Figure 4: ESO: EV Charging Connection.

scenarios. When the battery is operational, the model will be matched to the measured data and analysed to improve the system's performance.

5 Energy Sub-Sector: Findings from Data Analysis

In the context of ESO, we consider energy supply through the lens of the transmission grid-connected batteries – the first in the UK. The battery is a hybrid, using lithium-ion and vanadium flow technologies and specialist battery management systems to optimise use, and trading activity in the energy markets.

The initial phase of the project (as shown in Fig. 4 [24]) sees the transmission connection / battery at the Cowley substation connected to the Superhub at the Redbridge park-and-ride via an 8km cable to, in effect, become a private network for this part of Oxford, with the scope for further extensions to serve bus, delivery and fleet depots.

5.1 Factors Affecting ESO's Energy Supply Subsystem

Factors impacting the adoption of battery projects are depicted in Fig. 5 below. We see that the lack of a clear government policy on battery development has hampered battery projects so far. Although "there's general statements of support being released from time to time, those only hold limited weight in planning terms… there's nothing in national planning policy guidance to say what we do with a battery" (E17).

In the absence of a clear policy, the regulators also lack direction, and, in turn, provide poor direction to those wishing to develop battery projects. For instance, Ofgem is considering a new transmission connection charge regime for connections to the transmission grid. But a one-size fits all charge would make the ESO project unfeasible (potentially imposing a charge of 'about £700,000 a year' (E14)). Additionally, connection to the transmission grid is a lengthy process with

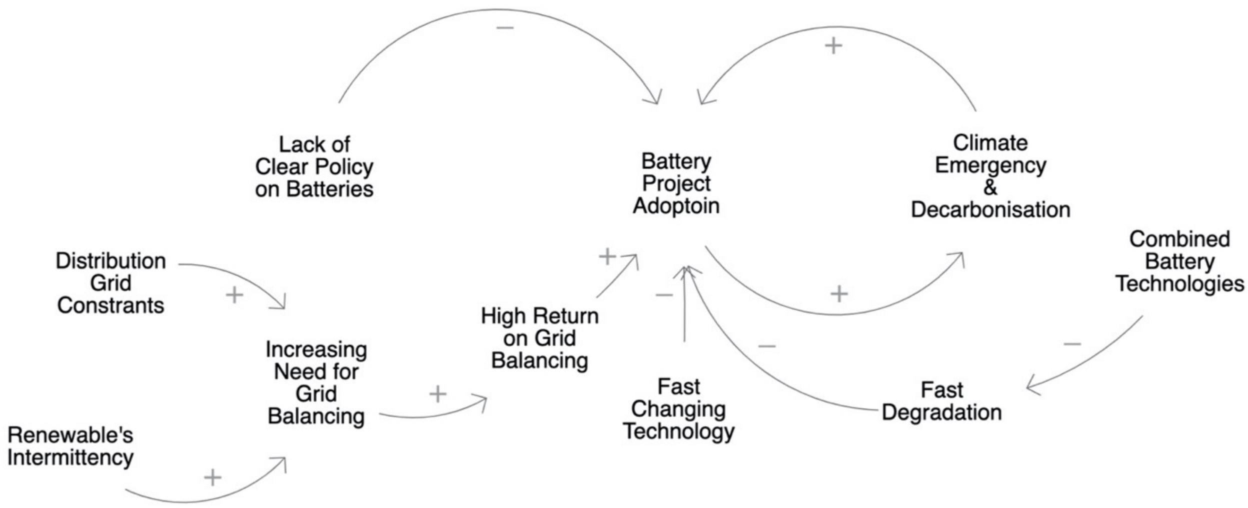

Figure 5: Factors Affecting Battery Adoption and Scaling.

detailed standards: 'to do the connection … you're kind of booking them a year or two ahead… switching off a part of the National Grid substation means a lot of energy needs to be rerouted' (E9) – this then becomes a critical date in the installation process. Similarly at the distribution grid level, the DNOs also have to manage connections and ensure sufficient capacity to meet demand. However, the adoption of battery projects is much needed, driven by the need for decarbonisation. This, in turn leads to ever wider integration of intermittent renewable generation sources into the distribution grids, while also having to face the constraints on the distribution grid's capacity. In Oxford, vehicle electrification was potentially limited due to such constraints. ESO's alternative solution - to directly link up a large battery to the transmission network and provide a private wire for EV charge stations, addresses both these problems. The battery can also access other income sources through participation in grid balancing services.

Another critical challenge in battery deployment projects is the fast technological progress. As noted by E9: "the technology is moving so fast, from the time that we can put in planning and started designing these sites to when we actually started building, the technology has completely changed… But you've got to freeze it at some point, so you'll probably find that each year, we're probably about a year behind what the latest technology is because it takes a year to design a site".

To address the challenge of fast changing technology, ESO is itself innovating with combining two battery technologies, aiming to optimise the characteristics of their use: frequent change/discharge of the non-degradable flow battery, reducing the degradation impact from use of the more easily degradable lithium one, only when the flow battery is depleted.

