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Exploring market change in the GB electricity system: the potential impact of Locational Marginal Pricing - stakeholder insight report

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The authors have worked together on this review of evidence and perspectives on what Locational Marginal Pricing would mean for the British electricity sector. The project has two main outputs – a main report and this record of findings from stakeholder engagement. An Executive Summary from the main report is also available as a standalone document.

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The documents are archived at the following links:

Main Report & Standalone Executive Summary: <https://doi.org/10.17868/strath.00083869>

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1 Introduction

There is growing interest in exploring the potential to move the GB wholesale electricity energy market to a more centralised arrangement using Locational Marginal Pricing (LMP). An LMP market could bring efficiency benefits to the GB system. However, its introduction to GB would present a number of practical challenges and could have significant implications at a time when major change is needed to deliver net zero. Careful consideration needs to be given to the interaction between LMPs and existing structures in the system and between LMPs and the wider package of market and system change before a final decision is reached.

The University of Strathclyde has been engaged in a short project to assess the implications of introducing LMP in Britain.

During the project a number of semi-structured interviews were conducted with a range of electricity sector experts seeking their views on aspects of LMP and its potential application in GB. The intention was both to gain a better understanding of the operation of existing LMP markets and to gather a balanced reflection of the arguments being put forward both for and against the introduction of LMP in GB. For an international perspective we held discussions with domain experts from the USA to discuss existing implementations of LMP and from Australia to discuss their own consultation on market reform and debate around transitioning from a zonal approach to a nodal LMP market. In addition, we spoke to multiple experts active in the GB energy policy and electricity market reform debate. This wide range of stakeholders included representatives with current or previous experience spanning market design and regulation, investment in generation and storage, system operation, research, consultancy and government.

The main findings from the project are set out in an accompanying report on “Exploring market change in the GB electricity system: the potential impact of Locational Marginal Pricing” which summarises our own reading and assessment along with key insights from the interviews. This stakeholder engagement report seeks to provide a summary of the key arguments that were raised via the discussions. Interviews were conducted under ‘Chatham House rules’ such that all selected quotes and inputs outlined in the following summary report are not attributed to individuals but instead reflect the range of views expressed by the various experts under each topic area.

As noted in the accompanying main report, the broad context is the target set by the UK Government to have a decarbonised power system by 2035, subject to achieving an adequate level of security of supply.

The collection of experts that we sought insight from had a broad range of views on LMP and its potential role in the future GB system. The international experts with direct experience of operational LMP systems were broadly supportive of it and believe it to have provided good outcomes in terms of efficient system dispatch while also giving warnings about some of the more difficult facets, particularly around experience with elements like financial transmission rights (FTRs). Experts from GB were split with some strong advocates of LMP citing a growing disconnect between the physics of the system and the market dispatch, while others expressed strong opposition to its implementation based on a range of perceived implementation challenges in the GB context and potential adverse impacts with regard to risk and investment in renewable generation in particular. Others were open to the concept but not convinced that the case for implementation has been clearly demonstrated.

The full range of viewpoints are categorised into different topic areas in the following sections using, as far as possible, the insights as directly expressed by the interviewees with additional narrative kept to a minimum and given to provide context only. Stakeholder remarks are given in italics while additional context such as the questions posed to them, where required, are given in square brackets or as introductory narrative.

The topic areas presented are:

1. The ability of LMP to influence efficient dispatch: how efficient would the dispatch be, what impact would it have on the cost of network constraints, what signals would be given to provider of 'flexibility' and what issues need to be considered in respect of exposure of the demand side to LMP.
2. The ability of LMP to influence investment and siting decisions, and what impact that might have on cost of capital.
3. The relationship between LMP and transmission network investment.
4. How LMP markets operate in practice, how market actors interact with them and how financial transmission rights work.
5. Interactions between LMP and other market arrangements such as contracts for difference for renewables.
6. Differences between zonal and nodal LMP-based markets.
7. What alternatives there might be to LMP that would help achieve the 2035 target.
8. What the key challenges are in market reform.

2 The ability of LMP to influence efficient dispatch of the system

2.1 Efficient dispatch

There was a widespread acceptance among the interviewed stakeholders that LMP is an effective means towards efficient operation of an existing power system with the only dissenting points raised in relation to the scale of efficiency gains that could be delivered in a future GB system dominated by renewables:

“LMP is a very efficient way of operating the existing assets that are already on the system.”

“There seems to be this fundamental problem that the market arrangements are getting increasingly divorced from the actual underlying physics of the of the system. There are quite a lot of behaviours starting to emerge that aren't helpful from a whole system perspective. For example, rising constraint costs and things like the interconnectors flowing in ways that that are unhelpful from the point of view of the system depending upon where they connect to the GB system.

The principle of having prices that are aligned with the real physical balance between supply and demand at different places on the network seems to be a good idea.

LMPs give the right incentives to different resources to be dispatched efficiently. LMP is one way of doing that. Obviously, there are other ways of doing that. I tend to be favourable to trying to do as much as possible through market-based mechanisms, but there will always be a residual system operator function so I support market designs which, in principle, reduce that role.”

“If you look at examples of markets like Texas, the reason that LMP could be said to have delivered more efficient dispatch is because it's delivered lower overall fuel costs compared to a counterfactual without it. This is because it enables you to dispatch particular types of (particularly thermal) plants more efficiently, especially anything that has a known ramp rate with efficiency penalties in it.

The difficulty, of course, is we're going to be running a lot less thermal plant on the system as we get towards 2050 or even 2035 and it's difficult to see how in a nodal system you can more efficiently dispatch wind because wind is always going to be produced when the wind blows.

It could aid future plants like Hydrogen turbines but given these will be a less important part of the mix I'm less inclined to say this should be an important part of our thinking.”

2.2 Constraint costs

There was general agreement that a move to LMP would represent a transfer of risk from consumer to producer in terms of constraint costs as, in the existing GB market, costs due to curtailment of generation output in order to respect network limits that currently fall on consumers would convert to a non-dispatch risk for generators. However, a number of stakeholders sought to make the point that generators are not well placed to manage those risks and that the costs could simply end up back with the consumer via other avenues.

A number of stakeholders gave a response to the question of where the burden of risk lies for curtailment and whether costs could ultimately end up back with the consumer under LMP as well. A response was also given on the general challenge that Britain's electricity system operator, NGENSO, faces with system balancing:

“Constraint costs do fall on the consumer and would transfer to generators or local demand under LMP – the trouble is that neither of those people can do anything about constraints so it places costs against something that they can't manage.

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The locational element is really about constraints and the physics of the system... yes on the B6 boundary there are lots of constraints but this is not fixed - you can build more [network] capacity. The ESO just ignored this and didn't talk about it at all in their paper. Network is treated as some sort of law of nature which impinges on your system design."

"We'd make an estimation of how much we believe we're going to get curtailed and assume we just don't get paid for it. In the investment case, we'd have to make up that shortfall elsewhere to effectively guarantee our return. To see it as a pure cost saving, I don't think is correct because that shortfall would have to be made up to hit the returns."

"Yes [non-dispatch risk may pass back to the consumer via other means], but you have incentives to actually correct that problem in an LMP world, whereas at the moment if you're an offshore wind farm all you care about is getting the shortest possible connection to land that the ESO will allow that is as cheap as possible in terms of upfront cost and you have no interest whatsoever in whether or not that energy can actually get to anyone which is hugely problematic."

"If I was a Scottish Energy Company, or a northern English wind farm developer in an LMP world I would be trying to do a deal with industry. I would be trying to think creatively about how I could connect to the grid. I'd be battering the [door of the] ESO to connect me somewhere where there might be customers. I would be taking a more whole system view whereas at the moment the only incentive is can I get it onshore, will the ESO allow it, and I don't care what happens once the power is energised."

"A certain level of constraints is going to be efficient and a certain level of constraints dynamically managed. A Higher level of underlying constraints, if you like, more actively managed by things like hydrogen is going to lower system costs overall. I don't see how you get that in the world of national pricing."

"Yes, ultimately the wind farm is a fixed asset with all the money going into upfront capital expenditure with very little you can do to change the mode of operation going forward. It's at that point of investment, [that] is the right time to give the signal and the cost profile. Because the more uncertainty you add in, it'll simply increase the cost of capital."

"[Citing the OFTO regime] it was basically a payment for availability over 20 years and it meant that the cost of capital came down to 2% or something like that, simply because people knew what they were getting. Quite frankly, wind farms and solar farms, I think, are in the same situation. You've got that resource, it's bought and paid for. You want it as cheap as possible."

"There will come a time obviously in the future where renewables will be building in, you know, what do we do with the curtailed energy? But it feels to me that's almost a different problem. It feels to me that trying to get the renewables built up at the moment is the key thing."

