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The energy crisis engulfing Europe is a crisis of both gas and electricity markets, with huge cost impacts on consumers across all European countries. In Britain, half of typical household energy expenditure arises from electricity. This paper examines how the cost of gas-powered generation feeds through to electricity bills, on the principle of marginal cost pricing, setting the price for most of the time though it accounts for only about 40% of GB generation. Combined with the steep decline in wind and solar costs over the past decade, this has resulted in an unprecedented degree of 'cost inversion' in the electricity system. We offer estimates of the increase of revenues across the wholesale market, and outline five principles for reform for addressing the combined challenges of energy costs and accelerating low-

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Economies across Europe face unprecedented energy-economic challenges, with cost-of-living/inflation impacts which hold the prospect of turning into major social and political crises. In the UK, without any intervention, total household consumer expenditure on energy is set to rise from £64bn in 2021 to around £200bn – an *increase* exceeding defense and education expenditures combined. This is dominated by expenditure on electricity and gas, split (on average) roughly equally between the two. Energy costs are a prime factor driving general inflation in the UK to at least 10%, whilst poor households face cost-of-living increases of almost 20%.

The proximate causes – a Covid-recovery surge of global demand relative to supply in global gas markets, followed by the Russian invasion of Ukraine - are well known. In addition, the *for funding investment in long-lived assets which cost little to run*. As demonstrated empirically in our first working paper (#1),[2] fossil fuels set the electricity price for most of the time, at levels which are now much higher than the energy cost of at least half the system (recent renewables and existing nuclear) – so the price of electricity is way above the average cost of generating it. The market design reflects largely static theories of 'optimal equilibrium' which neglect distribution, entry barriers, risk allocation and the evolving dynamics of the system.

This dependence on fossil fuels to set the wholesale price in practice introduces high volatility and uncertainty in the price that non-fossil investors would receive in the market, making it an extremely inefficient basis for funding large-scale renewables. Renewables investment in

3. *Some consumer groups are much more vulnerable than others and the price increases in train have untenable distributional consequences.* Economic ideas of 'aggregate static efficiency' do not capture essential distributional dimensions of welfare and the realities of different circumstances. Moreover, whilst high gas prices are a global phenomenon, electricity price impacts across regions vary radically according to market design:
   - For industry, high wholesale prices across Europe risk making it impossible for electro-intensive, trade-exposed sectors to compete internationally. In the UK, proposals for industry support – effectively, government underwriting to a fund to spread bills over many years – have been rejected, and would not address the fundamental problem.
   - For households, without intervention, average UK domestic consumer bills are set to almost quadruple from pre-crisis levels. Whilst energy costs are a major factor in driving general inflation at around 10%, the poor face an almost 20% increase in their basic living costs, not remotely matched by increased welfare payments. For 'fuel poor' households, even reducing the electricity price to the average generation cost would bring limited help, as

Overall, a strong role for public policy is inescapable given the 'perfect storm' facing our energy system. There is little evidence that public ownership is a better long-term solution, but it risks becoming the default if these problems are not tackled. The key is to recognize that whilst the emerging, non-fossil electricity system is both cleaner and cheaper, it is also fundamentally different. Exploiting the opportunities to escape the energy-climate crises will require fresh thinking: to combine asset finance with efficient dynamic operation of what is already becoming, by default a dual electricity system. Researchers have already identified multiple elements for achieving this, with at least three structural options for separating marginal from average costs in the system; our next report explores, in particular, options to harness 'dual market' approaches.

"Electricity is Different"

- Walt Patterson (2007), in *Keeping the Lights On* (Chapter, *Electric Challenge*)

"No method of economic analysis can determine, scientifically, what to do about the gap between average and marginal cost"

- J.R.Nelson (1963), in *The American Economic Review*

My title is plural, because we face interrelated crises. This paper outlines ways in which dealing with the energy crisis is intertwined with decarbonization, and why successfully navigating both requires tackling a third: a crisis of economic thinking and arrangements that are now inadequate for an energy sector in transition. The focus is upon electricity in Europe – the UK, European Union and related countries – though many of the themes are relevant to many countries, particularly those with competitive electricity markets.

