Smart and agile local energy systems hold the key for broader net-zero energy transitions

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***Abstract*—The UK has centered itself in the global race to mitigate the impacts of climate change with ambitious plans announced in 2019, committing to the elimination of the UK's net contribution to greenhouse gas emissions by 2050. These targets will require a transition of a historically inelastic energy system within a closing window of time. Our paper presents a whole system approach which argues that decentralized and distributed energy resources operating at grid-edge need an agile trial framework with multi-perspective and experienced stakeholders to develop balanced and well-supported network flexibility services. Incubating these new grid-edge network services require innovative markets, operators and digital infrastructure, particularly at local scales. Based on preliminary findings from a UK perspective, Project LEO, we propose a framework around the restructuring of local energy systems which reduce uncertainty through an innovative 'ecosystem' that gives room to failure while minimizing risk to extract value and learnings.**

***Index Terms*— energy transition, demand side response (DSR), distribution network operator (DNO), flexibility services, smart local energy system(s) (SLES).**

I. Introduction

In 2019, the UK Committee on Climate Change published a report urging broader policy changes to the removal of the UK's net contribution (net-zero) to global warming by 2050 [1]. When the government committed to this target in 2019 the UK became the first major world economy to adopt such an ambitious policy. The previous commitment ratified through the Paris Agreement set out for at least an 80% reduction from 1990 levels. The revised target places Scotland with a timeline set 5 years earlier (2045) owing to the country's pre-existing capacity to remove emissions compared to the UK as a whole. Wales has committed to at least a 95% reduction by 2050 relative to 1990. The Paris Agreement has spurred more evidence-based frameworks for more sustainable transitions and guiding bodies of literature such as the UK Climate Projections 2018 (UKCP18) [2] were used to inform current targets. The latter focuses on key climate 'forcings' such as predicted global temperature increases of 2.0-3.7°C and sea level rises of 1-2 m by 2100, and these global challenges will require local solutions to better frame broader policy. Specific to the UK, climate change has increased the probability of hot spells (>30°C maximum daytime temperatures), rising currently from an average of 0.25 occurrences/year to 4.3 by 2070. By the end of the 21st century, all areas of the UK are projected to be warmer (skewed to summer rather than winter) [2] and as much of the UK's decarbonization needs to revolve around gas-powered heating systems, climatic implications are pressing drivers in the energy transition. Engineers are faced with new challenges. We are no longer designing networks on historical models to address technological and service impingements, but where future scenarios and environments must be accounted for. The UK's energy transition will see swaths of the national grid become increasingly electrified and careful planning frameworks are needed to ensure effective energy systems and markets post-transition.

A. Congested and dirty energy streams

The UK's electricity system, like many other mature markets, can be distilled into three main components: generation, transmission and distribution. Here, we will focus on the electrical distribution network where electricity is converted into low-voltage (LV) networks (≥132 kV) at an annual retail cost of ~ £55 billion for residential and business consumers [3]. The UK has 14 licensed distribution network operators (DNOs) which fall under the umbrella of six larger companies (Electricity North West, Western Power Distribution, UK Power Networks, Northern Powergrid, ScottishPower and SSE) [3]. Fostering accelerated energy transitions will begin at these distribution connection points where consumers play an active role in unlocking grid decarbonization. Increasing renewable energy deployment will require innovative and flexible services to allow increased generation capacity from alternative fuels on a grid designed for unidirectional power flow. DNOs will thus play an important role as operators at the grid-edge and need to transition to distribution service operators (DSOs) to open grids for increased flexibility without the high-capital, short-term solutions of network reinforcement. The increase in electricity demand and distributed variable generation systems requires near-term approaches that can defer reinforcement until more certain futures become clear, thereby protecting against ill-planned measures through 'least-regret' options. Flexibility services and demand-side response (DSR), partial distribution alternatives, can see saving of ~£4.55bn/year in the UK by avoiding network capacity limits, generation peaking, and the curtailment of renewable energy systems [4]. For instance, where electric vehicles (EVs) are concerned, 28% of UK's LV distribution networks will need reinforcement of infrastructure to accommodate a 100% (and uncontrolled) charging fleet of residential EVs by 2030 [5]. However, only 9% of networks would need upgrades through smart charging systems at the distribution level. In a 2019 report, SSEN reported that ~48% of their bulk supply points within their southern license area are constrained [6]. Yet, challenges remain whereby learnings on decoupling energy systems from carbon-intensive networks often remain inaccessible behind private and commercial activities, limiting accelerated adoption through a lack of open multi-stakeholder environments.