"I think so many of the problems they [NGESO] think they have managing the system just require more information"

2.3 Signals to providers of flexibility

A range of views were expressed on the ability of LMP to provide useful signals to providers of flexibility.

Two stakeholder responses on the need case for locational signals and a comment on how difficult sending the correct signal could be without LMP:

“Greater digitalisation of the energy system and much better locational transparency gives you much better short-term price signals, which then ultimately build up into your long-term investment signals.”

“I think locational signals have been too weak. I think we have implicitly, deliberately taken the view that that was the right thing to do. The CfD mechanism has obviously been very successful in getting down the levelised cost of energy. But now I think we're moving into a different stage. We now need to start confronting the locational challenges and the system integration challenges. We really need to find ways of getting the mix of assets in the right places and operating in the right way. The flexible resources on the demand side need to have the right sort of signals to respond.”

“Let's say I have an electric car and I live in Cornwall or I have an electric car and I live in Scotland. The only way that you will charge those differently at the moment is if those cars are in the BM [Balancing Mechanism]. You get exactly the same signal if those cars are not in the BM so you're putting a huge burden on an energy supplier, for example, or a customer in order to get any locational value from doing something differently, depending on where you live or where you locate your business or where you locate your hydrogen electrolyser.”

“So you're going to have to have allocation rounds for hydrogen electrolyzers that tell you where to put them based on grid capacity...? How do you then dispatch them? Are they only dispatched in the BM - I mean there's just so many questions...”

A response to the question of whether a centralised market would bring efficiency gains to storage assets:

“It depends what we think of as the counterfactual – true compared with the day-ahead market as it stands – but I'm unpersuaded that we're just going to have our existing wholesale markets as our only forward-looking tool over the next couple of decades. If we don't do nodal pricing, I think there are other routes, especially around different ways of pricing congestion and thinking about the relationship between suppliers and gate closure and the need to buy certain sorts of assets to balance closer to real time. These could give a greater sense of system visibility and provide forward schedules that do not rely on a central operator.”

A response on perverse signals to flexible assets and other potential solutions:

“Yes, zonal pricing solves that for you to a degree without losing some of the features of the wholesale market. Right now, people are already starting to locate assets around network constraints because they can access the balancing market which acts as a proxy locational signal already. It begs the question of whether we really need to go all the way to nodal pricing to see the sorts of affects you want? This is key for me”

A comment on the volatility of LMP markets:

“Volatility is good and there will be more of it in future [LMP or otherwise] to provide useful signals to players to unlock flexibility. Anyone who can manage their demand should be able to get value out of that.”

A view on the potential complexity of LMP from a flexibility provider:

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"It has to be clear. I have not come out as anti or pro. I'm sceptical because no one has showed me the benefits.

If you think about my position I have [a large number of] sites at [a large number of] GSP's. It's a hell of a lot more difficult to optimise my portfolio across [a larger number of] different prices than it is across one price... we're sitting as a company going, do we like this or do we not? If we can do this better than other people, then it's good for us. But is it worth it for the amount of investment each company's going to have to do to manage this?

A bit of me likes LMP because I love optimisation and I think I might make money out of it, but for me as a flex owner the thing that drives the value of flex the most is the growth of renewables on the system and if something slows down the growth of renewables that is bad for my business and it's a very hard decision to make. This is a big change so we need to know that it makes sense".

An exchange on alternative ways of giving locational signals vs LMP:

[Couldn't you get that locational value through a supplier model where an intermediary (supplier/aggregator) strikes contracts with generation to provide complementary flexibility?]

"If you have LMP with some element of it exposed at domestic level potentially then you get that behaviour without any contracting whatsoever - that behaviour just emerges."

[On the ability of a Supplier to be able to offer locationally differentiated tariffs in a national pricing model]

"At the moment they can't offer me that unless they somehow access locational value through the BM which is now administratively complex. Or through some defraying of network charges for a local solar farm through some bilateral contracts between the supplier and the solar farm which is even more complicated."

A viewpoint from Australia on one of the potential benefits of converting to an LMP + FTR model that will need to be managed in another way if an alternative approach is implemented:

"What's happening when those constraints bind is you just can't get all of the solar generation down South. The sensible thing to do with those times would be to store that energy in some batteries or some pumped hydro, and then run in the evening to release that capacity.

But [the current market] acts as a disincentive because you have the same price across the region. Then anyone who wants to charge a battery at that time would also be paying a very high price for the privilege of charging the battery. So the lack of a locational price in those arrangements does work against the efficient use of storage as a way of addressing and moderating congestion issues. So that was one of the things that was identified as being something that's yet to be worked through in terms of this [proposed] congestion management regime and how it might work.

Whether that actually needs the full gambit of locational marginal pricing or whether it's more that we need to be able to separate into a regional model (zonal) and that might be more manageable in that if you've got a smaller number of regions, it becomes more manageable in terms of the hedging arrangements for people."

2.4 Exposure of demand to nodal prices

Some stakeholders offered opinions on the question of how much of the demand side should be exposed to a locational signal in an LMP system and the trade-offs and political difficulties associated with that:

“In the US all areas use zonal pricing for demand. There are some challenging decisions about where to draw zonal boundaries which can get political. For example, in ISO-NE there was a need to draw a zone area between an area close to NYC (highly congested) and separate it from Connecticut (less congested). The Connecticut area was expected to get lower prices. But the area close to NYC was home to some well-off people who were also more politically engaged. This made the decision political rather than purely technical.”

“In the States suppliers tend to buy at a zonal level and congestion charges are layered on top – a way of protecting consumers from the postcode lottery effect but it blunts signals. It has been taken to extremes in some places [e.g. Ontario] where the congestion charge for consumers is entirely optional.”

“If you want nodal pricing to work, you have to charge suppliers against their demand in a node at that nodal price rather some sort of average price, then give them the scope and tools to help consumers deliver additional value – and that is hard”.

“The post-code lottery argument is not really a starter for opposition to nodal pricing – locational signals themselves are good. What is more interesting is the ability of any participants to respond to them – that is key, especially for suppliers. If you limit their ability to contract with new sorts of assets because you want everything to be dispatched centrally then you haven’t got as many tools to manage your loads at a certain node.”

[Asked whether the package of market reform measures has got to add up – LMP on its own creates all sorts of problems but you've got the scope to address them if you design the package in the right way?]

“Yeah, and it will reduce some of the benefits like not fully exposing domestic households or their suppliers to LMP will reduce the efficiency, but it will make it politically more viable.”

[What's your feeling about the postcode lottery question?]

“There can't be a postcode lottery [from a political perspective]. So what you need to do is to expose Suppliers to the variations in price shape at different nodes, but not the variations in average prices. The important thing is not the average differential in prices in different parts of the country because you don't want people to move house. The important thing is the price shape.”

“The system I would like is that anyone who opts for a flat tariff for the whole year pays the same price regardless of where they live. It's only when people start going for more exotic tariffs that they're exposed to different price shapes, but not necessarily a different average price.”

3 The ability of LMP to influence investment and siting decisions

3.1 Siting and investment decisions

A number of respondents offered opinions on the general ability of LMP markets to influence investment and siting decisions. The first two respondents had intimate knowledge of US LMP markets and reflected a difference of opinion on their experience:

“I’m not convinced that LMP markets do give convincing signals to investment. There are too many other factors that affect the decision... you are not going to build a wind farm in the middle of a city... Apparently, there are some quantitative studies that support this conclusion although the literature is mixed.”

“We like to say that LMP markets provide signals to investment in generation (and transmission) but I was hard pressed to find an actual citation to a strong study that demonstrated that.”

“LMPs are good in a couple of ways. It’s not the transmission, it’s the generation location that does respond to LMPs, absolutely. The advantage is that generators follow the dispatch orders because the prices fall.”

One UK based proponent of LMP reflected broadly on its ability to influence siting decisions:

“There is controversy around whether or not LMPs effect siting decisions. There is a need for strategic planning of the network, you need some sort of collectivised strategic decision making around that. It would be wrong to present LMP as doing most of the work, that all the decision making around where to build just gets organised through the LMP price differentials. I don't subscribe to that view and I don't think that's the experience from the markets which have implemented LMP. There is quite a lot of debate in those different markets about how forward-looking and strategic they should be. LMP throws a lot of transparency into the debate around where to build network infrastructure, but I think you still need that strategic planning function.

Getting grid infrastructure put in place is also going to be a real challenge over the next 10-20 years and I think LMP and better locational price signals will play an important part in that. If you are waiting for a big network upgrade, under LMP, generation capacity would have an incentive to think about, OK, well, when does it actually make sense to get on to the system? Should I actually wait until that bit of infrastructure gets built. Building loads and loads of grid is going to be really challenging and it's going to be lumpy and difficult. And so actually there's a really important role for locational pricing to help manage that and optimise. For example, will [flexible] technologies actually be movable in a sense? Can they go in and help resolve constraints for a period of a few years and then move? I don't think you would get those sorts of incentives under the current market arrangement, whereas with better locational price signals you would start to.”