These innovative approaches demand specific components which come from a global supply chain: 'we manufacture the stacks which are a key component, in [Canada]…The structural shell of the system is made in China…. there's lots of other components ranging from nuts and bolts all the way up to a pump or programmable logic computer… they could come from anywhere, Japan, Sweden, South Africa… (E7) which can be impacted by unforeseen forces such as Covid or shipping delays.

Similarly, high voltage equipment isn't built in the UK 'you're going to Italy, Spain and Dubai to get this equipment… it can be up to 18 to 22 weeks for some of this equipment to arrive (E9).

5.2 Skills for the Energy supply subsystem

Below we discuss the skills required for ESO and those expected to be in short supply, as discussed by the interviewees from the ESO project. These skills have been aggregated into generic domain areas (e.g., energy supply, etc.).

5.2.1 Energy Skills in the Energy Supply Subsystem

Here energy skills are those related to the interconnections between ESO technologies and energy grid, both in terms of physical connectivity and for managing supply and demand.

- **Connecting to the transmission grid** (e.g. battery) requires both engineering skills and energy domain knowledge. As noted by E9, connecting the ESO batteries into the transmission network " is completely different from anything that anyone has done or even National Grid have done" which resulted in significant learning on all sides. In accordance with E9, the learning relates to "…working out how we'd do the protection, how we'd connect, what cables we need, what the transformers are". Though connecting elements to the transmission network is a well-established procedure [25], connection of large batteries is a new concern.

- **Commissioning Engineers** are required to oversee the transmission connection, trained to "a standard called a TP141, … there's not very many of them in the UK ... they're always so busy." (E9) The TP141 qualification can only be obtained through working for National Grid and requires a minimum HND / HNC or electrical engineering degree and substantial experience. Anecdotally, commissioning engineers are well-paid jobs where there is a shortage of suitably qualified applicants (based on a spot web search, 19/5/21 – e.g. job descriptions)

- **Integrating data analytics into grid operation and connecting grids to more digital platforms** is becoming a critically relevant skill, as 'the grid is fairly archaic; … and "we're really going through quite a large energy transition quite quickly. … in terms of where the skillsets need to be… you're thinking about smart grids, connecting grids to more digital platforms, that type of thing" (E18).

- **Upgrade/reinforcement of the distribution grid** capacity is needed to accommodate modern loads (E13), and although grid reinforcement skills are available and undertaken by DNO engineers at present, it is hampered by high costs, laborious processes and need for more personnel.

- **Distribution grid connection regulatory process flexibility**: The DNOs have rigid processes and requirements laid out by the Ofgem: 'stuck very much in, this is our way of doing things and this is what regulation says we have to do (E14)' - this is far from ideal as the energy system changes. There is a need to accommodate new ways of generating and delivering electricity to a wider range of consumers and to 'understand all of the different technological and team aspects that are needed to allow us to engage readily with small scale customers right up to major organisations or community groups that might have aggregated demand across a large area (E16). Thus, the regulatory processes for grid connection need to be reviewed.

- **Integration through APIs for dispatch and request flexibility**: The 'operational teams are looking at how we can have the interface … with the systems that dispatch and request flexibility. So that there's a real time interface - (E16).

- **Optimisation of battery use in energy market trading**: as batteries become a more integral part of the energy system, understanding the energy market mechanisms, the role of energy storage and how best to optimise their operation is key, with 'batteries sitting quite squarely in the merchant market providing all of these services (E18)' to different parts of the market, 'for example using a battery to trade in a balancing mechanism (E13). (Note: Successful use of batteries for trading requires software and data capabilities which are discussed in the relevant sub-section below).

- **Operations and Maintenance** skills ensure that there are no interruptions of supply. In relation to the transmission and distribution grids this responsibility falls to the National Grid (NG) and Distribution Network Operators (DNOs) but, as more assets are brought onto the system, these similarly need to be reliable so, for example with the batteries, the suppliers 'provide the long-term service agreement… [to] manage the assets throughout that contractual period… what we cover is the engineering and maintenance and the performance guarantees …. from an integration point of view to ensure that the assets are performing for the term at the levels contractually agreed.'(E18)

- **Real time network monitoring**: what the DNOs 'don't readily have on the low voltage network is monitoring. We don't know how much power is flowing through in real time on the networks. So all DNOs I think are rolling out monitoring devices and we've installed nearly a hundred in Oxford… it can give you if there's issues with maybe the power quality going through it...' (E16). As noted above, such monitoring requires significant augmentation of the network with monitoring device installations to start with, thus needing:

  – Monitoring device installations skills as well as

  – Monitoring information analysis and interpretation skills.

- **Upskilling of DNO skillsets**: There are multiple roles and skillsets required by the DNO, including:

  – '**traditional connections** skills and **account management** knowledge of the area and what our assets have got in terms of capacity' and,

  – from an 'innovation perspective, account manager, there was a **network planner, network designer, system planner** (E16). While these do not seem to be in short supply, they all require some degree of upskilling to relate their current activity to the changing energy system.