B. Innovation through a Lean Approach

As digitization increasingly becomes an enabler for smart systems, our framework for smart local energy systems (SLES) transitions is also inspired by software development protocols where we propose a "*build-measure-learn*" model to tackling complex issues in energy markets. These shortened assessments of change will accelerate development to unlock learnings and strategic growth in line with the rapidly evolving needs of the system. These Lean Approaches (LAs), which ground much of our findings in this paper, are key to fostering agile energy systems that allow for iterative change mechanisms without having to rely on broader and sweeping market changes. Our paper will examine a Lean Approach for SLES, basing our framework around learnings from the UK's Project LEO (Local Energy Oxfordshire). We will examine the historical evolution of the Theory of Change (ToC) management and how it can be implemented into local energy system design to facilitate complex yet adaptive systems which evolve in rapidly changing environments while minimizing risk. Recent findings from Project LEO, a multi-stakeholder consortium of leading academic and industry partners, demonstrate the difficulties that local energy transitions face and the careful coordination between active agents to increase energy access and provision through sustainable and commercially viable pathways. We will extract learnings from the first year of Project LEO to highlight how agile and lean energy transition models can more adaptively incorporate energy data management (baselining, service validation), wider community engagement, neutral market facilitators, fast followers and other key components of smart energy systems.

II. Many Agents, One Energy Ecosystem

Project LEO is a £40+ million multi-stakeholder consortium which places Oxfordshire as one of the largest testbeds for local energy systems in the UK. Announced in April 2019, Project LEO is funded by the Industrial Strategy Challenge Fund (~ £13.8 million) which is managed by InnovateUK, and private funding from project partners (£26+ million). Achieving net-zero goals demands smarter networks and operators which foster holistic and equitable approaches to tackling power, heat, and transport systems. Operating on a local scale, Project LEO will sync the operations of the DNO, SSEN, with industry, academic and local administrator partners[1]. This partnership aims to extract value from innovative market platforms and flexibility services where the ToC allows the project to morph to the needs of the local energy system. We define '*local*' as the area served by the network falling under the operations of the DNO, SSEN, within Oxfordshire, UK.

A. Energy Ecosystems

The UK's energy transition will gain empty outcomes without the strategic and well-coordinated planning of multiple stakeholders, each with their own goals for net-zero targets.
System transition on the scale required to meet net-zero targets requires an appreciation of the aspirations of all system stakeholders and thus frameworks must facilitate a multi-perspective approach, recognizing the diverse needs of various 'energy agents'. The participants, interconnecting processes and monetary flows are evolving towards a systemwide optimum that maximises social value, thus the term '*ecosystem*' is used.

B. A Lean Approach based in the Theory of Change

1) Foundations

The ToC management has been attributed to Lewin (1951) where his book [7] laid much of the foundation for the application of agile feedback loops in many modern industries. Lewin postulated that behaviour must be derived from a totality of coexisting factors which make up a "dynamic field" [8]. In fact, the development of his book draws on this theory, where papers published from 1939-1947 formed the 'totality' of his theory, much like the iterative system that many industries now incorporate into their operations. For instance, a well-cited paper by Spear (2005) [9] demonstrates how the U.S. healthcare system can be improved through agile change mechanisms which do not rely on legislation or market reconfiguration. Incremental mechanism can be introduced to tackle dauting issues in a sector. Spear also draws on other industries such as with characteristics of change at Toyota where "*dramatic cure-alls*" are avoided but instead broken into smaller and more manageable pieces that can facilitate a stream of iterative changes that merge to a steady-state optimum.

2) Industry inspired agility

Lewin's field theory has evolved into many various systems of change management, each applying change theory to garner accelerated growth. Innovating, particularly within increasingly digitized environments involves the navigation of complex issues [10] with very nuanced solutions and the

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design of Project LEO has been influenced by Lean Startup Approaches. The latter works to support entrepreneurs, allowing for the validation and innovation of their business models through fast feedback loops that have led to "*build-measure-learn*" approaches to growing startups [11]. Project LEO has adapted these LAs to local energy systems in the UK, conforming to a similar "Action, Analysis, Reaction" model which is liken to software development through versioned testing and deployment of products.