Another stakeholder reflected on whether the case for nodal pricing has shifted away from a focus on encouraging efficient siting decisions towards arguments around efficient system operation:

“I can see that you can argue that you can have efficient siting decisions if the Secretary of State in BEIS is all powerful and tells hydrogen electrolyzers, ‘you go there’ because there's offshore wind coming in there... but I cannot see how anyone can argue that you can solve the dispatch problem with anything other than something that looks like LMP.”

“I think the value is in both [LMPs ability to influence siting and operational decisions]. I think the operational decisions case is unarguable in my mind because the alternative is... local markets, where you have your national market, then you pay everyone to switch off and pay everyone to switch on again in the local market.”

“For investment, it's pretty easy to argue that LMP is the right answer there rather than all of the other things you would need to do to improve siting decisions in your hydrogen procurement, your CCS procurement, your wind procurement, your battery procurement, your flexibility procurement etc. There's obviously more argument there. I just think the operational bit is much harder for those opposed to LMP to argue that they have a credible solution. So, I'm not giving up on the investment argument. I think they're both equally important. I actually think only one of them needs to stack up in order to justify doing LMP.”

3.1.1 Investment and siting for renewables

A number of participants offered views on the potential impact of a move to LMP on the investment case and siting of new renewable developments:

“I would not be in favour [of an LMP market] if I were a Scottish generator. If I were I would be saying build me transmission, or give me all the congestion revenue in London.”

“I would be more relaxed about nodal pricing if I thought we could deploy generation without any form of constraint. Realistically there will be no onshore wind in England unless we get a new government that relaxes planning laws – even then only from 2026. Are we really saying the entire 25 GW of ScotWind is going to be forever? I'm unpersuaded on that.”

One stakeholder reflected on the experience in US markets:

[In the case of Texas] “basically all wind assets were built as part of the ‘CREZ’ process. Areas where the system operator had said we’re going to build new transmission capacity here just for wind so they were installed there not because of LMP but because there was transmission capacity and that’s where the resource was.”

“I think LMP has had some impact on choice to install smaller thermal assets and solar certainly, but for wind the resource is where the resource is and the existence of a transmission connection was the key determining factor for where they located.”

[On how wind in the US makes the investment case]

“[I don’t think] there are any particular mechanisms to protect them against volatility or uncertainty of exposure to lower nodal prices but the combination of tax credits and enough transmission capacity [so constraints don’t bite too often] make the business case.”

Another UK-based stakeholder with international investment experience focused on availability of resource, long investment timescales and comparison between the US and the UK:

“I think there is some [flexibility in location], but frankly that's a second order problem. The first order problem is the wind resource is where it is and where it's been possible to get planning. We need to mostly have decarbonised power by 2035. We've got a 10-year development time scale. So, if you change your mind today, you might [just] possibly affect a wind farm being located to come on in 2035.”

[Bottom line:] “the wind resource you're not going to move [neither are you going to move] the cities, so the network needs to get the power from the one to the other and work out ways of balancing it. You can't just take your project somewhere else, right? You just can't.”

[Question on why US experts tend to come down on the side of LMP being a good thing: they say it has generally done what it's supposed to have done. Do you agree? Is it something to do with the characteristics of the US power systems?]

"I think you've got to be pretty careful looking at factors in isolation. Planning and permitting regimes are very different in the UK compared to US. It's very difficult to build anything anywhere in the UK. It takes forever and costs a fortune. It isn't as bad in much of the US. The geography is very different with huge land areas, which is great from the where could I put things point of view, but it's a bit trickier to have a power grid that works out."

One respondent was probed in an exchange on how much generation might be built in Scotland and the ability to match projections in studies like FES [NGESO] under an LMP market:

"You might see a bit less of that, if you went to LMP – to be honest I think you might see a bit less of that if you stay with national pricing because the cost of transmission will be so eye watering that there'll be a huge backlash."

[Renewables developers say they have limited choice on location - how much wind capacity could we move further South?]

"I don't think that's true... floating offshore wind [for example] opens up whole new possibilities."

[Isn't floating offshore wind quite expensive and in ScotWind lots of floating projects won leases where there is no network capacity at all – isn't that even worse?]

"Those don't seem like particularly sensible projects, but we'll see. And let's have a market that can expose whether or not that is the case."

We can start to think a bit more creatively – the cost of floating [wind farms] are coming down a lot. We've got a lot of fixed offshore wind as well. I would say now it is clear that we can build more offshore wind than we can economically use and so that does mean that there is some choice around that location."

"We already make choices about where we build solar based on grid capacity... the grid is driving a lot of where solar is going for example."

A final stakeholder reflected widely on the difficulty renewable assets might have in responding to locational signals:

"You want to give investment signals that people will take account of when deciding to site an asset at one location or another. I would argue that, for renewables, you actually have very little choice where you can site. It is a locational resource that's available offshore or wherever it might be and actually it's determined by leasing rounds that are led arguably by government anyway and investors actually have very little choice... the locational signal is more a cost to them or a tax they just have to pass through as part of their investment."

"Ultimately it [LMP] will have the effect of encouraging, take the example of offshore renewables, to invest in places where grid capacity is readily available. But as we're seeing now in places like East Anglia, it just isn't readily available. Actually, there's a whole new blockage, but for different reasons, because locational marginal pricing doesn't take account of planning blockages and the need get grid reinforcements in these areas. So as a tool for signalling [investment location] it's, to my mind, completely meaningless."

The resource is in the North Sea or the Celtic Sea... those are the projects that are going ahead. While government is setting increasingly high targets and just saying build build build, it feels to me, what's the point of having LMP if government is taking its own decisions on where these things are going to be... while we're in a situation where we're just trying to get this strategic national investment into renewables, trying to then optimise it through locational marginal pricing, is immediately being overruled by government decisions."

To be fair, there is an economic test in that there are tenders for CfDs so there is some competition that's trying to drive value in that process. But then in driving that value, there's no reason why you couldn't put a

locational element and an additional cost in it at that stage. It feels to me this is a far better thing to do on an ex ante basis than have an ex post ongoing adjustment so personally I think giving the investment signal can be done in another way."

3.1.2 Investment and siting for demand and flexibility

A wide range of views were expressed on the ability of LMP to influence investment and siting for flexible resources including new sources of demand as well as the barriers that might inhibit the effectiveness of those signals:

"I can make batteries profitable now. How do you measure return on investment on [scaling up to manage LMP]?"

The current battery business case is based on ancillary services without any real locational signals... and this is a problem, people are saying they want to connect in areas that constrain, but you aren't going to get a connection agreement. So even if you've got LMP you need to be able to get a connection where LMP tells you and the current connection agreement regime won't allow that."

"An issue I would raise in terms of optimising capability is failure to take account of the use of flexibility resources because they're not used in planning timescales. Network is planned without taking account of flexibility resources. For example, I'm involved with a local authority that is trying to develop their own local energy system and have been told by the DNO that due to transmission constraints they can't export anything from there until the mid-2030s... if you're not given access to a market because of connection [restrictions], LMP is pointless. It is not going to give you anything because you can't connect without enough grid."

One flexibility provider considered the pros and cons of LMP for their business in the following exchange:

[The ESO argues that you're not going to get a signal to investment in electrolyzers in useful places unless you have LMP – and that you need LMP to make the risk and the cost transparent. Do you agree?]

"Yes, but in risk management you put the risks on the people who are best able to manage them. Do you have a constraint in Scotland because we haven't built the wires or we built the thing too quickly?"

[There is no real signal at present for storage to locate in Scotland over England. Isn't that a strong case for LMP to give that signal?]

"No, because it depends how long the constraint is active for."

[Some could take view that it will be active a lot because we're always going to be behind the curve with building wires.]

"Not if we slow down building the wind farms, because that's the sensible thing to do because it's more cost effective overall."

"We looked at [a new storage concept] for [a Pathfinder project] but when you did the maths of contributing to that constraint we couldn't get the power out. By 2027, we could not get that power out. You just couldn't get the maths to work and a one-hour battery doesn't help at all. You hear these people saying this stuff but they haven't done the maths."

"The constraint is such that my battery sits full and I can't get the power back out. What makes me money is cycling and volatility."

[Asked about the potential for giving signals to new hydrogen electrolysis demand.]

"You can give the signal to hydrogen but you then have to build the hydrogen infrastructure as well."