5.2.2 Engineering skills in the energy supply subsystem

Engineering in the context of the rapidly changing energy system is one of the key areas for supporting change, across a wide range of engineering disciplines, and it's 'important, getting the right people to those roles. So finding the right engineering skill, I think is key…the architecture teams, the software teams, the electrical engineers. You then have our civil engineers and our mechanical engineers as well who will spend time reviewing the solution and making sure that it's appropriate to work on this site. So I'd say those are kind of the key people (E7). All of these are explored below.

- **Civil engineering and construction**

  In terms of the infrastructure installation, 'it is essentially a construction project and so there's a lot of health and safety and planning permission and logistics' (E11), some of these are quite specific to the energy industry:

  – **Construction planning for battery project requirements** includes "a detailed understanding of the needs of the different elements, specifically battery and cabling, - which require civil engineering works, concrete slabs being laid and groundwork (E13). Beyond the planning stage, energy companies often 'outsource the actual construction, the design of the construction (E1)'. For the battery site construction, there is a need for 'preconstruction work:

    * **Checking suitability of the site for battery project**: looking at the sites, doing surveys, seeing what the buildability was like and advising them on what the best way to do it would be (E9).
    * **Planning a cabling route**: there is 'a question of land and how do you pick a route? There's a trade-off between going the shortest route which might be the most economical. But also getting a route which is compliant with environmental considerations. But also that the land is actually available' (E17).
    * **Risk assessments** might include "identifying structures which might cause us difficulties. So that might be bridges for example and how do we cross those? What are the implications? So a lot of detailed background work undertaken speaking with engineers and so on about how we might get across" (E17). We've learnt a lot about how we can get our private wire out to where it needs to go (E9).

  – **Adaptation of designs to context**: During the construction phase, a certain amount of flexibility is required in order to come up with the best solution for this new type of development within the given context 'to change designs quickly or come up with solutions quickly' (E9).

- **Electrical and electronics engineering**

  The core set of electrical engineering skills needed for ESO projects are what one would "expect a good quality electrical engineer to know … the basics of that connection is still the same" (E9). And the interviewees agree that there is no "immediate shortage of …electrical engineers" (E7). There, however, are some are specific areas where upskilling in relation to new technologies in needed, including:

  – **Battery integration into the high voltage transmission network** is a new task, and though connection of other assets to the high-voltage network is a well-supported process, batteries are a new and not well supported type of asset.

- **Multi-technology battery system design** is quite unique in ESO as it integrates different battery technologies. In this combination of batteries, for 'lithium you need to really worry about heating and cooling for the system to make sure that it doesn't go into thermal runaway and get into problems that way' [this compares with] flow, [where] you don't need to worry about the heating or cooling element because it's a liquid... What you really need to worry about is the pumping. So you need to make sure your pumps are running at the right time. So we have a similar kind of control question but it's not the same control question that lithium have' (E7). In battery design and management, "there are some choices to be made and there are some tradeoffs. So for example you could spend more energy to keep batteries at the right temperature but that would reduce your overall efficiency. You could prolong the life but that might be at the expense of efficiency again" (E13).
- **R&D in battery technology**: In the ESO project, batteries are a core component and technology is developing all the time – as we see here in the combination of Lithium ion and vanadian flow. Skills here are around "knowledge in terms of battery technology:
  - "...For example, we're looking at new types of lithium ion battery for our next tranches of procurement, obviously this is developing all the time" (E1)
  - where there are 2 different batteries with different characteristics, "What is interesting is taking the time to understand how a vanadium flow battery works such that we can then figure out how we optimise the two…. we'll need to have our models learn how the vanadium flow battery is performing over the course of the first six months". (E4)
- **Interface between mechanical and electrical engineering with electrical chemistry**: Battery design requires a wider engineering knowledge relating to chemistry, electrical and mechanical skills; 'I think there's quite an interesting opportunity at the interface between mechanical and electrical engineering and electrical chemistry' (E13).
- **Battery commissioning** is another set of engineering skills: 'to install it, test it and commission it… we have engineers that do all of that (E18) 'charging and discharging the batteries just to make sure everything is operating properly. That's about a six-week period, so it's quite a long period of commissioning with the battery… commissioning is where that actually took a lot of time to find the right guys'. (E9)

- **Software and Data Systems**

  A further group of engineering skills are about the data and ICT systems that wrap around the technologies to support optimal management. 'You need good software to manage [both the battery internally, and its actions in the energy trading market] and you need people with …quite unique skillsets to do that…' (E18). All of these skills are currently in high demand in the energy supply sector.