Fig. 1 shows the internal and external flows adopted in Project LEO which are underpinned by the Minimum Viable System (MVS) procedure to extract key learnings from activities. Progress is tested through a series of MVS trials which involve all system participants relevant to the service being tested. These are quick, low-risk, iterative trials which feedback learnings in an agile manner to all participants. This loop in turn influences both future MVS trials and individual stakeholder components (minimum viable products, MVPs, in the classic LA) accelerating system learning, and the subsequent evolution of the ecosystem itself. The focus of MVS trials in year 1 has been on the essential technical infrastructure to quickly set up a basic flexibility market. In an attempt to coalesce like learnings, MVS trials have been grouped into five sub-categories: *Prosumer*, *Generation*, *Smart Neighbourhoods*, *Aggregators*, and *Portfolios*.

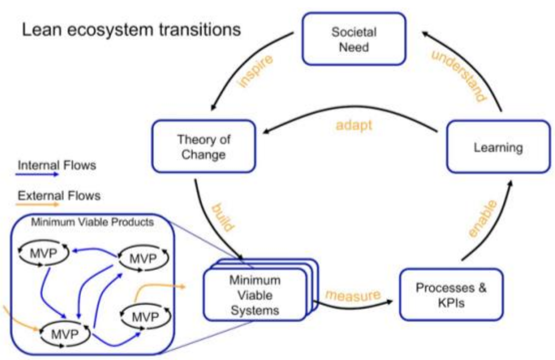

Figure 1. The Lean Approach (LA) utilized in Project LEO.

As the trials mature, learnings will increasingly shift towards the social, commercial and regulatory needs for a functioning local energy system. The MVS approach will also be applied to supporting elements such as 'Future System Planning', 'Informing Policy' and 'Building Communities of Skilled People' in later phases of the project. In mature stages of this feedback loop, MVSs are associated with Minimum Viable Products (MVPs) which are versioned services that add value to the energy system.

III. MVS EXAMPLE: VALIDATING FLEXIBILITY SERVICES

Flexibility within grid systems allow the DNO to address network constraints of various types and Project LEO has trialed these services through a utility market facilitator (Piclo) whereby asset owners (flex providers) can bid on registered DNO service requests. These services are particularly interesting to prosumers, both domestic and commercial, who wish to increase self-consumption of non-dispatchable renewable generation or avoid high network costs. The increase in flexibility services is important in the wider UK context as they will reduce the cost of operating the network in a future of more commonly electrical demand and variable generation.

Within this section, we demonstrate the key technical, commercial and procedural learnings from an MVS using a registered prosumer (generation and consumption) battery asset on the network to provide the delivery of a 30 kW downward flex in demand for 1 hour. The asset site had two 24 kW, 90 kWh batteries which are intended as a buffer for electric bus charging (due to import capacity constraints) and along with the 140 kWp co-located PV, the site provided Project LEO the opportunity to investigate necessary procedures and infrastructure for multiple market participants. This MVS set out to trial the delivery of a reduction in demand on the network using a known battery asset that SSEN could call upon to address a theoretical constraint. Using the LA developed (Fig. 1), the MVS assessed the *Prosumer* sub-category of energy services, relying on procedures which guide all associated partners through the trial, from asset registration and the DNO tender for flexibility services, to the dispatch of said services and eventual settlement of payment to the flex service provider(s). Pre-MVS testing uncovered the improper configuration of the battery by the manufacturers to allow for bi-directional charging at the site. These misconfigurations led to many procedural learnings that further led to widespread changes in the assessment process. Nontechnical questions around penalties to flex providers for failures to deliver were raised and many insights were gained through the two MVS trails with this battery asset.

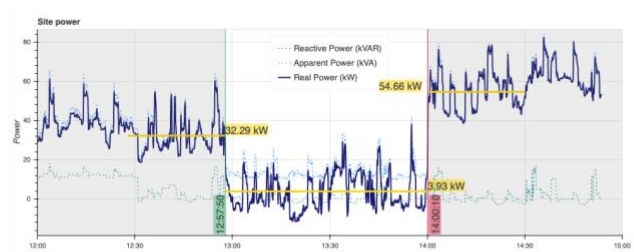

Figure 2. Power traces measured at the battery asset site showing the flexibility event. The annotations are determined from a convolution algorithm for step change identification. The algorithm was applied to the real power trace.