The first crisis looms particularly for every energy consumer in Europe (which is all of us, and many industries), impacting the cost of procuring energy and the price charged to consumers. In substantially exceeds combined expenditure on defense and education and makes energy the dominant driver of inflation.[4]

The huge surge echoes how the fossil fuel crisis is affecting energy bills across much of Europe and beyond without policy intervention. Its devastating impact, particularly on low-income households, has led to a mix of policy responses. In the UK, competing promises by candidates for the Conservative Party leadership to remove VAT and/or 'green levies' have been politically expedient but would slice only a few percent - respectively only the top sliver (VAT) or bottom sliver (green levies) - of bills as indicated in Chart 1,[5] and 'removal' may mean shifting those costs to general taxation or national debt. Hence these are more or less irrelevant - and potentially, even counterproductive - to mastering the underlying crisis driven by wholesale energy prices (the grey). In the UK, the more heavy-duty sticking plaster has comprised lump sum payments to households from the Treasury, touched upon in section 3.2.

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Figure 1: Typical UK household energy bills 2015-2023 Q1 based on price cap, and projections for rest of 2023

markets. The fact that low carbon electricity is now *much* cheaper than fossil-fuel based energy (see next section, and more generally, IPCC (2022)) signals a clear potential to do so.

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One common myth is that huge profits simply reflect monopolies dominating in uncompetitive markets. In electricity, if anything, almost the reverse is true in the short run. Increases in electricity prices have been particularly dramatic in competitive electricity markets, because they respond rapidly and with few constraints to the principle of marginal cost pricing (Box 1).

Underlying the economic theory of marginal cost pricing (MCP) is an idea of equilibrium – a long-run stable situation, with pricing providing market incentives to move towards such a state, as outlined in Box 1. MCP is indeed a very important incentive to operate existing systems efficiently. It ensures that the cheapest-to-operate plants are used as much as possible, with more expensive ones only called on when needed. The theory is that such pricing is efficient, including the lead incentive to construct new, low cost plants, which can use their operating profits to recoup the cost-of-capital and which (it is assumed) are much more expensive to build than fossil fuel plants.