  These skills include:

  - **Software design [and implementation]**, '..what are you bidding for with the batteries? Is it fast frequency response? Is it balancing? All of these things are different mechanisms of trading. And writing the software for the battery management system or the energy management system actually takes months. So there's a lot of software and coding to be done' (E9)

- **Algorithm development**, based on the:
  * **understanding of battery operation**, e.g., In the case of ESO, where there are 2 different batteries with different characteristics, there is “the question of how we technically manage the two assets...” (E4)
  * as well as energy trading needs and constraints in the market.
- **Machine learning** to automate data analysis ‘- …all of the software is AI rules-based machine learning software. (E18)
- **Software Engineering** skills to:
  * Develop **battery optimisation** software to operate the assets of the battery in terms of status charge management, health. It can also be used for very complex integration (E18) and to
  * and **work with grid systems** e.g. in balancing and other service provision (E1).
- Data science skills as “we’re really relying more heavily on data and analytics… And I think that that’s going to become ubiquitous for all network operators and anybody taking part in the SLES really’ (E16) including:
  * Skills to “**collate, clean, and integrate relevant data sets**; … collate them into a set of parameters that can then configure the system so that you’re constantly aware of the state of health of the project. If for example you’ve got a high wind day that the system can then curtail the wind or not, or use the battery to balance it” (E18). Or to combine information about cables, transformers, capacity ratings, materials used in the construction with detailed projections to create the constraint mapping tools (E16).
- **Data analytics skills** e.g., for optimisation of battery use (by observing the state of the battery, the impact of discharge now or in the future, prices at present and expected, etc.) or look at the data from different data points to identify a particular piece of trend evidence etc,
  * appropriate **control of the battery technologies** (e.g., does this battery degrade? what is its efficiency (E13).
  * **Data management, governance** and **data cataloguing** as “...having all of this data being utilised in our business and trying to make it available for third parties to support this smarter energy, we need to maintain that data, and catalogue it so it’s readily referenced or searchable and used in different models… also maintaining the data lineage so, much like GDPR... So there’s a whole team for ensuring that data management piece … that will only become more challenging as we have more data across different systems” (E16).

It is worth noting that the industry has considered both the options to upskill the current workforce for the above noted skills and to establish an interdisciplinary collaboration, e.g. “… Do we take data scientists and try and turn them into engineers with data science or do we do that for the engineers? I think we’ve realised there’s a happy medium of just getting them to work together” (E16).

5.2.3 Trades skills in the energy supply subsystem

At a trades level, many skills are taken from other parallel sectors, although, in scaling up battery and other installations, **greater numbers are required** “if you’re only building the same design but you’re building it 2000 times, your R&D team doesn’t need to be 2000 times the size. …[but] you do need 2000 more times of resource for insulation and the people doing the wiring and the people who are physically doing things” (E7).

- **Construction** operatives often come from other parts of the energy industry, “building these things is not that dissimilar to building large solar farms and these guys are experienced…” (E1).
- **Underground cabling** teams ‘just install infrastructure all around the country whether it be for within the renewable sector, to wind farms… This is pretty standard stuff to them’ (E8) so upskilling does not seem to be required but availability is currently limited.
- **Electrical trades** need some upskilling to “… deal with the risky stuff of live wires and the like” (E16). These are specialised skills relating to battery electricals where “the guys are now starting to do the cabling and attaching all the cables and putting up the cable containment” (E9).
- **Battery installation**: with the larger Warsila “battery module install, where there’s 7200 of them to slot into position, 54 kilos each ….” This is a complex operation as the ‘modules need to be kept within a certain temperature range… so it is necessary to “get everything onsite and connected and power on to the containers so that the air con and the climate control can be working and then we put in the batteries” (E9). This requires some basic upskilling for the installers.
- **Operation and maintenance**: installations of all types also require teams to be available to operate, make repairs, carry out regular maintenance: ‘we will maintain and operate that for 25 or 30 years. It will get annual servicing, again it’s very standard stuff in infrastructure (E8) although skills specific to new types of energy installations (for batteries) require a degree of upskilling.

5.2.4 Managerial skills in the energy supply subsystem

In the context of ESO and the energy system, management skills are needed across a broad spectrum in order to bring together stakeholders; manage construction, safety, quality and risks; and monitor and report on outcomes. It was recognised that senior leadership is important, so “ensuring that we have that leadership being driven from the very top” (E16) is critical. In all of the management areas discussed below, **communication** and **reporting** skills to senior management, funders and partners are also very relevant.

- **Technical Management**
  - **Technical project management**: “the first place businesses go to are R&D, proof of concept, product engineering, mechanical engineers, electrical engineers. And they create something” (E7) Engineers from different disciplines then need to be able to communicate and collaborate in the “detailed design phase. … involving the battery supplier

who is Wartsila, as well as the engineering team from Arun [construction], and Burnell were then brought in because they're doing the electrical substations and the connection design… and the guys from National Grid …actually all talking to each other" (E9). Technical project management skills are then critical in ensuring the clear engineering collaborations and communication processes are in place.