[So, to sum up your view: without huge amounts more transmission, LMP doesn't do anything even for the flexibility resources that the proponents are claiming it supports?]

"Yes, exactly. My message is to build more wires."

Another pair of respondents offered further opinions on whether LMP provides signals for siting hydrogen electrolyzers:

"I don't see what is unclear about [existing] signals at all. It is crystal clear that northern Scotland is export constrained and central London lacks power generation."

[But how does an investor monetise those signals if not through LMP?]

"A little bit beyond my expertise but it should be through demand [TNUoS]. If the current system doesn't do that just change the formula. I'm sure at the margin some stuff can move, but the power demand is driven by people, which is driven by where people live and the cities are not going to move."

"With hydrogen, where are you going to sell the hydrogen? If you crash the power price via locational signals in northern Scotland and a bunch of electrolyzers go in there. OK, they then have to transport that hydrogen to where it's needed and that that's an additional cost on top of the cheap power."

"If you don't think properly [about both systems] you are just outsourcing the challenge of transportation to another sector. It's a micro view of a macro issue in my opinion."

"...and if your bet is that hydrogen is cheap to move, well, why is the hydrogen going to be made here? Because power is going to be a lot cheaper in southern Spain or Morocco."

"There's other ways to incentivise flexibility than locational signals. I think you can have technology specific capacity markets. So, if the government wants electrolyzers or National Grid want electrolyzers, then effectively you could procure a certain amount of capacity through the capacity mechanism and it also allows for centralised planning."

"To get to net-zero, you are going to need renewables and you're also going to need flex. But I think if you introduce a mechanism that may be good for flex, but disastrous for renewables, you're never going to get to net-zero."

One stakeholder in favour of LMP offered the following views on the potential for signals to hydrogen demand:

"I think the bigger short-term impact that LMP would have on Scotland would be the amount of new sources of demand that you would build there, in particular hydrogen electrolyzers."

"If we're going to have hydrogen in the power sector for balancing it should all be in Scotland. At least originally... but at the moment the market refuses to tell it to be stuck in Scotland because we've dictated national pricing."

[If you build lots in Scotland but lots of the demand [for hydrogen] is in industrial clusters elsewhere then you need hydrogen transmission capacity – don't the costs of that need to be compared against cost of electrical transmission capacity?]

The ability of LMP to influence investment and siting decisions

“Or you're using your hydrogen to create electricity when it's not windy in which case you're not moving it anywhere.”

[But you would need storage capability instead?]

“What we get to is it better to build the wind in Scotland and build more grid or build the wind off England and Wales and build less grid, which isn't really a question of market design. It's a question of least cost system optimisation.”

[It's also about how much hydrogen we want and where the hydrogen is so it's a least cost energy system isn't it? Is LMP a means to that outcome, would it give the signals to a market to get to that outcome?]

“It would certainly give more efficient signals to get to that outcome.”

A final stakeholder emphasized a need for strong locational signals for flexibility but suggested that the same signals should not apply to renewable generation:

“I strongly believe that flexibility does need locational signals, and it actually needs quite strong locational signals because you need them next to the renewables that are constrained because they will enable more output from the renewables to be retained rather than be curtailed. It seems an absolute no brainer to me that you give very strong locational signals to flexibility assets...”

“... [but you need to] simply switch that off for renewable generation because it's a tax they have no choice but to pay or you just make it cost pass through. The whole renewable industry is absolutely terrified about locational marginal pricing and the impact that it might have on existing and new investments because they do have very little choice, they have no way of managing that risk.

“Flexibility assets having [locational] signals behind a boundary would be powerful but at the moment the lack of those signals is not stopping things like battery storage and peaking capacity developing. They are developing regardless of whether there's an LMP signal or not.”

[is there a risk that they might be developed in places that turn out to be less useful than other places because the locational signal is a bit weak?]

“I think that's absolutely right, I've spoken to a number of battery traders and so on and basically they don't factor in locational signals. The only time they would factor it in is if they've got a contract with the DNO to provide flexibility on a specific bit of the network.

“The fact that they haven't got a locational marginal pricing signal or some locational signal means that they aren't really taking account of that and the overall power system is not getting the benefits of giving that locational signal that should 1) mean that more renewables should operate because essentially these should be able to reduce curtailment of renewables which is happening increasingly frequently and 2) it should mean that new transmission lines don't need to be built so that there's a double benefit if a locational signal is given to flexibility assets.

“Whether that [signal is] nodal or zonal, it feels to me if it's driven by a transmission constraint then it's zonal and if you're within a distribution network or on a specific transmission point, then it's nodal, but it is location based and it's because there's a long term system need that's identified there and as soon as you know you've got a wind farm connecting in a remote area, then you know that you've got a system need for flexibility.”

3.2 Impact of LMP on risk and cost of capital

A number of stakeholders offered their opinion on the potential risks and cost of capital implications, particularly in relation to investment in renewables.

The first stakeholder gave their view from an investor perspective and experiences in other markets:

“Transmission charging [TNUoS] is assessed on the basis of long run costs and investment decisions are clearly long run and we feel as an investor that we can better assess that.”

[Proponents of LMP would say you can model that as well.]

[Strongly disagrees.] “[With LMP] you’re forcing an investor or an owner of an asset to take a risk they can’t really manage, mitigate, or do much about, so you’re exposing them to risk for no reward.”

[Comparing PJM and ERCOT price volatility with TNUoS:] “you have somewhere between four and six times the volatility in LMP markets that you have in GB [under TNUoS]. It’s not 50% more, 20% more, 30% more, it’s five times and that is what drives, in our view, a very significant increase in cost of capital.

“[There are] sites in ERCOT where it leaves you incredibly vulnerable. The ice storm happened in early 2021 [and] the political consequences for Texas led to reviews of resilience across the piece, increased conservatism, and [they] introduced safety cases and assessments of transmission capacity. That has caused them [ERCOT or the TOs] to dial back transmission capacity in several places. In some locations [it has resulted in] effectively six years of zero or negative pricing for most of the year until transmission investment comes in to relieve that. That is a totally different risk profile to underestimating TNUoS”

[Do experiences like that deter future investment as simply too big a risk?]

“Yeah, exactly. That has happened in waves in Texas. The first time it happened was in West Texas [then] transmission investment relieved a number of those constraints. It’s now more intensely constrained in southern Texas, but locational market pricing makes your vulnerability to that significantly higher.”

[What drives low cost for renewable projects?]

“So it’s about two things. It’s about the build cost and the cost of capital. Those are the things you’ve got to compress. The build cost has been compressed by scale and learning effects and technological improvement, and the cost of capital has been driven down by certainty. CfDs have taken probably 75 to 100 basis points off the cost of capital.”

[In Texas, can renewables manage risk through PPAs or other means?]

“You can’t get anyone to take long-term risk. Maybe you can you can get a couple of years or three, but these are 30 to 35-year assets. [The problem is] when you get it wrong, you’ll get it really, really, seriously wrong. So that’s what you have to price in up front: I need to make sure that when it goes right, I make out like a bandit because I’m often going to lose my shirt. So, you turn it into an out and out casino.”

[Is there evidence of the cost of capital effect in different markets?]

[Not LMP but] “in European markets we’ve seen a cost of capital spread between highly certain cash flow streams (government backed subsidy, or a high credit quality PPA with a large-scale long-term offtake) versus merchant cash flows. The cost of capital is approximately double [if exposed to merchant prices].”

[Recent UKERC research estimated each percentage point increase in cost of capital might cost the economy an extra £1bn/year – does that sound right?]

“That triangulates quite well. We think the renewables generation investment [requirement], never mind balancing and grid, from here to 2035 is £130 ± 20 billion. So yes, 1% on that – a billion a year.”

Another interviewee gave their view on the difference in risk profile that you might expect between a nodal and a national or zonal pricing system as well as a view on ability to secure PPAs in US markets:

“It comes down to the relative predictability of risk and the relationship with investment. In an LMP model your ability to know how your asset is going to perform and be dispatched is limited. Under a zonal model or my preferred option of national price + [alternative transmission charging regime] you have publicly available prices against different sorts of assets and a much better sense of how much you’ll need to pay to satisfy a consumer in another zone. It’s the overall predictability of the cost structure that supports investment. Certainly, wind investors want to know what their revenue is going to be above everything else. Under an LMP system you introduce additional uncertainty because a) you are no longer dispatching your assets and b) you don’t necessarily know how prices are going to evolve, especially at the hyper local level your price can be more readily cannibalised than it can be at national level.”

“PPAs aren’t necessarily as clearly a thing in nodal markets as they depend upon being able to buy the power directly from a generator who then self-dispatches but you wouldn’t be able to get the benefit of the lower congestion charge unless your demand is located in the same node.”

“What you do find though is that you’ll have a PPA with a renewable asset who’ll then have a point to point contract with some other form of asset in the node where the consumers demand is located, [e.g.] paying a thermal plant close to a demand node to switch on when the renewables are on to satisfy the load and avoid the congestion charge. PPAs just become horrendously complicated under nodal systems”.

Another respondent gave their assessment of the trade-off between the benefits of LMP and the risks it might bring for investment:

“If we only focus on getting the cost of capital down we won’t get investment to bring down system costs – we will get the wrong stuff located in the wrong places. Then the whole system becomes more difficult to operate.

“Ultimately, we want the collective market of investors to start behaving differently, not only investing in renewables, but also investing in the physical hedges that will go along with them. There is some increase in their exposure to market risk if you want to use market mechanisms to drive those kinds of behaviour.

“The alternative is you don’t use the market, you use a combination of administered mechanisms to get your mix of right resources, which then means you’re going down the road of OK, we carry on with insulating renewables investors from the system risks, then add mechanisms to bring on storage and flexibility. That leaves you relying on the system operator to resolve many of the system issues.”

“In terms of an investment hiatus, I do think that is a real risk. And if you go for wholesale reform you need to manage that somehow. But you do want to be changing the risks that market players make.”

[So, to summarise: we've got a risk that we don't get enough renewable capacity and we have a risk that it turns up in a way that is unusable by the system and we need to balance those two?]

“Yes – I agree, that’s right,”

Another stakeholder offered an opinion on how it might be possible to implement a low risk version of LMP:

[Isn’t volatility a problem under nodal pricing?]

“Yes, but let’s say you have LMP plus CfD but don’t have generator TNUoS, you’ve actually reduced risk for generators in the first 15 years. You have the same risk in the wholesale element but you have no risk on transmission charges. So, your risk has gone down in the first 15 years.”

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[Do you believe that the level of renewables required can be delivered by the market under LMP without undermining investor confidence?]

“A daft implementation of LMP would harm investor confidence but that's not what's on the table or at least not what will be on the table. If you just went LMP only, get rid of CM, get rid of CfD, yes, it would be a nightmare. But if you got rid of CfD and CM now it would also be a nightmare.”

“A world in which we move to LMP plus CfD plus getting rid of generator TNUoS, for example, is extremely good for investor confidence for the first 15 years. Yes, it's not good for the long term, but frankly, which developer now is thinking that in 2042 (when that contract ends which will be five years of build and 15 years of operation) we're going to have a national wholesale price?”

[On the prospects for investment in generation in Scotland:] *“actually, in the long term the best thing for renewables in Scotland is to get the grid built and get some electricity demand up there.”*

[What is your response to the view of developers that cost of capital will be much higher in an LMP market – a number of 150 basis points has been referred to before?]

“It will completely depend on the support schemes that are available. If you have a 15-year CfD [then you remove much of the risk]. Also, what would be the benefit of getting rid of generator TNUoS charges, how much benefit would that have on cost of capital? if you go for some sort of libertarian LMP energy only market then, yes, I would have thought the impact could be more than 150 basis points to be honest – but there's no world in which we go for that.”

4 Transmission investment

4.1 The link between LMP and transmission investment

A number of stakeholders offered their opinion on the critical role of transmission and the relationship between it and an LMP market. A number of respondents offered similar views on the limited role LMP might be able to play in influencing transmission investment including those with direct experience from the US:

[Should sufficient transmission capacity be required as a pre-requisite to implementing an LMP market?]

“Too often we assume a fixed transmission capacity and then transmission planning takes place on longer timescales of 15-30 years.

“I don’t want to say LMP doesn’t give signals to investment – you can use the LMP models to inform decision making but ultimately there are other stronger forcing factors - in the case of Texas this was the State policy [around development of CREZ zones]

“In the US different States have renewable portfolio standards that mandate ‘X MW’ [of clean generation] in this place by this year. These standards can only be met by earmarking new transmission to facilitate more renewables. So LMP modelling can inform knowledge on congestion but I believe it is a weaker variable in a host of variables that a developer would consider.”

[Proponents argue that LMP can help develop transmission efficiently – do you agree?]

“I think you’ll find that argument has been fairly thoroughly debunked. There is one paper a while ago arguing that it worked ... but it hasn’t been working. No one is arguing that anymore. LMPs don’t help transmission, they just don’t. Once you put transmission in you eliminate the congestions rents.”

“I think LMP provides more transparency about price differences making it easier for external players to access. What it doesn’t do is provide the right signals to [the] market to build that capacity.

“I think the real challenge is, what is the right balance between building network assets and locating generation more efficiently? Nodal pricing does not give you the answer to that question. It relies on centralised planning of network assets.

“I think the key thing here is the actual physical network connection assets above everything else determines location [for generation] and building more of them out feels like more of a priority than moving to nodal pricing, so the question is what market gives you more of those sorts of assets?”

“Firstly, we think that it’s relatively clear that significant transmission investment is needed in GB to move power from where it can be generated to where it is needed and the transmission constraint between Scotland and northern England even from northern England into southern England. Those lights have been flashing red for decades. A greater locational signal isn’t going to change that. We already have transmission charging which adds significant cost to putting generation in more remote areas. But that’s OK, we can make an assessment of those costs and price that in upfront to a degree.

“It’s clear that it’s not economics that’s holding back the transmission investment because the transmission investment case is crystal clear. It’s the practicalities and public opposition to it that does [hold it up].

“I think philosophically that the grid needs to serve the needs of the economy, not the designer.

"I think we are behind the curve in terms of the network build that we need for an 80% renewable system in eight or ten years' time."

"We clearly we need both loads more grid and we also need much better locational market signals as well – we need them both."

I think [the US markets] have traditionally used LMP price differentials in the way they've analysed the business case for grid enhancements. That provides good economic information to help you inform your business cases for new grid investment. They also create a natural Interest group [who would be thinking] how much effort do I put into advocacy around grid investment. I think LMP has the potential to throw quite a lot of transparency into the debate. But ultimately transmission remains a set of monopolistic assets that has to be done on a strategic basis.

One interviewee gave their thoughts on the impact of transmission investment to Scotland specifically:

"I don't think we'll get significantly less [network] capacity in the short term in Scotland because of LMP.

"The limiting factor is grid constraints and we are constrained on the build out rate of grid. Even in an LMP world the amount of wind and stuff we would want in Scotland will still be constrained by the amount of grid that we can build so I don't think we'll have any less grid build out to Scotland in the next 10 years as a result of LMP. I think the amount of grid we will need by 2050 if we were to put it all in Scotland. That's the bit that's in play."

[Is investment in sufficient transmission infrastructure a pre-requisite to successful implementation of LMP?]

"It's a prerequisite to a successful implementation of anything regardless of whether it is LMP or national pricing. I don't think anyone sensible is arguing that LMP means you don't build transmission. I think we're still going to be constrained on the rate we can actually build transmission and distribution just by engineers, cables, planning systems etc. I don't think LMP in the next 10 to 15 years significantly reduces the amount of grid you build."

Another respondent reflected on the importance of having confident expectations of the future connection queue for determining transmission need:

"People say just build more network and you build network for 200 gigawatts [volume in TEC queue], which is 1) going to cost a lot of money, 2) it's going to take a long time to build, and 3) it's likely it may not be possible to build it..."

"...there are big practical problems to doing that so it does feel that the connection queue is fundamentally the issue here, and until you have clarity on what is connecting, how can you set a proper LMP?"

Another respondent reflected on the debate around moving to a nodal LMP + FTR model in Australia:

"[LMP proponents] never quite addressed the problem of will it act in the right way to encourage the optimal development of transmission and give the right pricing signals. It's seen as a tool for managing congestion in an operational time frame. But maybe the real value is to actually plan your network and plan the development of the power system so you don't get material connected congestion, and if that occurs then the value of the FTR regime is somewhat diminished because there's a sophisticated regime, but you don't need it all that much because you've developed your power system appropriately."

[On the risk LMP+FTR has of delaying transmission investment based on uncertainty of future generation investment]

“The problem with the FTR + LMP ‘leave it all to the market’ approach is invariably the regulator, who is signing off on the transmission investment, then says ‘it’s all too uncertain [future network requirements], I won’t sign off on anything’, so nothing gets built.

“...whereas if you go the other way and you start to draw some lines on the map and say this is the renewable energy zone – within so many years, it’s going to have 5 GW of renewable generation, at the moment it’s only got transmission capacity for 1 GW – it’s a fairly safe bet that you need to build something, right. Then you’re anchoring one end of where you need to start to build and then your load centres are anchored at the other end and you start to have a problem that you can solve and build towards something that can be established in a time frame...

“...but if you overlay the uncertainty that you get with FTR and locational pricing, you just put in more delays. I think if you’re serious about meeting your targets, adopting something that allows you to do more confident planning has a benefit.”

4.2 New or alternative approaches to transmission investment

A few stakeholders offered views on alternative means of delivering on new transmission investment:

[On the need for reform to enable much more private investment in transmission:] “what you want to do to ensure efficient level of construction is to not just rely on a single licensed entity to make that assessment but open it up to multiple perspectives with multiple different sorts of risk appetite.”

“This is where zonal pricing becomes interesting especially across the B6 boundary where those constrained assets become equivalent to interconnectors – we have a reasonable merchant interconnector industry that would be happy to venture onto land if it thought there was value to be gained.”

Another mentioned some aspects of the existing framework that could be addressed and where lessons from elsewhere could be learned:

“The planning system does take a long time so you could speed that up, I’m sure. Projects have been held in scoping for too long by Ofgem before being allowed to proceed. I would let the TOs consent a lot more infrastructure now even if they don’t necessarily plan to build it immediately... so maybe that needs to change, the national planning policy framework or whatever it is in Scotland... and maybe look at what they did with renewable energy zones in Texas.”

“The ESO’s current plans for the transmission are completely undeliverable. Look at the map that they have for the offshore wind grid – 2029 is basically a bit like today but by 2030, there’s an entire offshore coordinated grid.”

Another respondent gave views on the approach Australia seems to be moving towards:

“So, it comes back to: do we let congestion just develop and then try and manage it operationally or are you better off to put your time and energy into trying to get the grid built and encourage people to invest where the grid is and therefore have less congestion? That seems to be where we’re going in Australia at the moment...”

“...what we’re getting to now is more identifying renewable energy zones and saying what sort of level of transmission capacity we’re going to build to those zones and to make the most of that capacity, what sort of

mix of renewable generation do we want within that zone. You might say that within that zone, we want a certain proportion of solar, a certain proportion of wind, a certain proportion of storage and then they will allocate rights according to that so the wind farm developers will all compete for the wind, and then once it's all sold then it's declined physical access until the next wave of transmission expansion occurs...

"...[So] moving away from an Open Access regime to a restricted access regime and we're going to restrict access so that we don't allow too much generation to come forward and that then is going to make sure that we don't run the risk of too much congestion over time because we just haven't allowed it to connect."

[What sort of criteria are used to determine the location and extent of Renewable Energy Zones?]

"It's a little bit of looking at what transmission is there, but the main thing is looking at resource availability and land use planning. You're trying to find areas where there's an abundance of land, you've got good resources and are reasonably close to transmission, [such that] you could come up with an option there [for a feasible connection]."

5 Operation of LMP markets

5.1 Centralised dispatch

Two separate stakeholders offered views on the potential difficulties associated with the central dispatch algorithm that would govern the LMP market and pointed to a philosophical argument over the best approach to optimising the operation of the future system:

“There’s a general philosophical battle going on at the ESO – it seems strange that in a system that’s becoming more and more dispersed with lots and lots of assets, we would move to central dispatch. That doesn’t seem to be the optimal thing to do for a highly distributed system.”

“You can’t have control over everything... the idea of global optimisation always appeals to me, but of course as your optimisation gets more and more complex and it becomes more nonlinear, it’s actually really hard to do as a global optimisation.”

“Assuming you achieve a vast digital twin of the system there is almost a philosophical argument as to whether you believe a large AI or machine learning tool can internalise all the required information about each asset to deliver a more efficient dispatch than allowing the asset owners to manage their own assets and respond to price signals? I think we could test that empirically; the EU are already running into trouble with a pan-European dispatch algorithm and in Texas due to some of the behaviour of some participants the ERCOT platform has slowed down.”

5.2 Market Monitoring

A few respondents discussed the role of market monitoring in LMP markets and lessons for GB irrespective of market design:

[You’ve argued for LMP to reduce the role of the system operator in mediating market signals to things like flexibility but in an LMP market, doesn’t the algorithm on which the LMP dispatch is based act as the mediator and the system operator plays a key role in specifying that so you can’t fully avoid it?]

“It’s not only the algorithm as well, it’s also the detail of the design of things like the bid formats that are used. In the US they reform and tinker with and improve those over time. You’ve kind of got this idea of a perfect market as your ideal that you are trying to get as close to as possible. But you’re constantly running into micro details of micro imperfections and there’s this ongoing process of trying to correct and improve the micro implementation of that.”

[The question is whether the imperfections which are always going to be there somewhere lead to perverse outcomes and dramatically wrong signals?]

“And that is why there is a market-monitoring function in place: independent people looking at the how well the market is functioning.”

[Market Monitors – do they deliver significant impact?]

“Yes, I think they do. If you look at some of the reports they produce, they are very detailed technical reports analysing the actual experience of those markets and what’s going on in them and what the new issues that are starting to emerge are.

“ISOs in the states, if you like, discipline themselves. They set up an annual market review process and commission a bunch of experts to do the analysis and publish a report. And then there’s a process of figuring out what do we do about this? What are the imperfections? I suppose that we need to be doing something like that too. I don’t think the need for strong market monitoring ever goes away whatever market design you

have, you will inevitably run into issues because of the nature of electricity markets. They're pretty difficult things, vulnerable to manipulation and perverse outcomes. But I think that doesn't mean that you can't try and do better."

[US LMP markets are constantly being tweaked and evolved and place a large regulatory burden on market monitoring – does this speak to an inherent complexity and regulatory burden?]

"No one is monitoring the BM [in GB – implication being they should be]. To do a fair comparison you have to compare the totality of the regulation and market changes. And we have a very simple wholesale market but we have an incredibly complex balancing market plus TNUOS charges, DUOS charges so actually the complexity just appears in different places.

"We have lots of rule changes here too so not too different to US nodal markets tweaking their design... there are ongoing rule changes around to TNUoS and DUoS. Everything is always under review [here too]. We have all our codes under review. Our licenses are always under review, government can review the licenses. Ofgem changes license conditions. Codes get changed.

"In an LMP world your market framework becomes more stable – no one has gone back on LMP, which I think is incredibly instructive... but there is more market volatility and there is more market risk and there's complexity in market outcomes but actually the regulatory landscape becomes a lot more simplified."

"Even if you had nodal pricing it seems to me that you would have to have some market protection in place anyway to avoid perfectly 'legitimate' trading abuse... It could lead to unforeseen consequences because of particular network constraints."

5.3 Financial transmission rights (FTRs) and hedging

Multiple stakeholders touched on the important topic of financial transmission rights – the first two respondents gave their view from direct experience in US markets:

"There is a large burden in enforcing and dealing with manipulation of FTR markets. I'm not sure I would endorse the way FTRs are done. I once worked on a case that was incredibly complex, litigated for years and had huge amounts of money at stake."

"FTRs were designed to get rid of the congestion rent and return it to customers.

"A large financial industry has grown up around FTRs. It has caused a lot of issues for ISOs. They have ended up running a futures and derivatives market and it becomes highly risky. Defaults have happened. FTRs are extremely risky. For long term FTRs there are not many bidders, they get mispriced, and in particular prices paid are particularly low. Overall, it's largely the financial traders that buy [FTRs].

"The alternative to FTRs is to distribute the congestion rent on a load-ratio basis in the same way that losses rent is handled. Overall, there are lots of manipulations of FTRs. For example, manipulating the day ahead prices in order to make money on FTRs.

"The California Market Monitor has come out against the FTR market stating that it isn't working. The prices the load is getting for the FTRs is very low. Similar effect has been seen in PJM and the PJM market monitor has come out against them."

[On 'grandfathered' FTRs] "This has been used in almost all market areas in the US. They are used to 'get people on board' with the transition to LMPs. There is a risk based on the length of the FTRs. For example,

FTRs don't depend on the operation of the plant. What happens if the generator retires and they still have the right?"

A stakeholder with experience of the Swedish renewables market reflected on their experience of hedging in that zonal market with a view to the challenges associated with an LMP market with FTRs:

"We hedge on the Nordic system price and then buy rolling EPADs which are equivalent to FTRs in America and what they're proposing under REMA for nodal pricing. There's only about two years' worth of liquidity so you're in a situation where you are putting in a 10-year hedge where you can only lock in the price area differential for two years. For the remaining eight years there's a basis risk between the zonal price and the Nordic system price so you'll effectively have to settle against the system price when you're getting paid the zonal price. Obviously, you can buy rolling EPADs, but you've no visibility of what they're going to be like in two years and they've gone from about €8.00 to I think over €100 in that space of time..."

"...I think Nordpool is a good example where zonal markets, basically another form of locational signals, don't function for renewables in Europe in my opinion."

[On FTRs and basis risk in renewables dominated LMP markets:] "I just think you've got a mechanism that's designed around most generators being fuelled and having a marginal cost within a range and sometimes it's gas and sometimes it's coal and sometimes it's nuclear, but they all cleared somewhere between kind of 35 and 70 £/MWh. What you've got with renewables is a phase change if your node goes from being one where most of the time a fuel generator sets the price..."

"...In fact, it might be better to stop describing zero pricing due to renewables in an LMP market as basis risk. You have nodes that change on a trade [and have prices set] on a fundamentally different structure. It's not how different the local LMP is going to be to the hub if you are a renewable dominated node, your price will be 0, it won't be about basis. Basis is just 0 minus whatever the fossil price is at the at the hub."

Another stakeholder discussed the need for FTRs and grandfathering in a GB LMP implementation:

"Yes. There has to be some FTRs. Yes, there's probably a role for the ISO in coordinating or making a market for those – there are lots of examples of that. I don't know which one is the best but it has to be on the table. But I wouldn't do grandfathered FTRs for existing generators."

[Do you think that would face legal challenge?]

"I'm not a lawyer, but primary legislation counts for a lot... and if the government changes primary legislation [then that may be sufficient] but there would have to be a renegotiation so that they are no worse off financially in the new world than the old world during the CfD period. This would be for detailed debate" [but could be via the deemed generation idea or otherwise]

A final stakeholder discussed the recent almost unanimous rejection by market participants of an LMP + FTR market reform proposal for the Australian NEM:

"There is a concern that it is hard enough at the moment (within the 5 region NEM model) to get year-ahead financial hedge positions negotiated. Most of the time all the regions and the prices are linked just by loss factors. But occasionally you separate when you get a constraint between the regions and the regional prices separate. So, it's hard enough then if you're trying to operate a business across the country to be able to manage those risks. When you then say we're now going to have locational marginal pricing where you could separate into any number of pricing regions, how do you navigate that risk?..."

“... theoretically you can use the financial transmission rights and allocate them appropriately to mitigate some of those concerns. I think at the end of the day, there was a very strong perception of risk around the entities that are operating in the market. But then we also have quite a volatile market with a \$15,000/MWh maximum price. So, if you're on the wrong side of that, you can go bankrupt pretty quickly.”

5.4 Self-scheduling

A number of participants discussed the issue of self-scheduling or self-dispatch in LMP markets starting with some insights from US LMP markets:

“[Self-scheduling] is included in the LMP optimisation but is treated as a simple assumed injection regardless of price... in Midwest US that is still how a lot of the energy is scheduled – sometimes 50-60% or more... it implies that generators might lose money if their operating costs are above the system wide price – in fact that is why a lot of nuclear power has shut down in the US.”

“Self-scheduling originated as part of the transition to LMP – as a way of saying to generators that we will make you indifferent to the switch, we only want to improve efficiency of dispatch. It allows 30-yr contracts from a simpler time to continue. However, introduction of zero-cost fuels (renewables) has put downward pressure on LMP revenues. Some plants may be losing money in every period in the LMP market but could be kept online by various other revenue streams, [for example] capacity markets, ancillary service markets, a bilateral with a CfD clause, a State subsidy [e.g.] because the plant is a large local employer.”

[Self-scheduling] “is usually undertaken by generators with the most stringent multi-periods constraints such as multi-day minimum run times. Nuclear is the most obvious... [Not aware of renewables self-scheduling] primarily because they don't really have the intertemporal constraints.”

“Self-scheduling causes a lot of problems and makes the market dispatch less efficient... In ERCOT, if you are undertaking self-scheduling, there is a requirement that you also have a self-schedule for the provision of ancillary services as well.”

Two stakeholders also discussed the potential issue of self-scheduling in the GB context:

“In nodal markets you do see some contracting between suppliers and generators at local nodes and they move into self-dispatch mode – how quickly the nodal market goes back to the existing market is a really interesting question...”

“...Quite frankly if you are a CfD holder in Scotland [as most gen in Scotland will be] you will self-dispatch yourself because your contract will pay out £50/MWh even if the nodal price is zero...”

[In GB we could have a scenario with 30 GW of wind sitting behind a boundary with 10 GW of demand and 10 GW export]

“Yes, it raises the question of how you deal with the 10 GW curtailment tail – you could be forced into non-price decisions.”

[Could self-dispatch lead to the potential for manipulation of what happens in the market?]

“Exactly! Most LMP markets do allow self-dispatch for various technical reasons but it is difficult for a system operator to judge whether those reasons are just or whether it's to make more money or to avoid congestion charges (via a contract with a local supplier only). These features start to complicate the market, it can't be efficient if you just decide to ban all private contracting. It comes back to the balance of where you use prices and where you use centralised signals. I'm not persuaded nodal pricing gives you that fine grain understanding of each asset and demand holder that price does.”

“You can only self-schedule if you bid negative prices would be my [favoured implementation] so you have an incentive not to do it in periods where you think prices might go lower at your node.”

“We have to avoid any grandfathering of FTRs [or other schemes] that lead to a situation where generators would want to self-schedule against the interests of the system.”

5.5 High penetration of renewables

Two stakeholders offered opinions specifically on application of LMP to systems with a very high penetration of renewables:

[Has much thinking has been done on how LMP markets will work in highly renewable systems?]

“There is lots of literature... the general argument is that you can still do LMP, operate the system efficiently and send demand useful price signals but you are going to need a different type of separate contract or other revenue stream [to make the business case], but they can co-exist and work well.”

[Are there examples of countries where you think they are well on the right track to implementing LMP in a deeply decarbonised system or would we be effectively the pioneers (or Guinea Pigs) in this space?]

“I've laid out a two-phase reform program. The first phase being LMP with incremental tweaks to CfD and the second phase being some unknown transition to either equivalent firm power auctions or supplier obligations. Set aside the second phase because it's five years before we need to really worry about that. The first phase, LMP is bog standard in markets all across the world and so I don't think we're a Guinea pig.”

5.6 Implementation challenges and complexity

A number of stakeholders offered thoughts on the complexity of modelling LMP and implementation challenges for GB:

[Some have argued in Europe that the non-convexities involved meaning that an LMP dispatch is problematic to solve and modelling simplifications are required such that the result can never truly be optimal – do you agree?]

“It's optimal to the extent that the assumptions are good but don't let them tell you the software won't be able to solve it – that is nonsense. PJM is a huge system and they solve it every 5 mins.”

“Look at bringing in NETA [New Electricity Trading Arrangements]. Look at when we tried to bring in EBS [Electricity Balancing System]. We're not very good as an industry at these big centralised projects.... we don't think it [LMP in GB] would be implemented in time to make a difference on the sort of scale that we need.”

[Isn't modelling of LMP going to be complicated for market participants?]

“Yes you need to do some modelling but you only need to get it roughly right – a 20 zone model might be good enough. That incentive [to forecast / model well] is strengthened in an LMP world and [market participants] are also incentivised to offer products that actually help the system whereas at the moment they're incentivised to offer products that help a theoretical system that doesn't exist. It sort of existed when we just

had thermal power stations but in the world with renewables, the system that they are trying to exploit or react to doesn't exist. It's becoming a joke."

[How quickly could LMP and other reforms be implemented in GB?]

"The complementary bits and pieces could be done by 2024 or 2025 [i.e. incremental changes to CfD & CM]. For the LMP bit we would probably be talking April 27 or April 28 at this point probably April 2028."

[Some may question that given the industry track record on speed of implementation for such reform programmes and IT projects is not that great]

"No [it isn't], but there are plenty of LMP implementations that we can learn from."

6 Interaction between LMP and other market reform options

Several stakeholders touched on the potential implications of other market reform options being considered under the Review of Electricity Market Arrangements (REMA) process for a move to LMP, including issues of compatibility and interdependencies.

6.1 Contracts for difference and LMP

The topic of CfDs and their continued use, compatibility with and interaction with LMP markets was touched upon by a number of stakeholders:

[Is an LMP market compatible with CfDs – could you retain a national auction?]

“I think you could make them compatible but then most of the assets would just self-dispatch. It’s the existing CfDs that cause the real challenge – the transition to nodal throws up an awful lot of challenges. Assume you aren’t going to implement LMP much before 2030 then you have 50 GW of wind on the system with existing CfDs and they all want to self-dispatch otherwise they are exposed to their local nodal price (which behind a single wire to the North Sea is going to be very low). How you make some of those calls against which generation dispatches in that scenario starts to get very complicated.”

“It’s not that CfDs are incompatible they just make the transition so much harder than it otherwise would be.”

“I don’t see any implementation of LMP [in GB] that throws away CfDs in the short term.”

[But it would depend on detail of CfD, e.g. if it doesn’t pay out on negative pricing then the risk profile is changed?]

“Yes – my implementation of CfD would use long term modelled expectations of nodal prices to improve allocation efficiency. It would award projects based on their expected costs to consumer, so on the minimum difference between strike price and nodal price instead of just the minimum strike price as now.”

[How would you envisage CfDs would react to zero or negative pricing?]

“I’m attracted to the deemed output model where if you’re constrained off that volume is credited as having been produced. I think that kind of works but then you’re actually making the negative pricing situation worse. If you wanted to just maintain status quo I think what you could do is say the negative pricing rule only applies when the national equivalent price or the load weighted average price is negative, that would be fair. That would be the same scenario as we have now I would say.

“It is problematic at the moment to pay generators to generate when their energy is worse than worthless – it costs customers money and the deemed output model effectively does the same thing. In a way it actually gets rid of the negative pricing model altogether. It just pays them a fixed price for their energy if they couldn’t produce it. It therefore increases certainty for investors, but puts the risk back onto customers and I’m kind of OK with that.”

One trader of CfD renewable assets expanded on recent behaviour in the balancing mechanism (BM) confirming the assumption that the theoretical competitive bid price for CfD holders in the BM would be market price minus strike price but noting other influences:

“Indeed, when prices first rose during the crisis CfD plant were submitting high positive bids into the BM. However, we (and this has been echoed across the industry) have changed tack on this and are now capping bids and setting them slightly negative. A change in strategy to bring that pricing down and put that pricing slightly negative because of the impact of that unexpectedly high BM activity that potentially occurs from very high pricing...”

“...this is because there is a fundamental concern that you built an asset that has renewable energy coming onto the grid, that's got a benefit to the consumer because it's zero carbon and a benefit to your customers. If that is unavailable for large periods of time, then there's a fundamental question as to what that means for your customers, who you're keen to sell green energy to and also what that means to the overall system. Also concerns with what it would mean in terms of large-scale shutdowns... in terms of the overall physical impact on the wind farm.”

6.2 Split market and marginal pricing

Some respondents offshore an opinion on the split market option being considered by REMA which reconsiders the role of marginal pricing for variable power generators:

“I'm a fan of the two-market solution because it provides you the right signals you need to get to the volumes of investment you need to get to net-zero. It is effectively an evolution of the CfD scheme in some sense.”

[What about the strength of coupling? Some argue that we need to decouple from marginal prices, but isn't LMP about strengthening that coupling?]

“Everybody is exposed to the real time price, but you can choose to forward contract as a way of managing your risk associated with the short-term prices and with the clean electricity standard (supplier obligation), you would have strong incentives. I think for the entities that serve demand to be forward contracting to be buying long term and those long-term contracts I would expect to be struck on the average price.”

[Is something like the 'Green Power Pool' idea compatible with LMP?]

“The thing that I notice about the green power pool and the bit that resonates with me is the idea of creating standardised contracts for clean electricity and that helps actively develop the forward contracting market, trying to actively stimulate it.”

6.3 Supplier obligation

Two proponents of LMP set out their long-term vision that the supplier obligation model could support the development of low carbon generation in a future LMP market in GB:

“The way I view LMP is that it's not the answer It's part of the jigsaw.”

[On a Clean Electricity Standard / Supplier Obligation model:] *“this would show the market that the UK is serious about full decarbonisation of the electricity system and there is a market-wide ambition to decarbonise. You need to retain confidence that the UK is a good place to invest...”*

“...the idea of that is to provide a big demand driver for clean electricity. It gets the entities that are serving demand to take responsibility for assembling a portfolio of generation and flexibility, including flexing their own demand to match it with their own generation.”

[Do you have a preferred market model / solution for GB?]

“My philosophy is that the LMP is the most important thing and the tweaks to the CfD should be incremental for now because I think in the longer term we're going to have to make bigger changes to CfD.”

“That probably means moving towards something more like [the] supplier obligation model, but I think that [would be] 2030/2035 for implementation of that and so I think incremental changes to CfD & CM, but with LMP being the primary thing we need to focus on for the next 5 to 8 years.”

[Don't suppliers lack a track record of being able to deliver something like a supplier obligation?]

"Exactly so you need your macro prudential financial regulation in place first – you need lots of things in place first. The alternative to the supplier lead model is the equivalent firm power auction model where effectively what you're trying to do is you're trying to have a CM, a CfD and the dispatchable power agreements that reward both firm and clean technologies.

"My question is, can the government mimic the type of portfolio contracting approach that an energy supplier would take if they had that obligation on them because if the energy supplier had that obligation, they would always be contracting in a way that would try and minimise their own costs and system costs. But when the government is doing that the government wants to achieve that, but all the generators don't want to achieve that, they just want to maximise their own profit in a way that doesn't necessarily help the system...

"...is the supplier or the government going to be better at building that portfolio of contracts? That is the key question – I really struggle to see how the state in whatever form can actually do that in an efficient way. No one has got this right globally I don't think which is why I'm not pushing for a particular solution at this point."

6.4 Other reform options

6.4.1 Local markets

[Is there is a halfway house where you do break things down and make a local optimisation, let's say under each GSP and report back into the central transmission level market – either just to say this is our position or to offer power at a certain price and give some up and down?]

"Yeah, and local markets are one of the ideas under REMA but the version I read was awfully complex."

6.4.2 Balancing market

[Why isn't demand side flexibility coming forward?]

"Because we haven't got system-wide half-hourly settlement."

[What about the BM? Isn't that a locational market?]

"I tend to be a bit sceptical about that because I think that kind of leaves too much with the system operator to resolve."

6.4.3 Dispatchable backup

[How do we meet demand for electricity during 'Dunkelflaute' (sustained wind drought)?]

"I think we're going to need some fossil for now and maybe in the future it's hydrogen based but some generation capacity that is used on average a small number of hundreds of hours a year and maybe in several years it's not used and then it is used for the one in 10-year event. You could have some unabated gas as long as you don't use very much of it very often without that being the end of the world and maybe at some point hydrogen does that job more cheaply."

7 Comparison between nodal and zonal market

Two stakeholders offered specific thoughts on how a zonal approach to locational pricing might compare with a nodal approach:

"I've asked the question why is [nodal] LMP so much better than zonal? Why don't we go for the compromise solution... sometimes a bit of pragmatism in life helps.

"They say we'd have to re-do the zones all the time, but right now we're supposed to review the zones every two years, because that's what the European regional regulations say, but we don't. So, we can choose what to do. We could choose the size of our zones.

"More importantly it also depends on how the CfD interacts with the LMP or the zonal system. If you have a zonal system, but your CfD was struck against that zone and you had a competition within that zone. That removes your exposure to that zonal price and you might choose how much [CfD backed capacity] you want to do in each zone."

"You can move to zonal markets with zonal balancing mechanisms if you like. That would be a halfway house. The problem is then you need to update the zone boundaries [on a regular basis] and you are still left with a system operator playing a significant role..."

"...resources within those zones, particularly the flexible resources who may help to resolve constraints [within the zones]; the market signals that they face are mediated by the system operator and then dependent upon system operators' decisions about how they specify products and specify the market."

8 Alternatives to LMP to meet 2035 target

[What is needed to reach 2035 target if not LMP?]

"I haven't seen the analysis to really know – I think you can get a good part of the way by changing the access arrangements to a degree – then you've got the question of do you have to be able to secondary trade that because of course the rights of everyone else is grandfathered from the beginning.

"I wouldn't allow you to put a negative bid in for any new plants... but then do you need other signals on top of that? Do you need to go zonal or not? I really don't know and I don't think anyone can say at this stage because the analysis hasn't been done... if we're going to do LMP, we have to assume it's going to take us at least five years and we have to be looking at what it does in that time period.

"Then the other question is how do you build wires more quickly?"

9 Key challenges for market reform

“The whole point of the power market is to deliver the cheapest power possible with the least amount of carbon while maintaining system security at an acceptable level that is politically defined.”

“[I’m] not persuaded that nodal pricing (as it deters investment in wind) is the right way to minimise the cost of the system as opposed to a route which emphasises more renewable development and transmission investment.”

“I view it as ‘how are we going to get to 2035?’ And then ‘what’s the engineering solution beyond that?’ because we’re not designing the enduring solution right now and we shouldn’t pretend to we are...”

“...I’m naturally a markets person through and through so I think markets can solve the problem, but the idea of setting up markets for 2035 that can solve this problem is impractical.”

“There is a need for someone to grab the steering wheel and be a bit more directive in this period, so that’s why I’m supportive of CfDs as well at this point, even though I wouldn’t want to see them as the enduring solution forever, because that means markets have failed and it means the government are always deciding how much we need... we probably need that [CfDs] to get to the target, but then beyond that it should be up to us as consumers.”