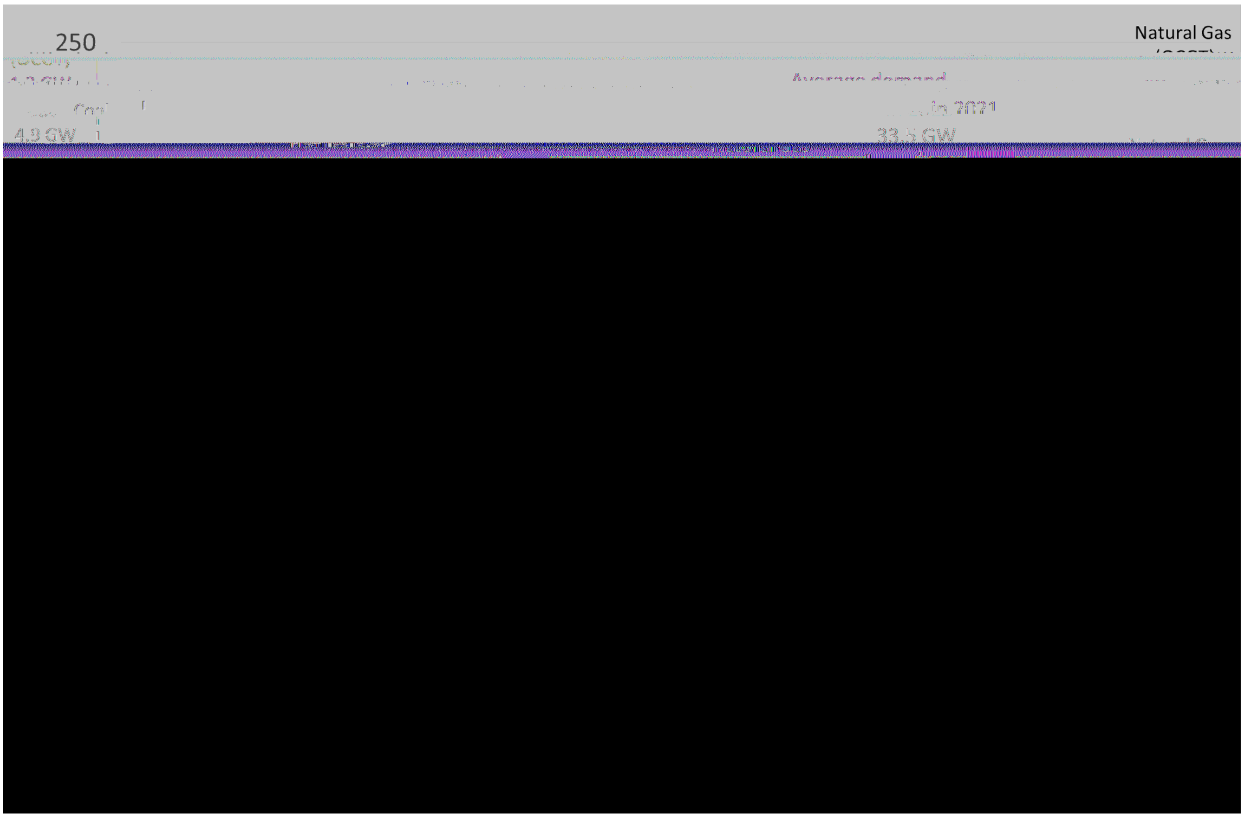

Figure 2: Merit-order of electricity generation in Great Britain in mid-2022.

Notes: Based on approximate short-run marginal costs in mid-2022. Capacity values given are based on average availability and capacity factors of each technology. Costs are the sum of variable O&M, fuel, and carbon costs (as applicable). Installed capacity per technology from DUKES 5.11, costs of fuels from DUKES 3.2.1, O&M costs from BEIS, carbon cost assumed at 80 £/tCO2, Capacity factors from DUKES 6.3 and availability factors for thermal generation assumed at 0.9.[6]

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Figure 2, which shows the GB[7] generating stock and operating costs, stacked up in order as at mid-2022, illustrates the practical implication. Expressed in term of power, the average annual demand of 33.5 GW far exceeds the average available output of low-carbon electricity sources, so gas plants are essential to meet demand for almost all the year – and, consequently, set the wholesale price, then at around £150/MWh. In theory, the operating profits for all the non-fossil plants, to the left in the Figure, are intended to cover their higher investment cost (Box 1).

Despite many positive dimensions, in terms of the wider and longer-term economics of the system however, the textbook idea of marginal cost pricing poorly captures implications of the instability of

Table 1: Percentage of time for which electricity prices were set by different sources in 9 major European countries (2019)

Germany (DE)	91%	7%	2%
Denmark (DK)	25%	13%	62%
Spain (ES)	89%	6%	5%

In normal conditions and earlier times, particularly when fossil fuels were cheap, the price-setting role of fossil fuels was hardly problematic. Renewables were a moderate part of generation in most countries, and along with nuclear, mainly state-backed.[12] The life-cycle costs of renewables were relatively high, and many were supported outside the wholesale market, though large installations sold power into it. Marginal-cost-on-all pricing, combined with such renewable supports, may have been a sufficient approach in this previous era. The time-and-place signals derived from short-run wholesale markets, particularly alongside locational or zonal pricing, provide some real incentives to operate the system efficiently - even more so with more variable inputs from renewables. In regions like Europe with an adequate carbon price, it also minimizes emissions from existing plants.

Marginal cost pricing in such a system may still be (some) economists' dream, but it has turned into a politician's – or even businessman's – nightmare: depending on the vagaries of fossil fuel prices and risk perceptions, it makes capital-intensive investment expensive and risky in case the future price collapses, whilst at other times creates sky-high prices and windfall profits.

Now, renewables are a rapidly rising part of many generating systems across Europe and elsewhere. Resources are ubiquitous and costs have plummeted. In the UK, the declining cost and the new system for contracting renewables led to rapid growth in the amount of renewables, and an even more dramatic decline in costs, particularly for offshore wind. Over successive rounds, the contracted cost of new offshore wind capacity fell (in 2021 currency), from about £170/MWh, to under £50/MWh, whilst the capacity and generation has grown exponentially (Figure 5).

: Offshore wind Contracts for Difference (CfD) Strike Prices, and historic and projected annual generation,

Source: Authors, with data from the Low Carbon Contracts Company (LCCC).