- **Project management**: skills here require:
  - **Cross-domain understanding**: for complex and innovative projects such as ESO, good project managers need to "understand the electrics, you understand how a connection works, you understand the construction, you understand the quality, the health and safety" (E9) so that there is "a project manager that can oversee all of those elements ... And there's a huge amount to learn" (E8).
  - **Simultaneous coordination of multiple work streams** is an important skill and whilst it "is not new it's definitely pushed management and organisational skills" (E8). In the specific battery context, there are processes to "install it, test it and commission it. We have engineers that do all of that. And we tend to have dedicated project managers who will manage all of those work streams" (E18).
  - **Knowledge of construction and electrical infrastructure** is a specific combination of skills: 'looking at a site and how we're going to build it and the process that we go through of that construction. Generally it's knowing what needs to plug in where, even if you don't really understand how it all operates, it's knowing what cables go where, how you would install steelwork, how you would install the foundations (E9) and being conscious of programme timelines and lead times for different aspects of the build. The battery operators also have a role as 'it's our equipment that's then going to be then sitting on that component …so it has to be suitable to bear this kind of weight. It has to be suitably flat. It has to be in this location so that we can actually unload onto it, … to try and make sure that the best process is followed so that our equipment will work when it gets to site (E7).
  - **Risk management for major electrical installation**, e.g. battery: "So it's a risk management process as much as anything" (E17). In looking at cable routes, "there's some very targeted risk assessment that needs to go on for engineering difficulties like bridges or aqueducts if you were crossing those" (E8). Here such techniques as "feasibility study of the cable route" must be carried out.

5.2.5 Finance and Business skills in the energy supply subsystem

Underpinning the project delivery are the business and financial arrangements that ensure projects are profitable and that business models identify growth potential in this rapidly changing sector. The skills in short supply here are:

- **Developing the energy trading business model**: In addition to the usual business model development (e.g.', …trying to work out what the project looks like. What the costs are … the rate of return…What are the risks in the project'? (E7) and '… know[ing] how the investment community works and how to raise investment" (E18) etc.) an additional layer of knowledge required for ESO-like projects is understanding how the energy markets work and the current commercial energy market opportunities. "A modelling element which is really important which is about how those batteries are going to be used as they're connected to the grid to support a business case and a lot of that is about prediction of energy demand, energy pricing and the like'(E1). There are many concerns in ensuring profitability, including being "very aware of markets and what's driving these projects, what's driving the investor appetite … in the UK it's very much a revenue stacking model, less contracted revenues, although capacity market lately has delivered some very good results. But we understand that and always look at that in terms of the project, how the project is going to make the money as well" (E18).

- **Business development** skills relate to the senior management's ability to "take a finished product out to market" from an R&D stage "through to something that can hold its own" (E7). The skillset that "wraps it all is really business development, so it's creating the opportunities, getting the teams together, … there's lots of multifaceted skills in there, sort of team management, financial modelling, understanding to a certain level, technical end-product information. Understanding the markets and the market dynamics. Competition. All those sorts of things you sort of have to keep the pulse on to keep these sorts of deals going forward" (E18).
- **Procurement** skills require familiarity with the supply chains, production processes and lead times for the technology used. Including:
  - **Understanding of the global nature of the supply chain** and the potential for delays (E7) as parts might need to be delivered from China, Europe etc.
  - **Understanding the process of sub-contracting** e.g. using a "preferred supplier who really is a battery systems integrator [to] bring the whole design and delivery together" (E1). Sub-contracting requires an ability to discern best possible suppliers as well as to consider what quality assurance clauses and constraints to specify for this newly forming business domain.

5.2.6 Legal skills in the energy supply subsystem

Legal skills are needed for developing contracts for land and electrical connections, for data and for agreements on how different parties work together and their liabilities.

- As with other parts of the energy system, we find that often smaller businesses employ 'an external legal team and it's a huge amount of work from them to come in and be specialists on individual contracts. So you need **legal professionals who have a very good understanding of energy and renewables**. And there are some of those people around and they are very valuable" (E7).
- **Setting up land agreements for energy supply projects**: In relation to land for cabling and other infrastructure "negotiating any agreements with landowners… in terms of what kind of land agreement values, the amount of money within those agreements that would be reasonable. And … legal agreements…. on everything to do with electrical connections and the commercial arrangements of those, so how the landowner can strike a commercial deal with the charge point operator/asset owner and the person that's bringing in the energy onto the site. Whether that's a DNO, or whether that's someone like Pivot, you want to have quite

a specific skillset within there. So the legal teams need to understand what those commercial agreements could be. And it's not to say that we're not coming across people like that but you would need many more of them I imagine if you were going to do 50 of these" (E8).

- **Data management in energy sector**: "Legal and commercial is one of the big ones in terms of making sure that those new interplays with third parties can take place. Because the sharing of data, different organisations have different acceptability in terms of liability and also what they're prepared to accept in terms of different terms and conditions. It's fairly standard but we've seen when it comes to sharing of data and good old GDPR and also liabilities, you start talking about putting in 5, 10, 15 million pound liability clauses, it's certainly not going to fly with some of the smaller more tactical organisations that we need to work with" (E16).

5.2.7 Policy and regulation skills in the energy supply subsystem

- **Local government's land use planning policy** is a key area in the development and business context – it also has a role from a wider policy perspective. Local planning policy can enable or block energy developments and early liaison with planning departments is important – to help influence the direction of policy as it is made and also to help interpret existing policy in a beneficial direction. Getting planning consents for a "battery … was very much a new thing when we started off doing this, … The planning authority at that point had very little idea as to what to make of it. That experience has been replicated elsewhere in the country" (E17). From a policy perspective, "you've got the planning policy aspect for where we're creating the policy case, the planning is about demonstrating your compliance for policy or otherwise persuading the planning authority that it is a reasonable development to pursue because there are other mitigating factors" (E17).