High-resolution monitoring at both the site and SSEN secondary substation feeder, in addition to standard commercial half-hourly meters, allowed for detailed technical analysis of the service delivered. These MVS trials were used to inform future decisions regarding metering requirements as tolerance and validation criteria are developed within Project LEO. Substation monitoring also provided the opportunity to measure the differences observed in service between the site and substation as a result of line losses. An algorithm utilizing a convolution between the real power measured at the site with a step function was used to automatically detect the change in power at the site which is shown in Fig. 2, during the service delivery window of 12:57 – 14:00 on November 18th, 2019. This MVS trail (second) showed a reduction in site demand from 32.3 ± 8.3 kW to 3.9 ± 9.0 kW, a shift of -28.4 ± 12.3 kW. However, as there was no monitoring directly on the battery, these values will include other variations in site load and PV generation which is likely the reason this is slightly below the expected 30 kW. After the service delivery, a shift in power of +50.7 ± 13.1 kW to 54.7 ± 9.5 kW was observed. This shift was higher than the power before the event by 22.4 ± 12.7 kW, largely a result of the batteries charging immediately following the event at an expected 10 kW each. Fig. 3 summarizes the service delivery in terms of the quantifying the energy import and export from the asset site but relied on low-resolution data.

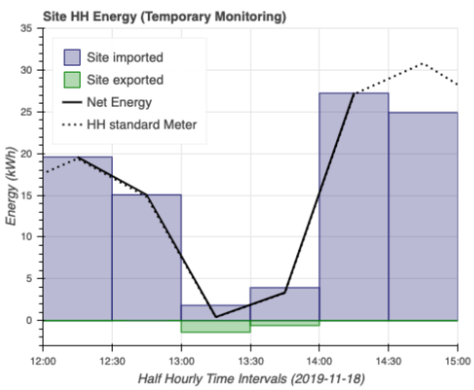

Figure 3: Half-hourly energy aggregated from the 5-second on-site monitoring (black solid). Site import (blue) sum of positive values, site export (green) sum of negative values. Standard half-hourly import meter (black dotted) shown for comparison.

Fig. 3, where half-hourly data mask details from the service delivery, shows the need for high-resolution monitoring at asset sites to account for power shifts unrelated to the flex event itself. Establishing the true value of flexibility to energy systems needs supporting data to validate not only the event but determine the exact impact of these events on the network. The lack of visibility (data) to the true service being delivered has major commercial and technical implications. For instance, from Fig. 3, it is not possible to tell if the 30 kWh were delivered at a flat rate of 30 kW for the full hour, or if this was delivered within 10 minutes at 180 kW. This difference could have serious implications for network stability. Thus, this MVS trial raised very important questions around baselining, metering/communications, and data resolution, all factors that need to be carefully designed and implemented when creating new markets. While this only had a very small impact in the case presented in this section, when scaling the service up to the MW scale, the impact could be much more significant. Decisions around these planning parameters can also influence the cost of participation in flexibility services, raising questions around market accessibility.

IV. Evalutation and Key Performance Indicators

The evaluation of technical and procedural trials within energy markets is important to allow critical reaction to learnings coming from project analysis. To successfully feedback into the '*build/measure* mechanisms in agile energy systems, metrics must show which aspects were actually realized as to prevent evaluations from being biased by agent expectations. MVSs within Project LEO are routinely assessed procedurally as the system aims to optimum efficiency. Table 1 shows how this is accounted for in Phase 1 MVS trails (2019) whereby procedure steps for conducting trials within Oxfordshire's local energy system are evaluated by '*Process Maturity*' on a scale of '*Manual*' (1) to '*Fully-automated*' (5). This table demonstrates the challenges with executing flexibility services within local energy systems and many processes require multiple MVS trails to test diverse aspects of these services from contractual obligations, to service penalties and financial settlement.

Table 1: Process Maturity for completed MVSs within Phase 1 of Project LEO with red (1) being the lowest score and dark green (5; not shown) being the highest. MVS notation is as follows: *MVS [Trial type where 'A' is for Flexibility services] . [Type of Service where 1 is for Prosumer services] . [Trial number where 1 is the 1st trial]*

	Process Maturity Stage														
MVS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Average**
MVS A1.1	1	3	3	1	3	3	3	2	3	3	3	2	1	3	**2.4**
MVS A1.2	1	3	3	1	3	3	3	2	4	3	1	1	1	3	**2.3**
MVS A2.1	1	3	3	1	3	3	3	2	4	3	4	1	1	3	**2.5**
MVS A3.1	1	3	3	1	3	3	3	2	3	1	3	1	1	3	**2.2**

Key performance indicators (KPIs) are a well-established metric system used to assess a project's progress to meeting outlined objectives. In an agile energy ecosystem with multiple stakeholders vying for varying objectives, KPIs must be relevant to the intended business model, comparable temporally as well as across diverse cohorts of agents, understandable to external stakeholders, and actionable as they must feedback learnings into future iterations in fast feedback loops. SLES must also be guided by objectives which prioritize a locally balanced energy system, positive ecosystem benefits through emissions and grid resilience. They must fulfil these while reducing inequalities, and increasing energy access for more equitable participation in whole system planning. The type of KPI will govern the feedback loops and the pace at which learnings can morph future system actions. Lagging KPIs evaluate historical activities in the project, disseminating findings into actionable pathways forward. Leading KPIs however, help forecast the future impacts of project activities (renewable asset connections to the network etc.). Both must work in agile frameworks that allow not only the constant evaluation of the network through a whole system approach, but the usefulness and metric mechanisms of the KPIs themselves. KPIs must be driven by effective data streams and communications and thus establishing streamlined data frameworks for SLES is essential to increasing impact.

A. Data Driven Loops

An agile SLES that iteratively cycles through LA loops is futile in impact without open and accessible data. In 2019, ~£1B was spent in balancing services which could have been saved through the reduced curtailment of renewable energy systems [4] with better underpinning data systems. In order for feedback loops to accelerate learnings, SLES data systems must account for the complexities involved with local energy systems in terms of the diversity in data streams, communications, asset types and owners, and DNO operations. Data must be fed into agile loops through both internal data provision activities and external databases which allow energy system projects the opportunity to tap into pre-existing resources. These needs further support the notion that SLES innovation requires multi-layered and diverse stakeholder consortia, including the tools for appropriate data collection and management. Milestone KPI workshops will allow project partners and external stakeholders the opportunity to measure the project against objectives. Project LEO, through working across diverse energy services, asset owners and with the DNO, have developed 11 pertinent KPIs for SLES stemming from year 1's activities. Though these will evolve, they provide a basis for energy system followers to adopt and they include the monitoring of the capacity under flexible control, additional generation capacity unlocked, impact on nonparticipants, and the estimation of reduction in network carbon intensity under project activities. It must be noted however that the diversity in these KPIs brings unique challenges in data acquisition, qualitative versus quantitative metrics, and feasibility of assessment.

V. Replicability and Fast Followers

Applying the LA within a complex public/private socio-technical system such as in local energy transitions will allow external stakeholders to adapt rapid-learning strategies. Otherwise known as '*fast followers*', external administrations, organizations and consortia must be able to easily and fairly access learnings from SLES to maximize impact stemming from this whole system approach. Agile feedback loops and LAs must also engage with external energy agents in order for local systems to penetrate broader domains within the national network. Thus, energy system learnings must integrate replicability into all levels of the whole system design with clearly outlined documentation and protocols that bear in mind the dissemination and reuse of findings. Although Project LEO is a UK-centric energy systems project, with particular focus within Oxfordshire, learnings are grounded within intrinsic whole system design, stakeholder development, and scientific methodology which can be translated to not only broader national-scale objectives, but across borders for other SLES to adopt. LA frameworks thus allow diverse sets of energy systems to innovate and shift away from ineffective *modus operandi* given the accelerated global carbon and energy transitions.

VI. Conclusions

Fast-track transitions, such as the UK's, require complex top-down and bottom-up approaches that are carefully designed to achieve strategic resources across a multi-stakeholder system. Applying a Lean Approach, we have demonstrated how SLES can unlock a whole system design through iterative and agile feedback loops which have been inspired from more private and commercial environments. Given the preliminary results from Project LEO (presented within), diverse consortia of energy agents are needed to support local energy system transitions, but they must rely on validated and agile learning environments to address multiple stakeholder, technical and policy objectives.

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