Notes: 'Allocated Contracts' were the prompt start contracts directly allocated by government in 2014, while subsequent rounds were subject to competitive auctions. Years in parentheses are years the allocation/auction rounds took place; the graph places the corresponding symbols in the year the projects generate at the contracted volumes (typically, 3-5 years after contract for large offshore). Round 4 generation assumes three awarded contracts begin generating in 2026 (Inch Cape P1, EA3 P1, Moray West) and two begin in 2027 (Norfolk Boreas, Hornsea P3), with average capacity factors of 40%.

This has opened up a huge new energy resource. By 2021, wind and solar already generated about a quarter of the UK's electricity, divided between solar (12.1 TWh), onshore wind (29.2 TWh), and offshore wind (35.5 TWh); about half the offshore wind in that year was under CfD contracts. These volumes compare with current total electricity generation of around 320TWh/yr. Between 2022 and 2027, CfDs already awarded to new offshore wind capacity are expected to add an additional 59 TWh per year, at an average contracted generating cost of under £50/MWh.

The result is a spectacular cost inversion. A decade ago renewables at scale, whilst cheap to run, were overall more expensive and required direct subsidy. But even *before* the energy crisis, wind and solar were competitive with fossil fuel generation, given appropriate financing structures (section 3.1). In the m[((se) (ru) -0.2ruhnhenh m t m(y 0.2 (icri) -0.2 (si) -0.2 (s,) 0.2 ( ) 0.2 (w) -0.2 ()-0.2 (

Second, the challenge of the energy transition extends way beyond the specifics of fossil fuels vs renewables investment. The ‘new electricity system’ is different in multiple ways beyond the finance-capital and environmental structures. As summarized in Table 2, the differences span other aspects of generation (notably, ‘on demand’ availability, vs renewables variability ‘as available’), the importance of storage, location, the role of demand and consumers, and the potential scale of the transmission system – as well as other, less prominent dimensions of system operation.

The veteran energy analyst Walt Patterson coined the term *infrastructure electricity* to underline

Table 2: The many dimensions of difference between fossil fuel and emerging electricity systems

Generation – output and economics	Baseload + flexible	Variable, inflexible
	Costs dominated by fuel & other operating costs	Capital intensive – costs dominated by capital
	At the margin, price-setting Differentiated prices reflecting variable costs	In wholesale markets, renewables price taker

Other services	System inertia, frequency control etc. largely inbuilt in the rotating mass of large power stations	System inertia, frequency control etc. – need for separate service markets / incentives to balance supply and demand capabilities

The important implication is that we cannot usefully think of renewables and decarbonization as simply involving a cleaner version of the current system, which is more or less expensive. The emerging system is fundamentally different.

The need for fresh thinking about electricity markets has in fact been recognized by analysts for many years.[14] With a rapidly rising share of renewables, falling costs of installation and accelerated change in related technologies and business models, it is overdue. In the UK, reforms in 2012-2014 were a major step forward in terms of accelerating progress in renewables themselves, but renewable energy will soon be at a scale for which the system was never designed. The energy crisis gives impetus towards a new phase of reform.

For economists, the compelling logic of marginal-cost-on-all pricing needs to be set against the economic "general theory of the second best".[15] As taught in all economic schools (but often then forgotten), this demonstrates that if an economic system already differs from the theoretical ideal of a perfect, optimizing, welfare-maximizing market – as is inevitable in reality - it cannot be automatically assumed that the normal economic policy prescriptions will necessarily improve things. So, for example, if markets are for some reason inherently short-term or riskhort back of strong government support, at initially high cost. Adequate access to the system may also hinge upon transmission, which new entrants cannot control, so coordination is required. If incumbent companies have market power, they may not only seek ways to raise the marginal cost of the system, so as to secure higher revenues, but resist more fundamental changes.

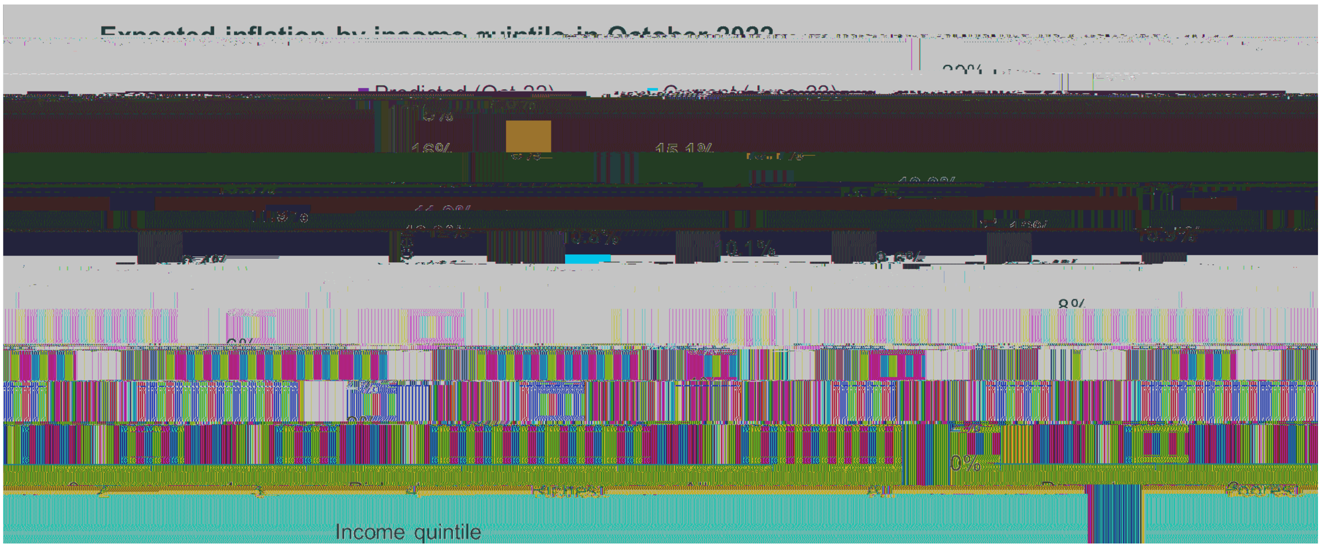
As noted in a classic economic textbook, regarding the relationship between government and industry and the British approach to competition policy, in the light of 'second best' realities, "a pragmatic approach has much to recommend it".[16] An effective, pragmatic approach to reforming electricity markets needs to incorporate the realities outlined in the next section.

Energy is a long-term business, nested increasingly in short-term financial drivers. Historically, most electricity infrastructure – the big coal, hydro and nuclear stations, and transmission – were built mostly by state-owned and directed companies.[17] Privatization and the establishment of short-term electricity markets (hereafter, 'spot markets' for simplicity) mostly drew upon these investments, plus gas plants which are relatively cheap and quick to build (most of which, indeed,

Such government involvement does carry its own risks, but market reforms should take great care before dispensing with the benefits of long-term fixed-price contracts for capital investment. Particularly when they now yield clean electricity at a fraction of the now-crippling cost of wholesale electricity.

The gravity of the energy crisis, in terms of its impact on bills paid by many millions of households, is starkly clear from Figure 1, which as noted, reflects that at the time of writing, the typical UK household bill is projected to exceed well over £4000/yr. next year (divided roughly equally between the impact on gas for heating, and electricity prices). This will take many millions of households well

(a) Distribution of expected inflation, by income quintile (Source: Johnson *et al.*, 2022)



(b) Distribution of expected household energy bills after £400 rebate, compared to 2019-20 levels, as % of expenditure by income decile. (Source: Brewer *et al.*, 2022)

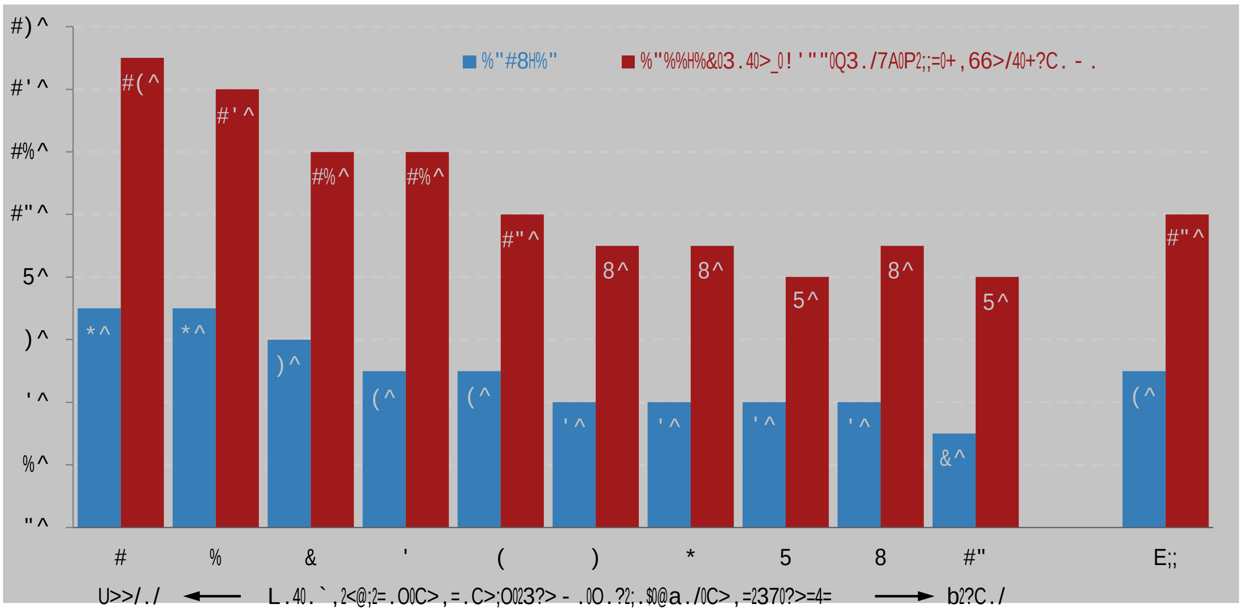


Figure 6: Distributional impact of the energy crisis on UK households

Obviously stronger energy efficiency measures could help to ameliorate energy bills, particularly in relation to heating, but beyond a few modest ‘quick wins’, for example in terms of boiler settings, achieving scale takes time. In the UK, the pace of investments to improve household energy efficiency largely collapsed after policy changes in 2012. [23] The scale of improvements within the scope of principles declared by the present government is limited, and anyway would need to be sustained over extended periods.

b) Relief and redistribution

The second option is crude, but conceptually simply: the Treasury can redistribute money. This has been the principal response to date. At the time of going to press (late August 2022), a mostly

Our estimates are gross revenues; the overall cost base including gas has also risen of course. About 40% of GB electricity generation in 2021 was from gas generators, and the price rise reflects the impact of their cost increase, 'at the margin'. Some of the more efficient gas generators will have made significant gains (their costs rose less than those of the marginal, older and less efficient generators that often set the price), but – excepting those on long-term fixed price contracts (FiTs and CfDs) - most of the balance of increased revenue accrued to non-fossil generators whose costs hardly changed.

The UK government already introduced a "windfall tax" on oil and gas producers, and hinted it might consider doing so for electricity, but then backed away from this. Several factors (including scale and feasibility) made it more attractive in oil and gas, including, there are precedents, and a pre-existing ring-fenced tax structure gave transparency and could be utilized; even so, the tax was only prospective, for the next 3 years after announcement – not imposed retrospectively. The contractual structures and tracing in electricity are (even) more complex due in part to the half-hourly settling of electricity markets and wide diversity of contracts and players, including small players. The complexities would be magnified even more should the government contemplate anything retrospective due to multiple bankruptcies of many small supply companies, which could not afford to buy the electricity they had already promised to sell to customers.

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- Economies-of-scale from larger turbines and more extensively developed supply chains
- Declining finance costs as the finance sector became more familiar with the technology and its

Figure 7: Distribution of electricity demand between different sectors

Source: Digest of UK Energy Statistics (2022), Chapter 5 (Figure 5.2):
https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-

[Energy Systems Catapult's] work with consumers highlights the current challenges that many consumers face in getting what they need from energy services, and the potential for substantial improvement. Consumers currently face undifferentiated offerings based on supply of electricity and pass through of costs (including levies, network charges, VAT), with few suppliers offering rewards for flexibility through time-varying tariffs or service-based packages.