- **Connecting with/lobbying policy makers** "is about intelligence gathering and it's about understanding what is driving a particular council ... What are their aspirations for dealing with climate change? Do they understand what a battery can bring to that process? Are they aware of any electrical constraints which they have within their area? Have they considered where their power is coming from for the other developments which they are proposing through their development plan? So I think one of the key things in this process is identifying the movers and shakers.… as much as it is technical, it's also very much about people and bringing those people onboard and along with us for the journey" (E17).

- **Standardisation of battery data and APIs**: In order to maximise the potential for local energy systems, different components need to be able to communicate with each other and "you don't want to encourage monopolies. If you want some kind of modularity between a company like Habitat and a company like Wartsila or whoever is supplying the battery then there needs to be an open standard for how the two things talk to each other, not a closed standard. And I think those kinds of discussions are not yet complete and concluded… In the end I guess it requires lots of different players from industry to come together and find a compromise. And government, Ofgem, and regulators" (E13).

- **Fostering flexibility markets through national policy**: this relates to the role of Ofgem in bringing in "points from the clean energy package … needing to signpost flexibility to the markets. Needing to be very transparent about the development plans and where there's likely to be constraints on networks and where we're likely to see uptake and increase in demand in future" (E16). This relates particularly to the role of DNOs in ensuring adequate future infrastructure by bringing in "a lot of policy requirements that should stimulate the industry to understand where some opportunities [for investment] might lie" (E16).

5.2.8 Soft skills in the energy supply subsystem

Soft skills support engagement with new energy approaches and help to bring people and organisations together to collaborate for common goals. These skills include:

- **Stakeholder engagement**: this varies from "being able to manage that relationship with the Council" (E1) and "trying to up their level of understanding about what this is all about. What the battery can do for that authority" (E17), to including organisations who might in future connect to the battery project. Another area is engaging with groups like the EV energy taskforce that the government set up to try and bring together energy and automotive industry players.
- **Public engagement and understanding**: within the industry, it is recognised that there is "a slight skills gap in … understanding customer behaviour related to energy… [and] relying on academia or consultants during projects" (E16). Public understanding and acceptance are essential for acceptance of energy projects (E17).
- **Communication skills** are needed to explain the project message to different audiences, using correct terminology with no space for misunderstanding, e.g., "to convey things in laymen's terms but also rapidly switch to the other end of the spectrum and converse in great technical detail if it's needed in that same meeting." (E16)

5.3 Training for the energy supply sub-system

5.3.1 Training needs

In relation to new training areas, there are some specific needs highlighted:

- **Battery design as part of engineering degree courses**: '…it would be great to introduce battery storage understanding into electrical engineering courses …or other engineering courses so that students could start to understand battery cell chemistry. Where batteries are applied, why they're applied…battery across the board would be great to be introduced into these types of engineering courses (E18) … 'to find people with large scale battery storage skillset is not always that easy. It's still fundamentally quite a new market and I think it's not necessarily taught in colleges yet.'
- **Business courses need to include new models for energy**, for example "at MBA level where a student could start to understand how to finance or build a business model for a renewables project" (E18).
- **Understanding all of the elements that go together for battery projects**: "if you were a company and looking to develop skillsets to develop these projects, I think it's having people that understand all of the elements that pull together battery projects" (E18).

- **Collaborating across disciplines**: for example, combine data from "different types of datasets, be they temporal, spatial, behaviour science... You've got to have the ability to look at socioeconomic factors. So there's a number of aspects there and also combining them with traditional engineering" (E16).

- **Combining traditional engineering and trades skills with new IT and data**: "a lot of old boys who are very good at really getting stuck in and getting covered in grease and oil and mud … And then you've got modern whippersnappers … [who are] quite adept at data. And it's around trying to see how that skillset requirement matrix changes so that these skills can be brought together and there is mutual understanding across skillsets" (E16). "… The software piece …has become much more of a high priority in the last years. And we've realised that we need to teach undergraduates more about software engineering and coding" (E13).

In all of these knowledge areas, it is necessary to deliver skilled people at scale to support the scaling up of initiatives helping to make change happen: "we're not looking to bring in one person, we're looking to bring in 10. … it's really part of that scaling up because if the business then takes off you then don't have to wait three to six months for that software person to get up to speed, they've been there for three to six months and they know how it works" (E7).

5.3.2 Modes of Training

Training can be delivered in different ways and, as there will be "a step change, in terms of energy and society, we need to rethink how we handle that training" (E16) in order to bring new skills to a range of energy professionals. The noted training modes include:

- **Under- and post-graduate education**: Engineering is key to so much of this, so university courses have a critical role to play in ensuring sufficiently qualified professionals for the future energy system. However, some universities are not "particularly good at changing quickly as an institution" (E13). This is across engineering courses and undergraduate and postgraduate course need to stay current and could benefit from "actually going out and asking what industry wants" (E13), although there can be some reticence from academia to been seen too "subservient to industry".

