD-supported generators overall already equates roughly to the likely demand of these groups, though not (yet) if the focus is only on the auctioned CfD contracts.

Our analysis of sectoral characteristics however suggests an additional, more specific, lens, for considering priority sectors, in relation to the potentially different pools of renewable energy.

Specifically, our research suggests a case for the steel sector to be a priority beneficiary of a CfD-based Green Power Pool, for four reasons:

- **Economic characteristics.** The steel sector is economically struggling to a degree which has and will inhibit its ability to strike long-term electricity contracts. Since CfDs already guarantee the revenues to the generators, demand-side contracts can simply reflect the evolving cost of generation under these contracts, but do not require any commitment from the consuming entities. Moreover, as noted, the UK is currently exporting scrap steel for processing abroad, but the current system of emission benchmarks actively deters our blast furnaces from switching to electric arc production, for the reasons indicated. GPP electricity would avoid the complexities of benchmarking and carbon cost compensation by directly reflecting the cost of non-fossil electricity without any carbon price.

- **Strategic and political importance.** Many view steel as a critical industry of national strategic importance, for its input to national infrastructure and even military capability and, outside the EU, the UK's access to European production in times of crisis is less assured. Also, the UK's two blast furnaces are centres of major regional employment (Port Talbot in South Wales, and Scunthorpe on England's east coast Humberside estuary), and closure would be regionally economically traumatic.[10] The huge volume of CO_2 from these blast furnaces[11] is a major problem for meeting the UK's mid-term carbon budgets, which is another strategic goal, and cheaper electricity is an absolutely necessary (though in itself insufficient) condition for credible conversion to electric arc production.

- **Flexibility.** Electric arc furnaces are potentially highly flexible in their operation – the production volume can be adjusted relatively rapidly to make the best use of times when electricity production from the Green Power Pool is sufficient to meet all its demands, and the scale of the operations would justify the more complex contract structures required to reflect this in terms of low electricity prices.[12]

- **Location.** Converting the blast furnaces to electricity- and hydrogen-based production would involve major new electricity demand, but the coastal location of each would facilitate direct access to the output of offshore wind in particular (and each is also close to regions with good solar PV potential), as are several of the existing electric arc sites.

Of course, other sectors could stake a claim for access to cheaper and more predictable electricity prices. As the volume of CfD-based generation grows, so does the potential to expand access far beyond initial priority groups, particularly if some or all the of renewables currently supported by ROs were brought into such a pool.

There are however other options for expanding the principle of green power pools to such sources, and potentially for new renewables investment beyond CfD supports (e.g., smaller scale onshore investments), which may also be suitable for other sectors. We discuss these after presenting the operating principles a green power pool given the variable nature of renewables.

9: We estimate that in 2021 these accounted for 9.9 TWh of electricity demand, 45% of the electricity produced under CfDs (Author-derived estimates from government reports on the respective industry schemes).

10: Indeed, British Steel was reported on 1st January 2023 as warning that the Scunthorpe operations are losing £1m/day, and that one or both furnaces there face imminent closure, with "UK ministers in 11th hour plea for £300m to save 3,000 jobs" (FT, 2023b)

11: Port Talbot and Scunthorpe in 2018 each produced close to 3 million tonnes of steel, along with 5-6 $MtCO_2$ emissions.

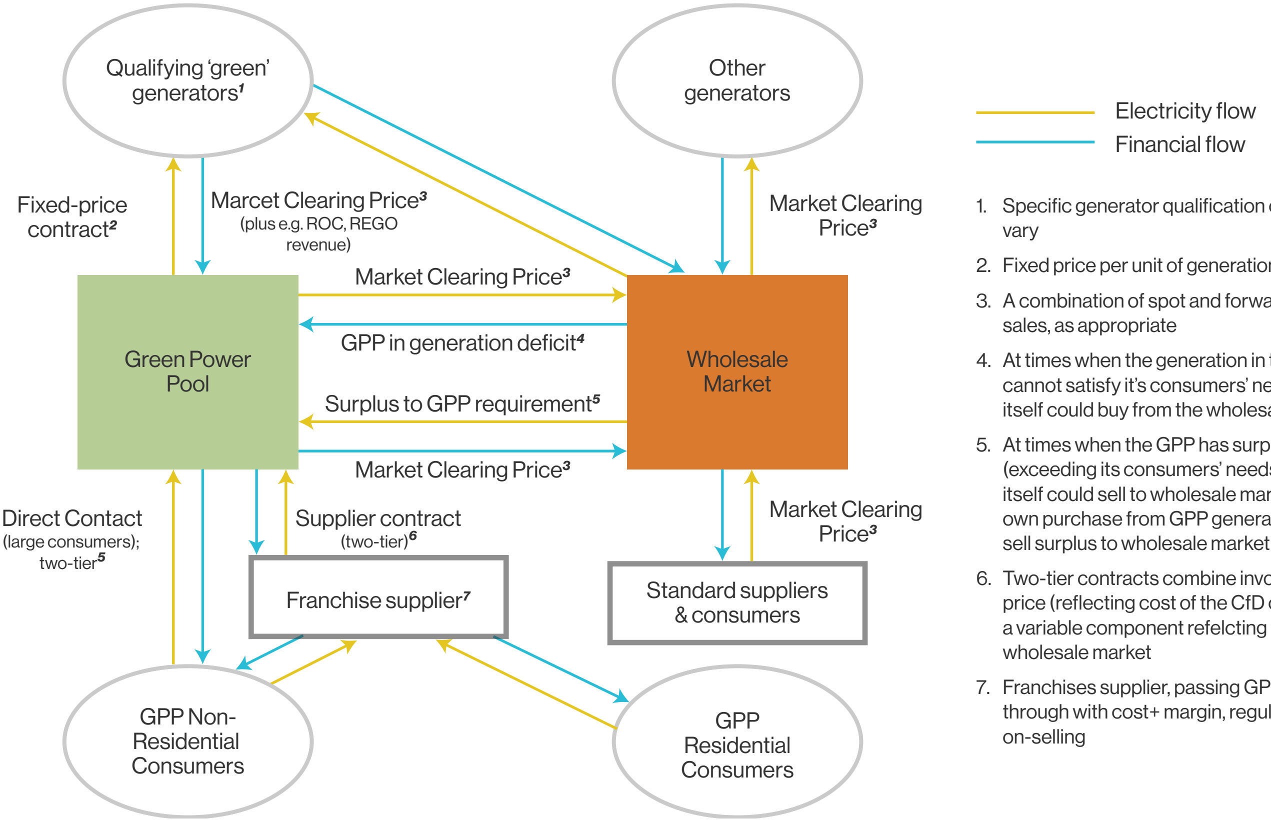
12: As detailed in (Grubb et al., 2022), p.30

BALANCING A GREEN POWER POOL

Regardless of which specific sources are brought into a Green Power Pool and over what timeframe, the generation is likely be dominated by wind and solar generation – variable sources which generate 'as available'. Efficient balancing and backup is ultimately a property of the system, not individual sources of power generation.[13] To provide reliable 'firm' power to its customers, the pool operator would buy electricity from the wholesale market when there was insufficient renewable generation and sell back to the wholesale market when the pool generates more electricity than needed by its customers. We refer to this as 'GPP-balancing'.[14]

Figure 10 summarises the overarching structure of a Green Power Pool, and its relationship to generators, the wholesale market, and consumers.

Figure 10: Basic structure of the Green Power Pool operation



1. Specific generator qualification criteria may vary
2. Fixed price per unit of generation, as per CfDs
3. A combination of spot and forward market sales, as appropriate
4. At times when the generation in the GPP cannot satisfy it's consumers' needs, the pool itself could buy from the wholesale marktet
5. At times when the GPP has surplus electricity (exceeding its consumers' needs) the pool itself could sell to wholesale market, or limit its own purchase from GPP generators who then sell surplus to wholesale market
6. Two-tier contracts combine involve a fixed unit price (reflecting cost of the CfD contracts), with a variable component refelcting trades with the wholesale market
7. Franchises supplier, passing GPP costs through with cost+ margin, regulated to prevent on-selling

Source: *(Grubb et al., 2022)*

13: For a detailed exposition, see (Grubb, 2022)

14: Note, the term 'balancing' is also used for the short-term 'balancing market' in the half-hourly market, to provide intra-day adjustments to deal with fluctuations from predicted demand and generation.

GPP PRICING AND CONTRACT STRUCTURES

There are several options for how the costs of buying additional power – and benefits from selling any 'surplus' generation – into the wholesale market, are distributed to participants in the Pool that satisfy our guiding principle #4 (i.e., that these costs should be allocated appropriately and proportionately). A somewhat simplified approach is indicated in Table 7, which ensures that consumers pay some additional charge when the pool generation is itself insufficient to meet demand – paying the marginal generation cost of purchases from the wholesale market, but only "at the margin" of their additional consumption.

A somewhat more complex and fully 'cost reflective' approach would be to introduce a two-tier pricing structure for GPP consumers. Under the first tier, GPP consumers could pay an 'assured price' for the electricity they consume from Pool generators. This price would reflect the output-weighted average strike price (£/MWh) of the capacity generating in any given period. We use the term 'assured price' (rather than fixed) because it reflects the contracted costs both of real-time generation (with relatively limited variation), and an evolving mix of generators over a longer time horizon. Indeed, whilst individual generator costs are fixed (in real terms) by the strike price, the average portfolio cost declines as the newer, cheaper renewable generators come online, as shown in Figure 9.

The second tier would reflect the costs (and benefits) of GPP-balancing activities, in terms of the cost balancing purchases from, or the sale of surplus GPP generation into, the wholesale market.[15] Such 'two-tier' contracts would help to meet the fifth principle indicated, of enhancing consumer engagement – particularly if GPP contracts were accompanied by smart meters to ensure transparency and incentives around the real-time variation in electricity costs particularly at extremes. Over time, this may increasingly include times when renewables generation approaches total national demand, to yield cheap electricity for industrial and hydrogen production, and/or charging (other) storage.

Table 7: Physical and consumer cost states Green Power Pool – Simplified consumer cost model

GPP State	Physical flows and payments with wholesale market	Consumer costs (simplified model)
Pool generation is **surplus** to Pool demand	Pool/generators sell surplus power to wholesale market	Pool consumers pay the 'assured price' for all their electricity consumption
Pool generation is **insufficient** to meet Pool demand	Pool buys additional power from the wholesale market to meet demand	Additional costs passed through to pool consumers, applied to demand exceeding their 'proportionate' share of Pool supply, as either a changing unit price as the volume of purchase required by the pool grows, or "two-tier" pricing, i.e., with the proportionate power at the assured price, additional power charged at the wholesale market price (if suppliers have capacity for such contracts)

Source: *(Grubb et al., 2022)*

15: This requires identifying the proportionate consumption consumers would pay at the assured price. The remainder would then reflect the cost and benefits of GPP-balancing actions. In economic terms this is preferable so that consumers see the real marginal cost and benefits of increasing or decreasing consumption at any given time. It provides incentives to – for example – engage in demand-side response or utilise local storage (including for example, choosing when to charge and potentially discharge EVs, or when best to operate industrial facilities). The place of consumers here could of course be taken by 'franchised' suppliers, who would be best placed to judge the extent to which such a two-tier pricing structure could be practically and meaningfully passed on to different types of consumers (through 'indirect' contracts). To make sure the costs (and benefits) of participating in the GPP are fairly passed through to the end consumer, such suppliers would have to be closely regulated. For further details see (Grubb et al., 2022), section 5.

EXPANDING GREEN POWER POOLS

A green power pool derived purely from current CfDs and targeted to a few priority 'most-in-need' groups has obvious limitations as a long-term solution for the large expansion of renewables envisaged and in separating the average price of electricity from the marginal cost of gas-based generation for an increasing proportion of consumers (principle #2).

One option would be move other existing renewable (and potentially other low marginal cost generators) onto long-term contracts. The volume of renewables would then easily match the present electricity demand of at least two additional consumer groups, who could be natural customers for renewable electricity. These could include business, public, and private consumers who are already signed up to 'green tariffs'; [16] and consumers who are contributing to reducing fossil fuel dependence through, for example, industrial or commercial electrification, or the use of electric vehicles and heat pumps.

Current green tariffs vary in their exact definition, but they are often supported by guarantees of origin – 'Renewable Energy Guarantees of Origin' (REGOs) in the UK – certificates issued for every unit of renewable generation produced, which may then be sold. Suppliers of green tariffs can purchase REGOs on the open market in sufficient numbers to cover their supply under such tariffs, with such supply divorced from the renewable generation against which they were originally issued. The actual electricity underpinning these green tariffs may have been purchased from the wholesale market and be generated by any technology – renewable or otherwise.

Customers who signed up to receive what they believed to be clean power through green tariffs – many of whom paid a premium to do so – would be a natural additional group for early access to a GPP. The second group indicated – consumers who are moving away from fossil fuel dependence by electrifying their transport and/or heating – are other obvious candidates.[17]

As many firms in the cement and chemicals sectors in particular already actively procure electricity through 'green tariffs', a reliable supply of renewable electricity was seen as an essential feature of ongoing decarbonisation efforts, with a direct supply of renewable electricity providing a greater advantage in terms of both price and corporate messaging over the use of green tariffs backed by REGOs. A supply of renewable electricity to deliver decarbonisation may also help to maintain competitiveness particularly with Europe with the introduction of a CBAM, and potentially competitive advantages.

However, actions to draw upon the wholesale market at times when the GPP is in deficit may pose difficulties for firms that wish to maintain a commitment to 100% use of renewable electricity, and which have limited ability to regularly flex demand in response to marginal price signals – particularly in the chemicals sector. The extent to which these issues manifest would depend on the specific design of the Pool and associated contractual structures.