Consumer satisfaction in the energy sector is relatively low compared to other sectors …"

The ESC report goes on to note that much future electricity demand growth will come from sources that are intrinsically flexible (which applies to electrification of industry, as well as consumer uses like EVs and heat pumps, which bring some built-in storage capacity). This is potentially very valuable for creating an efficient system with a high share of renewables, with one estimate that such demand-side flexibility would save around £7bn/yr. *(OVO Energy and Imperial College London, 2018),* along with significant additional savings from reducing the need for grid reinforcement in distribution *(Energy Technologies Institute, 2019).*

Consequently, the report concludes that *"Major innovation in new demand-side business models, exploiting data and digitalization, could deliver win-win outcomes for the power system and all consumers",* but that *"Attractive consumer offerings, however, will be key to unlocking flexibility…"*

In theory, since there is substantial value in flexibility, the private sector could offer more sophisticated contracts to deliver this. Some do, but as noted, the offerings remain very limited. Since large swings of electricity demand have always imposed significant costs on the system (and by 2020 the UK already had 25% of its electricity from variable renewables), the first question is – as with the absence of adequate private long-term contracts - why have they not emerged at scale?

Without going into detail, there are various possible reasons but they all likely combine both demand and supply factors. First, since consumer-based flexibility is complex there are transaction costs if people have to actively respond to price changes. Automation (e.g., programming for pre-set responses of smart appliances) offers an alternative but may involve some technological capacity or investment in control systems – as well as overcoming human inertia for people used to plain vanilla electricity at a given price. Regulatory protection could be important, similar to that around complex financial products, to provide assurance.

The energy crisis is forcing everyone to think more about energy consumers. The chance to engage them better in solutions which could also help to build a cleaner, cheaper and more secure energy future should not be missed.

This paper has argued that successfully navigating the combined crises of energy and climate change requires understanding the unique characteristics of the electricity system, and the markets for electricity that we have created. The foundation of an effective response should be recognition that, in electricity at least, the crisis is a structural one. European countries, including the UK, already get more than half their electricity from non-fossil sources, and that proportion is set to grow rapidly, in this decade and beyond. Yet the core electricity market remains based around fossil fuels.

In electricity, the crisis has therefore exposed, not created, the fact that overall electricity prices cannot sensibly continue to be set on the basis of short-run-marginal-cost-on-all pricing, in which gas sets the price in wholly disproportionate ways. The fact that new renewables in particular cost a small fraction of the electricity wholesale price underlines the potential opportunity, if reforms can effectively support and accelerate the transition already under way. Against that backdrop, the paper has identified at least four key challenges and associated principles, of which the first two are closely intertwined:

- The transition is from a commodity-based towards an asset-based system, with strong implications for appropriate types of markets and finance; more specifically, short-run commodity-based pricing (an energy-only market) is an extremely inefficient way to finance assets that are capital intensive but very cheap to run.
- Distributional impacts – between producers and consumers, and amongst different consumer groups - matter hugely; governments cannot ignore the large gap between marginal and average costs in the system, and need to consider options for targeting help for the most vulnerable.

In principle, the energy cost burden can be alleviated either through relief / redistribution, or through reform; and each comes with the same philosophical and practical choice, whether to help all consumers equally, or to prioritize support for the most vulnerable. Relief and redistribution, as in the current emergency packages, is the only credible option for this winter, but policy needs urgently to engage options which involve reform.

Part of the answer is already at hand. Across Europe, the majority of renewable generation has been based upon fixed price contracts in some form. In the UK and several other countries, the Contracts-for-Difference have been very effective for renewables and will pay back to suppliers most of what are now surplus revenues, helping to dampen the gap between marginal wholesale and average costs on the system. Some direct private contracts (Power Purchasing Agreements) also help address these two challenges, for the participants involved.

In the EU, several countries called for reform as the crisis developed and in July, Greece proposed a systematic way to integrate non-fossil sources into the existing wholesale market in ways to bring the electricity price down to average rather than marginal cost.[34] Other EU countries including Germany are now actively pursuing the options.[35] Such options have not yet featured in current UK political debates about responding to the energy crisis.

Structural reforms should also take account of other strategic challenges to be navigated in the electricity transition, notably:

- As the renewables / non-fossil part of the system grows further, it should increasingly bear the costs of backup and balancing (including locational dimensions) currently provided by the rest of the system;

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- Consumers – both private and business – are very diverse, their interests and options matter, and policies should aim to engage consumers much more actively in the system, giving them real options for contributing to and benefiting from the transition under way.

Few proposals address all of these challenges together. Options which could offer consumers

[See footnotes for weblinks to shorter commentaries and data relating to energy crisis]

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