- **Internal upskilling** is a common practice and often happens through:
  - **'internal knowledge sharing'** (E18), carried out in-house (E16) or
  - **'learning on the job'** (E16). With bespoke systems, 'there really is only one place to get those skills from and that's spending time working on our systems. So there's no course you can go on, there's no external training you can get for this. You just need to spend time with our control engineers (E7). In some organisations, there is 'very much an ethos in the business to knowledge share, be open, key learnings, if you get it wrong why did you get it wrong, learn from it, that constant continuous improvement (E18).
  - **Some businesses train new recruits by shadowing existing staff** members or
  - **using placements** through the business to learn about different aspects, this is especially good for graduates or junior staff.

- **Collaboration instead of additional training**: “there’s a question we have internally of do we try and upskill one or the other? Or do we actually just get them to collaborate? Do we take data scientists and try and turn them into engineers with data science or do we do that for the engineers? … there’s a happy medium of just bringing them together and getting them to work together” (E16).

- **School education**: “having something in the curriculum that helps children understand what are the interplays between the environment, society, energy, transport, heating, whether it sits within geography, physics, or another course… with the onset of technology being readily incorporated into the curriculum we’d really like to see that whole system piece being brought in as one of the subjects…. if we can start to shape their thinking from an early age, I think there’s a double benefit there, they might join the industry, they might help advance it. But they also might just be willing to adopt new technologies and new processes” (E16).

- **Beyond interns**: in these highly technical areas, “hiring interns is kind of not so possible with things like electrical engineering because you have to have experience. … there’s an additional set of training that has to happen” (E7).

5.3.3 Recruitment for the ESO-like green energy supply jobs

- **Beyond consultants, matching salaries**: In relation to recruitment, ‘with the innovation projects … over the last probably ten years or more now, we’ve always brought in third parties where they’ve had the skillsets that we haven’t. Or the bandwidth to accommodate the work …. utilising academia, consultancies and also just traditional technology or engineering firms. Recently we’ve started to bring some of those skillsets into some of our more business as usual and innovation stimulated aspects (E16). It is increasingly necessary, as these types of initiatives scale up, to ensure that the right skills are available in-house – and that different parts of the sector can attract the right recruits. It was suggested that the regulated parts of the energy industry – DNOs for example ‘don’t have the same pulling power in terms of benefits package, the salaries can’t match consulting firms. (E16)

- **Green / societal drivers**: There are other motivations for working in this area, where you can ‘really make a difference to society’ (E16) which is seen as a significant draw, alongside addressing climate change, especially to ‘graduates and skilled young people … that next generation really does have this at the forefront of their mind … the green companies are starting to lure a certain type of candidate into the industry …. The climate strike, you look at everything that all the business is doing from a green perspective, it is a good place to work, so we do get some good candidates for roles. (E7) Other draws to working in future-looking energy businesses are ‘their values and the type of people they are’ (E8) and ‘joining a small business where you have impact, … in a business that’s say 100 people, your ideas will be heard, you can really make a difference’ (E7)

- **Engineering background**: Inevitably, there are ‘a lot of people from engineering backgrounds. … by and large it’s people who have done engineering degrees and have also then done some sort of environmental piece on top of that’ (E7) and ‘finding the right engineering skill, I think is key’ (E1): ‘an electrical engineer who has a strong history in control systems for example who has worked on lots of electrical engineering projects for big companies, would likely be a very good hire' (E9). With batteries, specifically, 'all the calculations, it's very engineering based, maths based, there would be electrical engineers or engineers background in that' (E18)

- **Graduates**: In relation to attracting graduates, it is 'a challenge to outreach for people at university … a lot of these jobs are new on the market and I think that a lot of the milkround [big] companies have a little bit too much exposure actually on university campuses, at the expense of smaller companies who probably just don't have the resource to go and woo clever undergraduates. (E13) Without these formal connections to universities… 'at the moment it's very ad hoc… personal connections. …. These companies can certainly reach out to the career services and meet students like that (E13). Students with engineering degrees are equipped for a wide range of future jobs but universities could do more to emphasise how climate change 'is a real challenge that's going to require a huge range of skills and it's immediate' (E13) and that engineers can make a real difference with their knowledge rather than being "lured by the high salary and jet set lifestyle [of consultants or banking which] they do for a couple of years, realise that it's actually pretty tiring and they then go back and do something else with a bit more near term impact" (E13).

- **Moving from other parts of the energy sector**: On the trades side, workers have often moved across from fossil fuels to other parts of the renewables industry. E.g., "Our installation team, … previously worked for onshore wind, [but] as onshore wind slowed down a bit … they then became people who were green focussed, who were very focussed on sustainability and innovation and didn't want to go back into oil and gas" (E9).