Green Power Pools do not necessarily have to be confined to renewables backed by government CfD contracts. The basic idea of the GPP as outlined above could be extended to aggregate power from non-CfD renewables – in effect, with a sophisticated exchange – and sell on to consumers, thereby gaining the benefits of aggregating dispersed renewables, but without direct government underwriting implicit in the CfD-backed pool. This indeed may be more attractive for some other industrial sectors because it would give more flexibility in contract design according to the needs of diverse industrial activities for example across the chemicals sector.

Drawing on the principles of a government-backed CfD-based pool, government and the institutions involved in overseeing the UK electricity market (e.g., National Grid, the Future System Operator, and Ofgem) should also therefore actively engage these and other sectors to explore whether and how regulatory developments could facilitate a private sector green-power-pool structure.

Power Purchase Agreements (PPAs)

For expanded access over time, it becomes important to think beyond a targeted Green Power Pool based on government-backed CfD contracts, towards different but complementary approaches.

The existing market of private sector Power Purchase Agreements (PPAs) generally comprises of individual, long-term bilateral contracts between generators and business or suppliers that directly purchase the electricity they generate.

There is a vibrant and expanding market for PPAs, with growing demand from companies keen to procure zero carbon power, including energy intensive industries desperate to find ways to escape the trappings of the wholesale electricity market.

A rapidly growing and evolving PPA market could in principle help to bring huge levels of private investment into new renewables without government involvement. However, a non-trivial proportion of renewable PPAs have not stimulated 'additionality' in renewables deployment and draw on renewable capacity constructed with government support – either directly through bilateral contracts between renewable generators and off-takers, or indirectly through the purchase of REGOs (discussed above). The cost of such PPAs have also risen sharply, however given the profitability of the wholesale market, buyers are reportedly finding it difficult to persuade new renewable capacity to take part in PPAs.

16: In the UK in 2021, roughly 9 million households were on green tariffs – about a third of all households. If their household consumption approximates the national average, households on green tariffs account for around 36TWh/yr. (BEIS, 2021c)

17: Currently, the scale of demand for electric vehicles and heat pumps is modest, but there are two obvious reasons why they should also be part of an expanded GPP: (1) they contribute to reducing emissions and dependence on fossil fuels, and (2) they bring a degree of valuable flexibility to complement the variable output of renewables in a GPP. For these consumers in particular, two-tier tariffs would provide valuable incentives.

PPA contract lengths and forms vary considerably, with some linked to wholesale prices or with adjustment clauses. The administrative costs of negotiating such contracts – particularly given the potential complexity of balancing provisions – have been considerable, though there has been significant progress in standardising some of the legal dimensions.[18] These can significantly reduce transaction costs and legal risks associated with PPAs but, almost inevitably, do little to standardise actual contractual terms around time horizons and treatment of balancing, let alone price. This unavoidably means that the finance associated with PPA contracts reflects some element of counterparty risks – i.e., the risk faced by either party should the other fail to deliver for whatever reason – along with potentially complex and somewhat expensive 'firming' provisions.

In principle there are two approaches to reduce such costs. One is aggregation: for intermediaries to try and aggregate different PPA buyers and and/or generators into a larger pool. The other would be if it were possible to try and standardise key terms of such contracts sufficiently to enable them to be tradeable. On the one hand, this would help with aggregation by increasing contract familiarity and therefore ease of pooling buyers/generators. It would also substantially reduce the risks involved in signing such a PPA, since if either the generator or the buyer failed (a risk revealed dramatically by the scale of supply company failures in the energy crisis), the contract would be available for other parties with a minimum of complexity.

There are of course obstacles. One is the tension in designing PPAs which match the time horizons desired by renewable investors with the timescales over which most buyers are willing to commit. The other potential obstacle to both aggregation and tradability is coordination. We have had open competitive electricity markets in Europe for over two decades, and private markets have not yet solved the problem of coordination (though, the presence of many government-backed schemes also complicates matters). The private sector can be very effective at optimising operations within a given market structure and can also "compete for markets". It is much harder for the private sector on its own to create a largely new market structure – which is what would be implied here.

The PPA market continues to develop and is making a growing contribution. In addition to underwriting risks to help accelerate the pace of large-scale renewables deployment where required, governments could explore options for working directly with business to co-design PPA contracts that could engage consumer companies – suppliers and businesses seeking to procure renewables on fixed prices over reasonable timescales.

It is unclear whether direct government efforts to coordinate or standardise PPA contracts more generally would help or not – but at the very least, the example of, and lessons from, building demand-side contracts to a publicly-backed 'green power pool' should offer useful examples and lessons. In the long run, the result could be a structure of contracts which are genuinely tradeable. In essence, they might take the form of 'electricity bonds' – a tradeable contract which promises to deliver a fixed price of electricity over a fixed time horizon.

18: As established in Europe through the European Federation of Energy Traders, which in 2019 launched a standardised renewable PPA contract. (EFET, 2019)