5.4 Insights and recommendations for the energy supply subsystem

We have focused here primarily on issues to do with energy supply, and new, localised approaches to engaging with energy markets. In relation to the technologies deployed in ESO, particularly with regard to batteries, private wire, transmission connection and the interplay of regulator, NG, DNO and commercial business, we note the following key skills issues:

5.4.1 Digital Innovation Drive

The 'smart' in SLES increasingly applies to the whole energy system and all aspects need to be technology-enabled in order to communicate across systems. This necessitates **upskilling across ICT and data management**, from systems to manage battery charge / discharge and trading, connecting across different battery types, DNO systems etc. **All** engineering courses need to include aspects of ICT and data management.

5.4.2 Need for Cross-Disciplinary Expertise

The increasing need for **mixed disciplinary backgrounds** (cross-siloed education and experience) arises from the increasing complexity of work that employees in SLES sector have to undertake.

1. **Engineering** as required by industry is often a **mix of different disciplines** and engineering courses need to teach these wider skills – for example an understanding of electrical, software, electro chemistry, design, mechanical and civils in addition to the deeper knowledge of a particular engineering discipline.

2. **Project managers** similarly need to be multi-skilled and adaptable, bringing core engineering knowledge alongside communication and collaboration skills to support the development and roll-out of local energy systems.

3. The alternative is for the professionals from the relevant disciplines (e.g., data analysts and software engineers) to **closely collaborate** together. This has been the established method in other areas, however, it introduces its own complexity of communication and cooperation.

While cooperation requires two (or more) employees working together, mixed-disciplinary education can be time consuming and expensive. Specialist (mixed-disciplinary) educational programs would be required for, at least, the most common mixed-background skills needs (e.g., software engineering with data analytics skills).

5.4.3 System-wide Engagement

Success of SLES projects (such as ESO) is critically dependant on system-wide engagement: from policy making at national level (setting the regulatory and long term funding scene for these emergent energy service models), to collaboration with local authorities (who provide access to local land and resources as well as act as a potential major service consumer) and integration of citizens (as key clients) with the project services.

- In relation to national policy, we see for example how **planning and government policy** has not caught up with batteries as part of energy infrastructure, which causes regulatory confusion and policy change risks, dis-incentivising investment into batteries. Thus, clear, long-term and joined up policy – at national and local levels – needs to be set as soon as possible. In ESO this has meant that policy makers had been engaged with and educated on the role of the energy system and its components (batteries and EV charging infrastructure in this case). Policy makers need better education on the relationships between energy system and their impact on other policy areas – such as net zero, climate emergency, mobility, warm homes etc.

- **Local authorities** (as major land owners, service providers and users as well as local policy makers) are, therefore, a core actor in local scene-setting for policy and regulation for SLES and need knowledge of the energy system, climate drivers and how batteries, digital energy services and alternative energy provision can help.

- While engineering skills sit at the core of the changing energy system, **collaboration and engagement** skills are vitally important in order to bring together strategic partnerships, broker agreements and engage and bring the public along with the new systems. This engagement piece is at all levels, from engaging with schools, across university disciplines, in recruitment, with local partners and citizens and for lobbying locally and with national government.

5.4.4 Upscaling Battery Projects

- Batteries at scale, such as deployed in ESO, should be seen as a core component of the energy infrastructure in the future, so there needs to be a significant upscaling of **skills associated with battery design and deployment**, including the knowledge of changing energy markets and how to engage in flexibility, balancing and trading.
- With the growth in new types of localised infrastructure, the **installation skills** also need to exist locally across construction, cabling, electrical connection, transmission connection etc. As noted earlier, there is a particular need for TP141 registered transmission-qualified commissioning engineers to enable greater use of large-scale grid connected infrastructure.
- New entrants to the energy sector bring new ways of working and **new business models** which then need to grow and develop, so good business skills and a broad understanding of energy markets and how they are changing is essential for scaling of SLES. Incumbents are also changing their business models and need to be able to be increasingly flexible in order to work with these entrepreneurial innovators entering the sector and help to address Net Zero targets.

6 Transport and Mobility Subsystem: Findings from Data Analysis

Electrification of transport is a significant part of the ESO project and consists of:

1. the installation of different types of EV chargepoints and associated infrastructure
2. trialling of electric vehicles within the City Council fleet (managed by Oxford Direct Services – ODS) and with taxi drivers.

6.1 Barriers and enablers for the transport and mobility sub-system

Factors impacting the roll out of EVs and associated infrastructure are summarised in Fig. 6 below.
Local and central government policy A key enabler for the project is local policy implementing a zero emissions zone for the centre of the city which makes EVs a necessity both for "Oxford direct services [which] need vehicles to go into the city centre to collect rubbish, clean the street, work with the homeless, go to the parks" (E2) and also for taxis. The zero-emission zone also means that businesses and the public wanting to drive into the city centre will need appropriate vehicles and "it makes sense to have a couple of these high power hubs around the city centre and the Park & Rides and the accessible area so that drivers can really meet the needs of the zero emission strategy" (E15).
Disjointed policy:
Planning policy, however, does not always join up with climate policy so it can take time to get planning consent for infrastructure which is directly addressing net zero needs.

EV charging infrastructure:
In order to accelerate EV take-up, charging needs to be accessible and suitable to the location but there are some barriers: