EVALUATING FLEXIBILITY AS ALTERNATIVE TO TRADITIONAL NETWORK REINFORCEMENT

Prepared for the Scottish and Southern Electricity Networks

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CONTENTS

1 EXECUTIVE SUMMARY

1.1 Since 2016 the Scottish and Southern Electricity Networks (SSEN) have deployed the Constrained Managed Zones (CMZ) schemes to secure load injection or demand reduction services from flexibility providers to offset the need for reinforcing their electricity networks. In 2018, SSEN joined the Great Britain Distributed Network Operators (DNOs) in the Flexibility First Commitment co-ordinated by the Energy Networks Association (ENA), committing to assessing smart flexibility service markets when reviewing requirements for building significant new electricity network infrastructure.[1]

1.2 Towards that goal, SSEN asked Frontier Economics (Frontier) to help them develop a decision-making framework to evaluate the option value of flexible resources as an alternative to traditional network investment. The framework would evaluate options around timing of network investments, in particular taking into account:

- the range of different options available (e.g., reinforcing the network, using flexibility, or doing nothing);
- the time periods in which actions can be taken; and
- the existence of uncertainty, and the impact of incremental information which becomes available over time.

1.3 The investment decision-making framework developed in conjunction with SSEN was implemented into a prototype Excel-based model ("prototype") that determines the optimal decision today (covering the period 2020-2024), and the optimal decision at each future four-yearly decision points (2024, 2028, 2032, 2036, 2040, 2044 and 2048) over a 32 year horizon (2020-2052). Against a backdrop of inherent uncertainty in demand, the prototype can help evaluate whether a network reinforcement or a flexible solution would be the more optimal choice under a given set of input assumptions.

1.4 The prototype was then populated with information from a real-world situation in order to demonstrate its effectiveness and the results which it might yield. The "case study" selected was a recent network investment decision made in respect a Bulk Supply Point (BSP) at Drayton that supplies to Milton, Fulscot, Cholsey and Air Products by four 33 kV circuits. As of 2017, the demand at these sites was forecast to increase and it was expected that the capacity of the 33 kV circuits could be exceeded during 2020. In order to meet this increase in demand, SSEN considered whether to reinforce the network using traditional reinforcement in electricity network infrastructure, or alternatively use flexibility through their CMZ Prevent scheme.

1.5 In this paper we set out the investment decision making framework, describe the prototype developed to implement this framework, and set out the experience of applying the prototype to the Drayton case study. While we expect the prototype to be a useful tool to support the investment decision making processes of network

[1] SSEN. SSEN joins industry in commitment to 'flexibility first' approach. 17 December 2018. Available at: http://news.ssen.co.uk/news/all-articles/2018/december/flexibility-first-commitment/

companies, there are nonetheless certain limitations to its use that are worth noting upfront.

1.6 First, the prototype was intentionally simplified in several respects with the idea that refinements to the prototype can be developed at a later stage. For example, the prototype only looks at a subset of costs (capex, opex and outage costs) associated with each decision and hence does not take into consideration other relative merits, e.g., the carbon footprint, of the different options being evaluated. Second, we expect there will inevitably be material uncertainty in relation to the various inputs (costs and probability of demand scenarios) that feed into the prototype. Coupled with the fact that the outputs are highly sensitive to these inputs, it follows that the prototype should at best be considered as a tool that can support the decision maker, and not an automated decision maker in its own right. Third, the prototype does not take explicit account of existing or future regulatory arrangements for flexibility under network price controls. The model seeks to find solutions, whether through network reinforcement or flexibility products, that minimise long run cost (including any option value). It does not consider the possibility that poorly targeted regulatory arrangements could create circumstances under which a company may face a financial incentive to choose a solution (whether a flexibility product or network reinforcement) that is more expensive in the long run instead of some cheaper alternative. As such, the prototype presumes a world where the regulatory framework is well targeted and incentivizes cost minimization effectively. This seems a reasonable approach, in anticipation that future DSO regulation will be designed with sufficient care.

1.7 Nonetheless, by imposing a structure on the decision-making process the prototype forces the decision-maker to think about the drivers of the optimal outcome under a given set of input assumptions. The prototype is therefore most useful in helping answer the question: what would I need to believe for an action to be the optimal choice? Most significantly, this means that the prototype can serve as one tool in a wider toolkit to assist in the investment decision making process and help highlight key areas of ambiguity to be supported and informed by additional analyses and stakeholder engagement.

1.8 This paper is set out as follows:

- In Section 2, we introduce how the ongoing energy transition is driving a need for a flexible energy system and how the value of flexibility arises from the uncertainty associated with how the system will evolve.
- In Section 3, we introduce the decision-making framework and its conceptual and theoretical underpinnings.
- In Section 4, we describe the implementation of the framework into a Microsoft Excel-based prototype decision making model.
- In Section 5, we discuss the experience of applying this protype model to a real-world problem, looking at the results it yields when populated with actual data, and test the robustness of these results as input assumptions are varied.
- Finally, in Section 6, we conclude by identifying a range of possible refinements to the analysis presented in this paper.

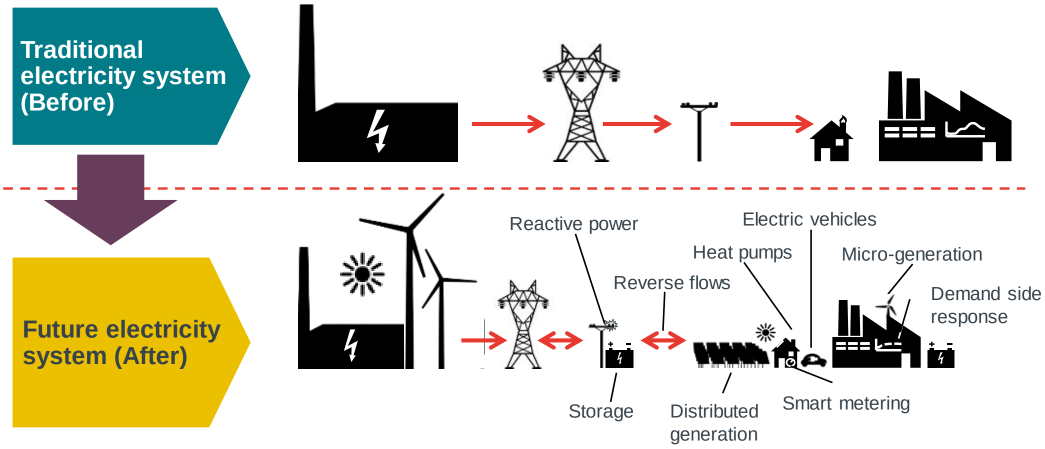
2 INTRODUCTION AND CONTEXT

2.1 The energy system is undergoing a significant transformation driven by the trifecta of decarbonisation, decentralisation and digitalization. Historically, power generated in large power plant would primarily flow on high voltage (transmission) networks and be stepped down to low voltage (distribution) networks before reaching the end consumer.

2.2 Now increasingly more so, smaller scale low-carbon generation is locating closer to the point of consumption, producing varying levels of electricity depending on the time of day or the weather, and increasing the intermittency of electricity supply. Electricity consumption levels and patterns too are changing significantly as consumers choose to self-generate, take up electric vehicles or heat their homes using electricity. These developments are happening against a background of increasing digitalization where smart metering and charging devices are unlocking the potential of and facilitating the wider penetration of distributed energy resources (DER) -- different types of distributed generation, but also dispatchable loads, electric vehicles and energy storage (“flexible resources” or “flexible solutions” or “flexibility”) - and allowing them to become more price responsive. Commercial developments such as the development of aggregators are increasing the extent to which demand side technical potential is available to the market.

2.3 It is likely that these trends will accelerate going forward as part of efforts undertaken to meet the UK government’s Net Zero emissions by 2050 target. In addition to producing more electricity from low carbon and renewable energy sources (RES), National Grid envisions that the path towards Net Zero will require electrification of the heat and transport systems to happen at scale, which is expected to nearly double the electricity demand in the future. Matching the intermittent generation mix with higher levels of more price responsive demand will require that the system becomes more ‘flexible’ with respect to both how power is consumed and produced.[2]

Figure 1 Energy system in transition



[2] We define flexibility consistent with Ofgem’s definition: ‘modifying generation and/or consumption patterns in reaction to an external signal (such as a change in price) to provide a service within the energy system’. Ofgem website. Electricity system flexibility. Available at: https://www.ofgem.gov.uk/electricity/retail-market/market-review-and-reform/smarter-markets-programme/electricity-system-flexibility

2.4 These changes in the energy system are particularly noticeable at the distribution level. Under the traditional system, the six DNOs in Great Britain would optimize the distribution network and ensure sufficient network capacity to meet exogenous consumer demand for electricity generated upstream. Under the new system, the DNOs need to actively manage the increasingly more complex power flows that are arising on the distribution grids both because large volumes of renewable and conventional generation are connecting directly at lower voltage levels, and also that consumer demand is becoming increasingly harder to predict given the uncertainty associated with the take up of electricity intensive yet flexible technologies like electric vehicles and heat pumps.

2.5 As they transition to become Distribution System Operators (DSOs), the DNOs will increasingly need to balance supply and demand on their networks and alleviate constraints through deployment of flexibly connected and controllable DER. While it is likely that significant levels of investment in energy network infrastructure (new pylons, transformers and substations) will be required to provide for the levels of electrification expected on the path to Net Zero, the much less predictable patterns of electricity supply and demand could mean that using a flexible resource to resolve a network constraint may in some instances deliver better value to consumers than investing in traditional network reinforcement.

2.6 The uncertainty associated with how the system will evolve in the future – how much new demand will materialize and by when, how intermittent the supply will be, and what technologies will exist and by when – creates a value for flexibility in the present. If network operators knew with sufficient certainty what levels of demand will materialize at each point on their network, then indeed they could build the network infrastructure to meet that certain level of demand. However, because there is considerable uncertainty associated with level and timing of future electricity demand, flexibility solutions may help network operators deliver services efficiently and economically at lower costs and shorter timescales than conventional network reinforcement.

2.7 For example, it could be that only under an expectation of high future demand is the existing network capacity expected to be insufficient, resulting in a need for network reinforcement, but if a medium or low demand scenario were to materialize then any new reinforcement would not be necessary. Under this situation, at least initially a decision to not act may make sense in order to wait and see if the reinforcement is needed. Alternatively, the network operator can enter into a contract with a flexibility provider to mitigate the risk of a possible increase in demand, say if this risk were to only be significant during certain "peak" hours. Both options provide alternatives to making a capital-intensive network reinforcement today which would be irreversible once it is undertaken.

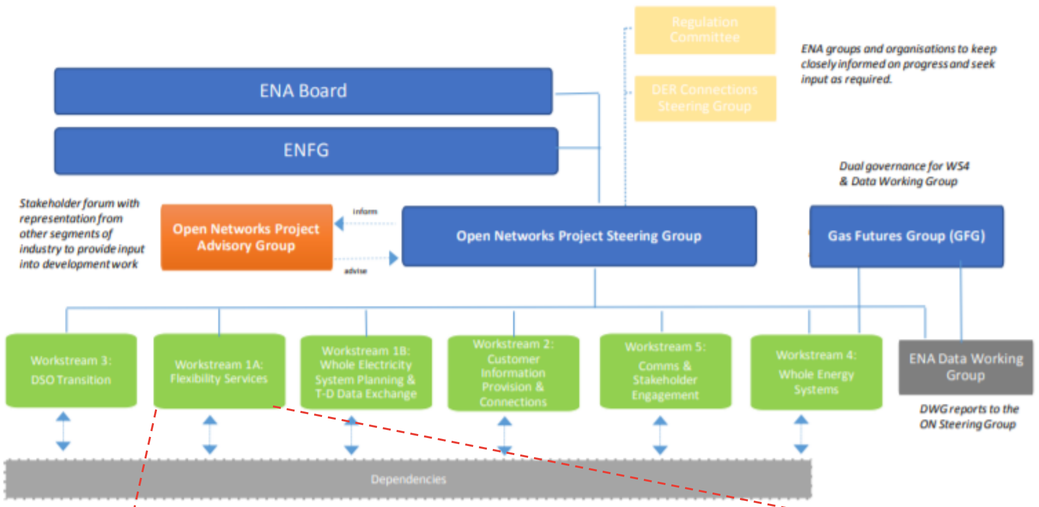
2.8 There is an opportunity cost of investing in a network reinforcement now rather than using a flexible resource to help defer the investment to a later period when it can be known with greater certainty whether the investment is needed. The combination of uncertainty and irreversibility creates the so-called "option value" of using flexibility as an alternative to enhance the network today and can be estimated using option theory. In general, the greater the uncertainty, the greater the value of optionality and the greater the incentive to keep these options open.

We describe in Section 3 how the decision making framework described in this paper attempts to estimate this option value of flexibility.

Regulatory and sector-wide initiatives

2.9 The motivation of this whitepaper is to support several regulatory initiatives pertaining to improving energy system flexibility that are currently underway. In particular, we understand that the Energy Networks Association (ENA) are in the process of developing a common evaluation methodology and tool to help DNOs make decisions around the selection of possible network solutions. It is expected that this common methodology would be used to decide which intervention (conventional reinforcement, flexibility, or an alternative) to procure to mitigate a network reinforcement need. The methodology will constitute an integral part of the pre-procurement decision-making process under Workstream 1A (Flexibility Services) of the Open Networks project and was a key action outlined in the Ofgem and BEIS Open Letter to the ENA in July 2019 pertaining to standardising processes and methodologies for flexibility procurement across network and system operators.

Figure 2 Overview of the Open Networks project and WS1A



WS1A		P1 ANM vs Flexibility vs Reinforcement Common Methodology
	A	Report or slides outlining analysis of existing decision making criteria and methodologies across DNOs for ANM vs Flexibility vs Reinforcement vs other options.
	C	Paper outlining first iteration of common decision making criteria and methodology for all DNOs to adopt. (as supporting document for Flexibility Consultation)
	C	Paper outlining final decision making criteria for all DNOs to adopt and change process for making changes to it in the future.
	D	Flexibility Valuation Tool to support ANM vs Flexibility vs Reinforcement decisions
	E	Implementation Plan for agreed decision making criteria and methodology

Source: ENA. Open Networks Project Phase 4 2020 Project Initiation Document. January 2020. http://www.energynetworks.org/assets/files/ON-PRJ-2020%20PID-v1%20Final%20(PUBLISHED).pdf

2.10 There are several other ongoing initiatives that have informed the work presented in this whitepaper. The Open Networks Project is a key initiative to deliver Government policy set out in the Ofgem and BEIS Smart Systems and Flexibility Plan, the BEIS' Industrial Strategy and the Clean Growth Plan. Under the Open Networks project, a workstream dedicated to Flexibility Services (WS1A) has been looking at how to define and develop transparent, standardised approaches for the procurement of flexibility services across DNOs, as well as how best to facilitate and encourage new markets and platforms for flexibility.

2.11 The Open Networks project is being supported by a few other initiatives being led by BEIS and Ofgem. BEIS' Smart Systems and Flexibility Plan has outlined 29 actions the government, Ofgem and industry needs to take to remove barriers to smart technologies (such as storage), enable smart homes and businesses, and improve access to energy markets for new technologies and business models. As part of a series of papers on the future of the energy landscape in GB, titled the 'Future Insights Series', Ofgem has also published their views on the development of flexibility platforms in the GB electricity system covering a range of issues such as the challenges faced by stakeholders, conditions that would assist innovation, standardisation of products and processes, and the development of competitive markets for flexibility.

3 DECISION-MAKING APPROACH

3.1 The first stage of developing the methodology of any investment decision making tool is to define and agree a conceptual framework for use in relation to decision making. In this section, we set out the main building blocks of such a framework based on our discussions with SSEN.

Conceptual questions

3.2 We outline in this section the conceptual questions that need to be considered to develop a framework for network investment decision making.

3.3 Under such a framework, for any given decision, a first step will be to define the range of actions which a DNO can take today in relation to a potential future problem. These might include, for example:

- reinforce the network – which might in itself cover small or large reinforcements, or potentially staged reinforcements;
- draw on a flexible resource – which again might include different levels of flexibility provision;
- a combination of the above two options; or
- do nothing, to wait and see whether the reinforcement is actually required.

3.4 By network reinforcement, we refer to the requirement for incremental network capacity and for capacity-based reinforcements required to avoid bottlenecks.[3] Some reinforcement projects could be large enough to be phased, with the option to cancel part of the way through. For some projects, development work prior to the main build may be considered significant enough to represent an initial "enabling" investment. Any investment required to develop a platform to facilitate greater use or optimisation of user flexibility may be considered similarly.

3.5 By drawing on a flexible resource we refer to the deployment of flexibly connected and controllable Distributed Energy Resources (DER) to alleviate network constraints. This is typically done by entering into contracts with a flexibility provider to provide energy to meet peak demand, or lower consumption during peak hours. Equally, there may be other actions to be considered. For example, the DNO may consider using non-firm connections that can be more easily "interrupted" to resolve network constraints.

3.6 Having defined the set of actions, a sense of the potential outcomes resulting from different actions will need to be assessed. These outcomes should include at a minimum:

- the direct costs of the action, i.e. the capital (capex costs) and operating expenditure (opex costs); and

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[3] The framework could, in theory, also be required for broader decision making (e.g. in relation to local voltage stability issues)

- the indirect costs, which should include some assessment of the cost of potential congestion, overloading or interruption on the network if it were to materialise (outage costs).

There are then several other indirect costs that could also be considered. These may cover a broad range of factors, from changes in network losses to greenhouse gas emissions that arise due to the action.

3.7 The indirect costs (and possibly the direct costs) will depend on future states of the world – which could include the level of background demand growth, growth in new uses (e.g. EVs, heat pumps), and the growth in storage and/or distributed generation on the grid (or behind-the-meter generation). For example, congestion or overloading may be significantly more likely if there is high load growth in particular areas (e.g., clustered uptake of EVs or electric heating), or if there is new generation development in generation dominated areas. This implies that the cost of not reinforcing (or undertaking delayed or smaller reinforcements) may only be high in such states of the world, and that the cost is expected to be lower if there is (for example) lower load growth.

3.8 Other than identifying what such states of the world may be, possibly more challenging would be to set out the likelihood of these states materializing. For example, it is likely that when forecasting future demand levels, network companies would formulate a “high” or “low” expectation around a base or central scenario. These could conveniently provide three future states of the world, i.e. high, medium and low demand. What is perhaps less likely is if the network company has ascribed specific probability to each of these demand scenarios materializing, i.e., being able to say that there is a 40% chance that the high demand scenario would materialize. Such an explicit assessment of probabilities may be necessary; alternatively, the decision-maker would want to look at the optimal action under a range of possible state of the world probabilities.

3.9 Another important consideration is the number of time periods over which decisions can be taken and over which new information arrives, which would involve considering a few different factors:

a. The horizon over which the investment decision is made;
b. The frequency with which new information comes to light and decision making is updated, particularly for actions like flexibility solutions where the contracting costs may change more frequently;
c. The point in time at which a decision to pursue a flexibility solution can be reassessed, likely guided by the duration of the flexibility contract (typically between 1-4 years); and
d. Other considerations such as internal targets of a DNO or wider regulatory and policy targets (e.g., net zero by 2050, or x% electric vehicles by 2030).

3.10 Once the key inputs have been identified, there are then a few considerations regarding what the decision making framework should be. For instance, it could be based on the lowest expected cost approach, i.e. the action with the lowest expected costs is considered to be optimal. Such an approach would necessitate the definition of probabilities in relation to each state of the world. Or it could be based on an alternative metric, such as a “least regrets” approach which may be simpler, and does not require the definition of probabilities, but may have undesirable outcomes in particular situations, such as states of the world in which there are very large downsides.

3.11 There are other approaches which could be deployed guided by the set of actions being considered. For example, it may be simpler to look at a comparison of the net present value of different actions in a single, “known” state of the world. Moreover, it is more likely than not that regardless of the choice of the mechanism, there are other factors which can only be qualitatively assessed and will need to supplement the outcome of the decision mechanism deployed.

3.12 There may then be further questions to be addressed, including:

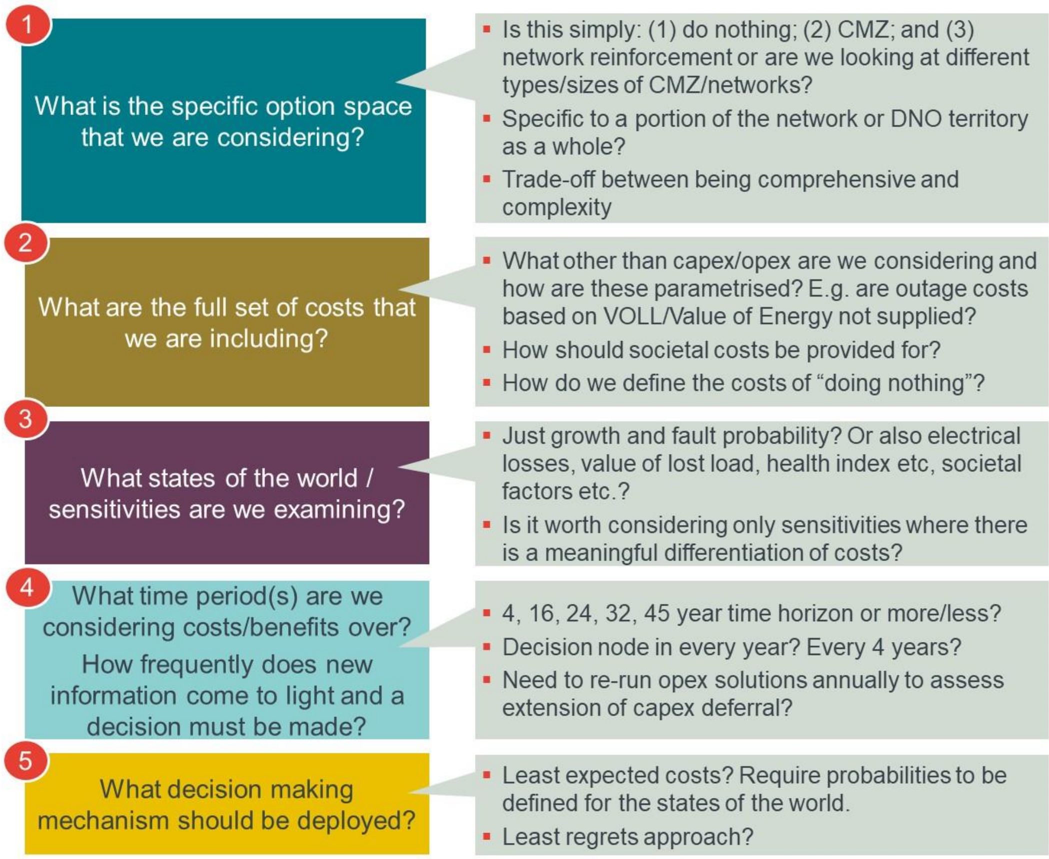
- how inter-related the actions in question are across the network (e.g., to what extent does the optimal decision in relation to Problem A depend on the solution adopted for Problem B); and
- whether states of the world should ever be considered to be known with certainty, or whether they just become more or less likely.

3.13 Broadening the set of possible actions, costs and states of the world will inevitably make the analysis richer. However, it will be important to bear in mind that:

- the problem needs to remain tractable, and hence a relatively small set of alternative actions / states / costs needs to be chosen given that the complexity of the problem across time periods and states of the world will increase exponentially; and
- the actions / states need to be sufficiently differentiated in terms of credible direct and indirect cost estimates which may again constrain the set chosen.

3.14 The questions that a decision maker would need to consider are summarised in Figure 3 below.

Figure 3 Questions underpinning the decision making framework



Source: Frontier Economics

In the next sub-section, we provide a (simplified) example of how such a conceptual decision-making framework can be created and used to guide decisions based on these inputs.

Decision making framework

3.16 As outlined above, an important consideration is around what the decision-making framework for evaluating the costs across the different actions should be. The choice of the decision-making framework can in turn create the need for additional inputs. The two major factors guiding the choice of our decision-making framework in this context are:

a. the inherent uncertainty in how the energy sector will evolve in the future; and

b. the irreversibility of the costs associated with such a reinforcement.

3.17 These factors create an "option value" for the alternatives to traditional network reinforcement, that is, a value of not making an irreversible network investment at a given point in time. Any decision-making framework should factor in this option value of flexibility. Ideally, a decision-making framework should also be based on expected costs over time.

3.18 To achieve this, one option is to use backwards induction to solve a multi-period optimisation problem, wherein the user first finds the optimal decision in the last period, and then works backwards to arrive at an optimal decision today.

3.19 We set out below a stylised example of how such a decision-making mechanism would work. We note upfront that the example of an investment decision used in this section is purposefully simplified as compared to what we have implemented in the prototype model. Also an investment decision is expected to involve more alternatives than those evaluated here. We begin by applying the lowest expected cost approach to decision-making in this simplified example, followed by a brief contrast with the "least regrets" approach.

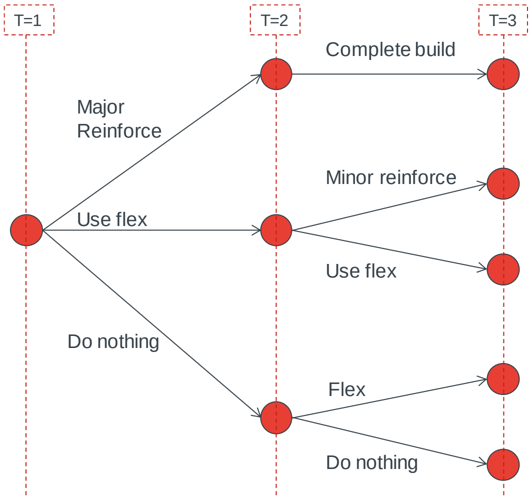
3.20 The methodology of arriving at the optimal decision follows four main steps, as set out below. We expand on each of these steps subsequently.

- **Step 1:** Define the options and action in relation to an investment decision;
- **Step 2:** Set out the direct costs (opex/capex) in relation to each action and at various points in time;
- **Step 3:** Provide for indirect costs (outage costs);
- **Step 4:** Backward solve to work out the action with lowest expected cost at T=1

Step 1: Define the options and action in relation to an investment decision

The first task as described above is to define the actions which could be taken in relation to a given decision, and over which time steps. As shown in the diagram below, these could relate to commissioning a major reinforcement, drawing on a flexible resource or to wait and see and do nothing. For the purposes of the example in this section, the decision space has been deliberately kept simple.

Figure 4 Example actions and timesteps

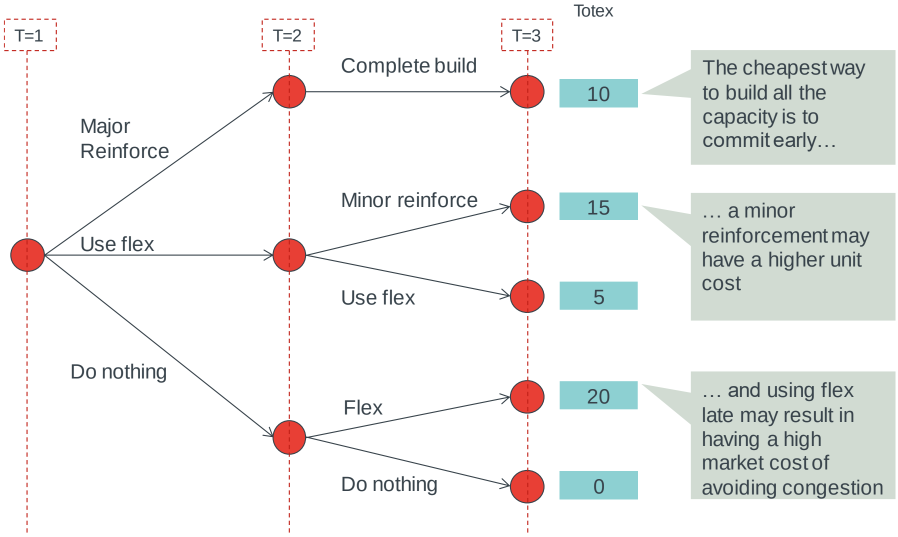


Source: Frontier Economics

Step 2: Set out the direct costs (opex/capex) in relation to each action and at various points in time

Associated with each of these actions over time will be a level of total expenditure (totex). This could include both capex and opex. For now, we assume that the totex is invariant to states of the world (i.e., it is just a function of the action taken, and its timing).

Figure 5 Direct costs of each action



Source: Frontier Economics

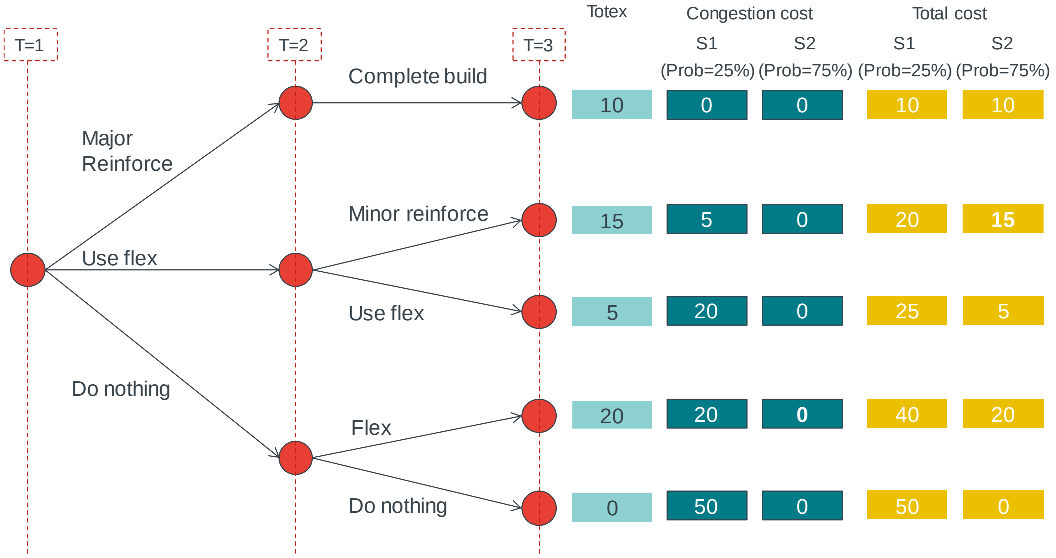
Here, the values we have used for the actions are such that the cheapest way to deliver a given level of capacity is to carry out a major reinforcement. Using flex followed by a minor reinforcement could be more expensive, but if even the minor reinforcement is avoided (because it turns out not to be necessary), the use of flex is cheaper than the major reinforcement.

Step 3: Provide for indirect costs

To these direct costs, indirect costs need to be added. These could reflect the cost of having insufficient network capacity (risk of overload, risk of customer interruptions), or the cost of additional losses. Here, we assume that there is uncertainty as to the level of indirect costs. In one state of the world (S1), the current network is insufficient to accommodate load growth, whereas in the second (S2) the existing network capacity is sufficient (in the time horizon under consideration). We assume S1 has a 25% probability, and S2 a 75% probability.

Based on these indirect costs, we can calculate the total costs to society of different actions under different states of the world. We assume that the state of the world is not known at T=1, but will become known at T=2.

Figure 6 Total cost by state of the world



Source: Frontier Economics

In this simple example, we assume that in the timescale under consideration there are no other decisions (e.g., on other parts of the network) which impinge on this particular decision – in other words, the decision can be considered in isolation.

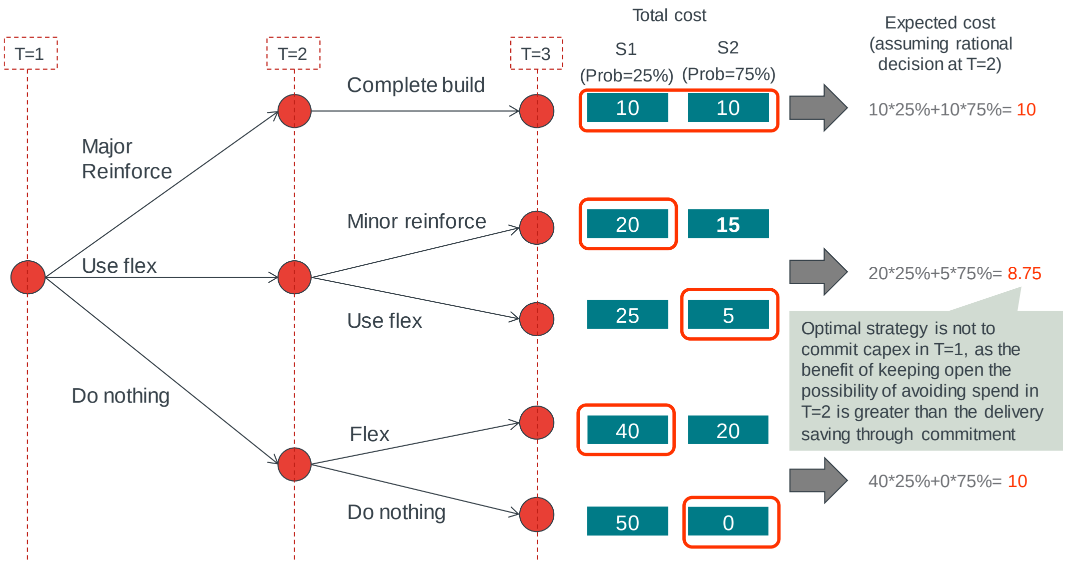
Step 4: Backward solve to work out the action with lowest expected cost at T=1

From this information, we can then work out the action at T=1 with the **lowest expected cost**. To do this, we work out what the optimal actions would be at time T=2 (i.e., once the state of the world is known with certainty). These are circled red in the diagram below. For example, if the action taken at T=1 was to use flex, then at T=2:

- if it is clear that S1 is going to materialise, the best action is to undertake a minor reinforcement (cost of 20 vs. 25); and
- if it is clear that S2 is going to materialise, the best action is to rely on flex (cost of 5 vs. cost of 15).

Having worked out the optimal action in each scenario, at T=1 the expected payoffs to each T=1 action can be worked out using this information, combined with the probability (as seen at T=1) that each state of the world will occur.

Figure 7 Working backwards to evaluate the optimal action at T=1



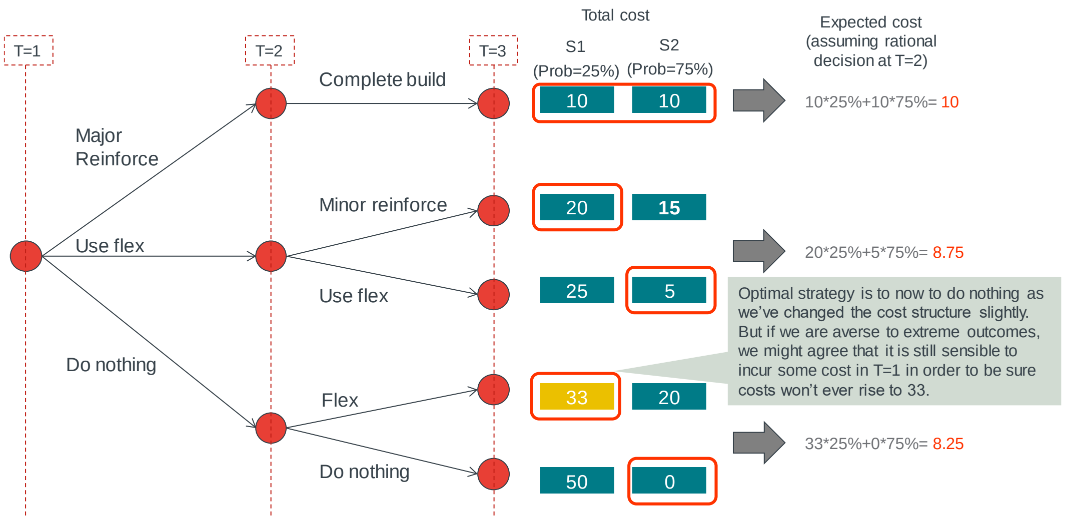
Source: Frontier Economics

The result of this is the intuitively reasonable outcome that using flex in the short term, and then working out whether to do a minor reinforcement later is better (in expectation) than just going ahead and commissioning a major reinforcement, and also cheaper than doing nothing and risking the flexibility solution not being available when it is really needed.

Step 4a: Alternative metrics to expected cost e.g., least regrets can be used

The lowest expected cost is not the only metric to consider. In Figure 8, we change the cost structure of the above example slightly, to make the cost of doing nothing and relying on short term flex cheaper. This results in "doing nothing" being the lowest expected cost outcome.

Figure 8 Alternative cost structure – rationale for "least regrets"



Source: Frontier Economics

However, even though the expected cost of doing nothing at T=1 is low, if S1 materialises, the absolute cost will be very high (higher than any other possible outcome). In other words, while the expected cost is low, the maximum regret is high. This might be a reason for incurring some cost at T=1, as an insurance policy against the extreme outcome that could otherwise materialise.

4 THE PROTOTYPE MODEL

4.1 The conceptual questions and decision-making framework described in Section 3 were translated into a prototype tool that identifies the optimal decision under a specified set of inputs. We outline in this section how the different aspects of the decision-making framework have been reflected in a Microsoft Excel-based model.

Application of conceptual framework

4.2 We outline below our assumptions in relation to each of the inputs in the prototype model, in line with the decision-making framework outlined in the previous section.

Set of actions

4.3 The first aspect to consider is the set of actions available to the decision maker. The action space considered in the prototype model include the following options:

- **Traditional network reinforcement:** This could involve either building new networks or reinforcing existing networks.
- **Flexibility solutions:** The model uses SSEN's Constraint Managed Zones (CMZ) scheme as an example of a flexible solution serving as an alternative to traditional reinforcement. This could however be any viable opex-based alternative to a capex-based network reinforcement that can equally resolve the system constraint (e.g., provide for an increase in future demand).
- **Combination of reinforcement and flexibility:** The model also provides for a combined option of resolving a part of the issue with traditional reinforcement, and partly through a flexible solution.
- **No intervention:** As outlined in the decision-making framework, it is possible that doing nothing (and incurring higher outage costs) is economically a better option than the above three options.

Time period

4.4 Next, we determine over what time period/horizon to consider the costs/benefits associated with the aforementioned action space as well as the frequency of decision making, i.e., how frequently does the decision maker revaluate their decision based on new information that comes to light.

4.5 For the purpose of the prototype model, we make the following assumptions in relation to each of the above factors:

- Assume that new information comes to light once every **four years**, and hence investment decisions are also made with the same frequency. The four-year period was selected to ensure alignment with the typical duration of a flexibility contract, which we understand can be anywhere between 1 to 4 years.
- We model the costs and benefits of the actions over **32 years**, that is, from 2020 to 2052. The time period was set to ensure we cover the government's Net Zero emissions by 2050 target. This provides for eight (8) four-year decision periods over the 32-year horizon (2020-2052), allowing the decision maker to assess the optimal decision today (covering the period 2020-2024),

and the optimal decision at each future four-yearly decision points (2024, 2028, 2032, 2036, 2040, 2044 and 2048).

Costs considered

4.6 For each aforementioned action, the prototype provides for the following costs:

Direct costs

4.7 These would be the costs directly associated with the actions, and are mainly of the following two types:

- **Capex:** This involves the capital expenditure, or the investment in physical assets such as cables or circuits, associated with each type of investment, spread over the period of investment. The capex is primarily relevant for traditional network reinforcement although it may be likely that some flexible solutions require an upfront capital investment (e.g., to establish a platform).
- **Opex:** Operating expenditure is the ongoing cost of the investment, and is primarily relevant for the CMZ option, i.e., the fee paid to the flexibility provider. There may also be opex associated with traditional reinforcement projects as well to cover the ongoing costs for maintaining the infrastructure.

4.8 Consistent with the irreversibility of a capex-based solution, the prototype model assumes that once traditional reinforcement has been selected as the optimal choice in a given period, it will continue to be selected as the optimal action in all future periods. In these future periods, the prototype allows for the provision of any continued costs in relation to the traditional reinforcement built in the future period, e.g., any costs required to maintain the cables or circuits installed.

Indirect costs

4.9 These include an assessment of the cost of potential congestion, overloading or interruption on the network if it were to materialise. The prototype incorporates these as outage costs in the manner described below.

- **Outage costs:** These are the costs to the DNO of not being able to meet the demand on the network. The main parameters used to measure the outage costs are:
  - **Customers Interrupted per Year (CI)** is the number of customers whose supplies have been interrupted per 100 customers per year over all incidents, where an interruption of supply lasts for three minutes or longer.
  - **Customer minutes Lost (CML)** is the duration of interruptions to supply per year, where an interruption of supply to customer(s) lasts for three minutes or longer.

  Using these parameters, the outage costs are computed using the formula:

  *Outage costs = (£ per CI * Number of customers) + (£ per CML* Number of customers * Annual outage in minutes).*

It is noteworthy that the CI/CML reflect the societal costs associated with outages and may be different from the incentive rates in network price controls which relate to these drivers.

4.10 We note that the prototype does not account for other costs or benefits (negative costs) that may additionally need to be taken into consideration to determine the relative merits of the actions being evaluated. We can expect these could range from operational factors, like electrical losses, to societal factors (like carbon costs) to more directly take into consideration the carbon footprint of the actions being proposed. If the scope of the evaluation is not limited to a particular portion of the network (say if the action has broader impacts), it may also make sense to think about wider whole system impacts, e.g., the overall impact on despatch costs. Such whole system costs are not taken into consideration in the prototype.

States of the world and associated probabilities

4.11 The prototype provides for three future states of the world in line with expected levels of demand and based on key drivers that influence demand growth. These states of the world could be picked by a decision maker based on any other driving factor (aside from demand) that they envision would influence the costs of the investment options being evaluated.

- **State 1 (S1) – Low demand growth:** Base load growth, plus any committed new connections, less any connections that drop-off.
- **State 2 (S2) – Medium demand growth:** Base load growth, plus any committed new connections**.**
- **State 3 (S3) – High demand growth:** Base load growth, plus any committed new connections, plus additional growth arising from electrification of the heat and transport sector.

4.12 The next step is to provide for the likelihood of each of these states materializing. Towards that end, we considered whether states of the world should be deemed to be precisely known, or whether they become more or less likely. For example, given the electrification of the heat/transport networks required on the path towards a binding net-zero-by-2050 target, a high demand scenario can be expected to become more certain the closer we get to the target year.

4.13 Given the difficulty and subjectivity associated with ascribing a specific number to the likelihood of a particular state of the world materializing, the prototype has been set up to allow the decision maker to look at possible optimal outcomes under a range of probability assumptions. There are two sets of assumptions in relation to the probability of the three states occurring in each period, as outlined below:

Probabilities in Period 1 (2020-24)

4.14 For the first period, there are five different sets of assumptions in relation to the probability of each state occurring, as set out in Figure 9 below.

Figure 9 Initial period probabilities

Initial Probability Options	New Connections Unlikely	Low Forecast Uncertainty	New Connections Likely	Agnostic	DNO Estimated (indicative)
S1 – Low demand	70%	10%	5%	33%	10%
S2 – Medium demand	25%	80%	25%	33%	50%
S3 – High demand	5%	10%	70%	33%	40%

Source: Frontier Economics

4.15 In a scenario where new connections are unlikely the probability of a low demand state is higher than that of high demand state; and vice versa in a scenario where new connections are more likely. In a situation where there is low forecast certainty, the decision maker would likely want to more heavily weight the central or "medium demand" state relative to the high and low demand states. Finally, the model also allows the decision maker to be agnostic between various states of the world (meaning equal probability for the three states), or to input their probability estimate for each state.

Probability updating for future periods (2024-2052)

4.16 For all future four-year periods, the probability of each state occurring is assumed to be the same and conditional upon the state that occurred in the first period. The prototype model allows for five (5) possible "belief states" about the future based on Period 1 probabilities and updates the probabilities for future periods accordingly. These are outlined below.

Figure 10 Probability updating for future periods

Belief state	Description
Strong	State realised 2020-2024 very likely to be realised again
Weak	State realised 2020-2024 likely to be realised again
Asymmetric	High demand growth realised 2020-2024 likely to be realised again, not low demand growth
No updating	Probabilities not updated given 2020-2024 load growth
DNO Estimated	As estimated by the decision maker

Source: Frontier Economics

4.17 A "strong" belief in Period 1 probabilities implies that the decision maker believes that the state realised in the first period is likely to occur again. This means that a greater likelihood of new connections and hence higher demand over 2020-24 is followed by a greater likelihood of new connections in all future states of the world as well. A "weak" belief is similar to the "strong" belief above, but with a slightly lower probability of the initial state being realised again.

4.18 Figure 11 summarises the various inputs to the prototype model that are described above.

Figure 11 Summary of inputs to the prototype model

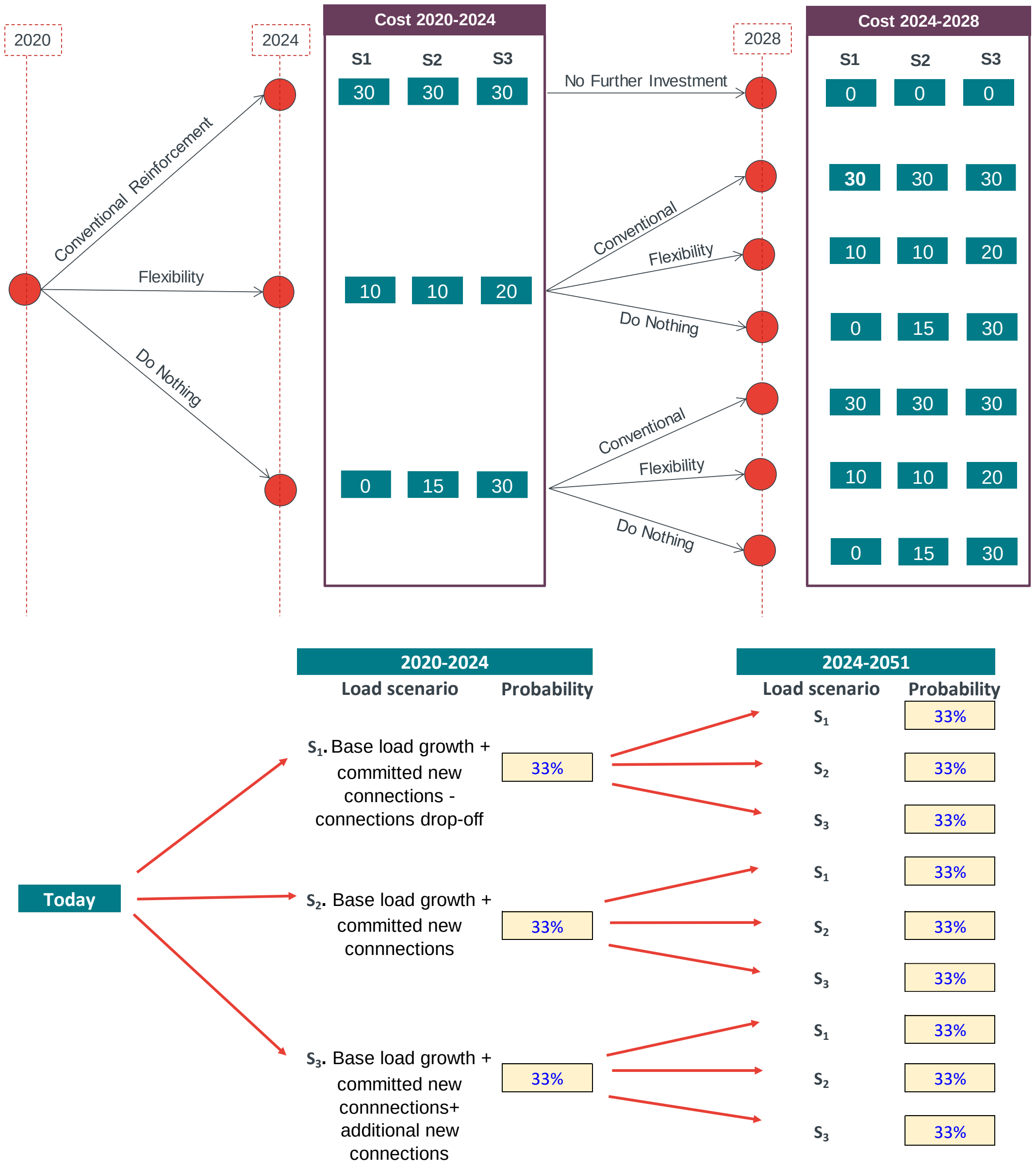
	Prototype model inputs
What is the specific option space that we are considering?	▪ 1. Traditional network reinforcement ▪ 2. Constraint Managed Zones (CMZ) ▪ 3. Combination of 1 and 2 ▪ 4. No intervention
What time period(s) are we considering costs/benefits over?	▪ 32 years
How frequently does new information come to light and must a decision be made?	▪ 4 years
What is the set of costs that we are considering?	▪ Capex + opex + CI/CML outage costs
What states of the world / sensitivities are we examining?	▪ a. Base load growth + committed new connections - connections drop-off ▪ b. Base load growth + committed new connections ▪ c. Base load growth + committed new connections + additional new connections

Source: Frontier Economics

Decision-making approach

4.19 Determining the optimal action today and at each future four-yearly decision points (2024, 2028, 2032, 2036, 2040, 2044 and 2048) based on direct and indirect costs and expectation of different states of the world is a dynamic optimisation problem. Figure 12 below sets out how the prototype applies the decision tree framework and analyses this optimisation problem using the backwards induction approach described in Section 3.

Figure 12 Decision-tree and associated costs in the prototype



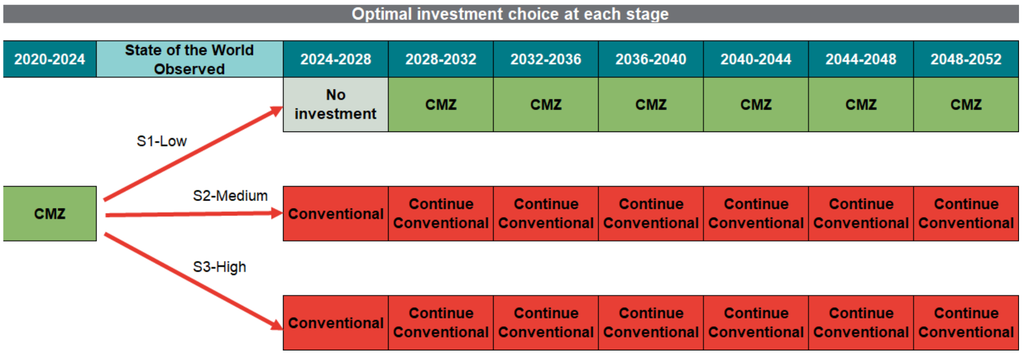
Source: Frontier Economics

Outputs

4.20 In this section, we describe the outputs that the prototype is capable of producing conditional on the input assumptions in relation to the costs of investment and probabilities of the states of the world. We note that all outputs shown in this sub-section are illustrative and based on dummy values for the input assumptions.

4.21 The prototype model provides the optimal investment decision today (covering period 2020-2024) and the optimal decision at each future four-yearly decision points (2024, 2028, 2032, 2036, 2040, 2044 and 2048) given the observed state of the world (and its likelihood) in period 2020-24. An example of such an output is presented in Figure 13.

Figure 13 Illustrative example of the prototype output



Source: Frontier Economics

Note: The decisions shown above are based on dummy values for inputs

4.22 Consider a decision-maker that is agnostic between the three states of the world i.e., they think it is equally likely that each of the three states manifest in reality. In such a case, the output in Figure 13 indicates that:

- If the low demand state were to materialize, then the optimal decision today would be to undertake flexible reinforcement. This would be followed by undertaking no investment in 2024, and then providing for increased demand through a flexibility solution.
- However, if the medium or a high demand states are to occur, the optimal decision would be to deploy a flexibility solution today, and in the next period undertake a conventional reinforcement. As noted earlier, once a decision-maker chooses to undertake conventional reinforcement, the model ensures that it remains the optimal action for all future periods.

4.23 The model also outputs the expected and maximum cost of the optimal decision path for each state of the world observed in 2020-2024, as shown in Figure 14 below.

Figure 14 Expected and maximum costs of the optimal decision path

	2020-2024	Scenario 2020-2024	2024-2028	2028-2032	2032-2036	2036-2040	2040-2044	2044-2048	2048-2052	Total net present
Expected Cost	£19,157	S1	£569,606	£964,447	£5,718,398	£38,761	£33,133	£28,322	£24,210	£7,396,034
		S2	£569,606	£964,447	£5,718,398	£38,761	£33,133	£28,322	£24,210	
		S3	£569,606	£964,447	£5,718,398	£38,761	£33,133	£28,322	£24,210	
Maximum Cost	£54,437	S1	£1,115,388	£1,964,030	£8,685,288	£38,761	£33,133	£28,322	£24,210	£11,943,569
		S2	£1,115,388	£1,964,030	£8,685,288	£38,761	£33,133	£28,322	£24,210	
		S3	£1,115,388	£1,964,030	£8,685,288	£38,761	£33,133	£28,322	£24,210	
Standard Deviation	£8,575	S1	£437,502	£779,824	£2,783,134	£0	£0	£0	£0	
		S2	£437,502	£779,824	£2,783,134	£0	£0	£0	£0	
		S3	£437,502	£779,824	£2,783,134	£0	£0	£0	£0	

Source: Frontier Economics

Note: The numbers in the table are based on dummy values.

4.24 Finally, the model computes the value of optionality, that is, is the reduction in expected net present cost compared with having a fixed investment decision for the full time-horizon.

Sensitivity analysis

4.25 The prototype provides for the option to test the sensitivity of these decision outputs by varying one or more of the input assumptions. For the cost assumption, the model focuses on the primary cost drivers of each action, that is, capex for conventional reinforcement, opex for flexibility solutions and outage costs for no intervention. In addition, the model allows for sensitivity testing around the probabilities of the low and high demand scenarios. We outline below the main functionalities of the prototype that allow for a sensitivity analysis around the central input assumptions.

Sensitivity sliders

4.26 The prototype has a “Slider Control” functionality that allows the user to test the sensitivity of the outputs to the central view on the input assumptions. This is done by varying the capex, opex and outage costs by up to 50% in either direction (see Figure 15). For example, if the optimal decision is to pursue conventional reinforcement, the user can use the Slider Control to gradually increase the capex and observe the point (percentage increase above the central input assumption) at which the optimal decision switches to deploying a flexibility solution instead.

Figure 15 Slider control functionality

Option 1. No intervention	Move slider to sensitivity value	% change from central
Capex	‹ ›	0%
Opex	‹ ›	0%
Outage costs	‹ ›	0%

Option 2. Network reinforcement	Move slider to sensitivity value	% change from central
Capex	‹ ›	0%
Opex	‹ ›	0%
Outage costs	‹ ›	0%

Option 3. CMZ	Move slider to sensitivity value	% change from central
Capex	‹ ›	0%
Opex	‹ ›	0%
Outage costs	‹ ›	0%

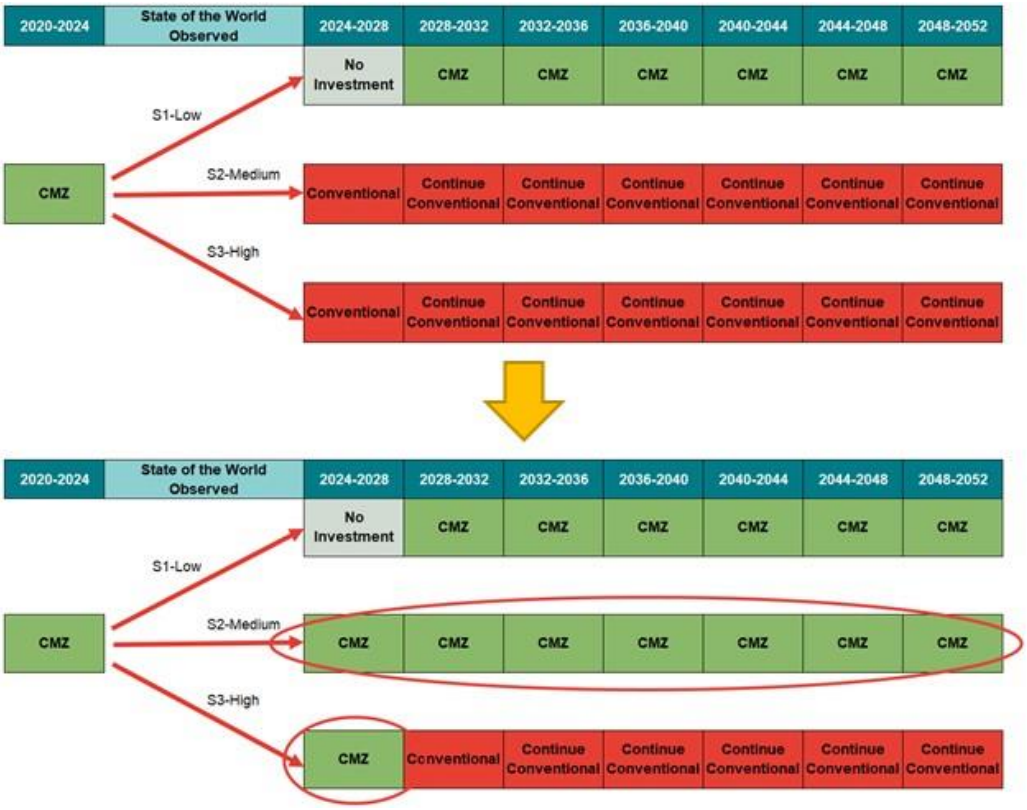
Option 4. Combination	Move slider to sensitivity value	% change from central
Capex	‹ ›	0%
Opex	‹ ›	0%
Outage costs	‹ ›	0%

Source: Frontier Economics

4.27 Figure 16 demonstrates the change in outputs that arise when one of the sliders is used to increase the capex associated with the network reinforcement by 35% compared to the central assumptions.[4] It can be observed that the optimal decision switches away from conventional network reinforcement to a flexibility solution for a number of decision points.

[4] The percentage changes in costs are applied to dummy cost inputs throughout this section.

Figure 16 Change in model output with an increase in network reinforcement capex



Source: Frontier Economics

Automated outputs based on range of input assumptions

4.28 The prototype has a further functionality that automates computation of the optimal decision over a range of input sensitivities and displays them in a table. This has been done using Microsoft VBA within Excel to “loop” over specified combinations of input values.

4.29 For example, Figure 17 shows that the optimal decision to choose a flexibility solution in 2020-2024 remains unchanged even with an increase in opex of up to 35% from the central assumptions. However, once the opex increases beyond this threshold, the optimal decision in 2020-2024 switches to traditional network reinforcement.

Figure 17 Optimal decision in 2020-2024 with a range of input sensitivities

Central Assumptions

CMZ Opex deviation	-50%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
2020-2024 optimum	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	Conventional	Conventional	Conventional

Reinforcement Capex deviation	-50%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
2020-2024 optimum	Conventional	Conventional	Conventional	Conventional	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ

Change in probability of low demand	-10%	-9%	-8%	-7%	-6%	-5%	-4%	-3%	-2%	-1%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
P (Low demand)	23%	24%	25%	26%	27%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	41%	42%	43%
P (Medium demand)	38%	38%	37%	37%	36%	36%	35%	35%	34%	34%	33%	33%	32%	32%	31%	31%	30%	30%	29%	29%	28%
P (High demand)	38%	38%	37%	37%	36%	36%	35%	35%	34%	34%	33%	33%	32%	32%	31%	31%	30%	30%	29%	29%	28%
2020-2024 optimum	Conventional	Conventional	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ

Change in probability of high demand	-10%	-9%	-8%	-7%	-6%	-5%	-4%	-3%	-2%	-1%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
P (Low demand)	38%	38%	37%	37%	36%	36%	35%	35%	34%	34%	33%	33%	32%	32%	31%	31%	30%	30%	29%	29%	28%
P (Medium demand)	38%	38%	37%	37%	36%	36%	35%	35%	34%	34%	33%	33%	32%	32%	31%	31%	30%	30%	29%	29%	28%
P (High demand)	23%	24%	25%	26%	27%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	41%	42%	43%
2020-2024 optimum	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ

Source: Frontier Economics

4.30 The model also allows one to observe the changes to the optimal decision in periods other than the starting period, and in each state of the world as can be seen in Figure 18 below.

Figure 18 Optimal decision in 2024-2028 with a range of input sensitivities

Decision period	2024-2028

Central Assumptions

Deviation from central CMZ Opex Assumptions	-50%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Optimal 2024-2028 option - Low demand	CMZ	CMZ	CMZ	CMZ	CMZ	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conve ona
Optimal 2024-2028 option - Medium demand	CMZ	CMZ	CMZ	CMZ	CMZ	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conve ona
Optimal 2024-2028 option - High demand	CMZ	CMZ	CMZ	CMZ	CMZ	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conve ona

Source: Frontier Economics

Limitations of the prototype

4.31 While we expect the prototype to be a useful tool to support the investment decision making processes of network companies, there are nonetheless certain limitations to its use that are worth noting.

4.32 First, the prototype was intentionally simplified in several respects with the idea that refinements to the prototype can be developed at a later stage. For example, the prototype only looks at a subset of costs (capex, opex and outage costs) associated with each decision and hence does not take into consideration other relative merits, e.g., the carbon footprint, of the different options being evaluated or the network losses under each decision. This means that the prototype cannot, for example, determine what would be the "greener" decision to undertake, or which decision would reduce network losses most. Moreover, the prototype by construction looks at a specific issue at a specific point on the network and is not design to consider any interactions (and any interrelated costs/benefits) with other issues in the wider network.

4.33 Second, we expect there will inevitably be material uncertainty in relation to the various inputs (costs and probability of demand scenarios) that feed into the prototype. Coupled with the fact that the outputs are highly sensitive to these inputs, it follows that the prototype should at best be considered as a tool that can support the decision maker and not an automated decision maker in its own right.

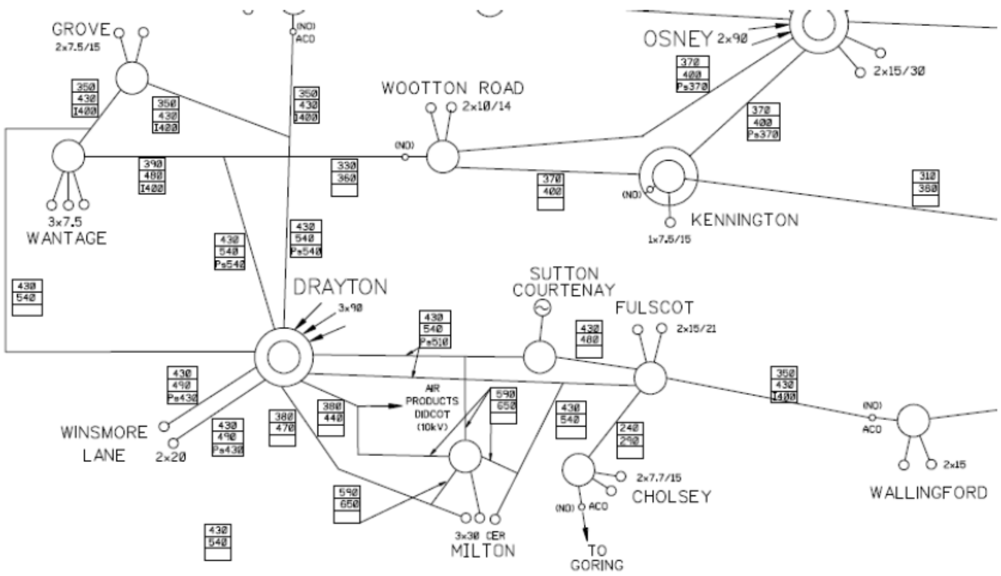
4.34 Third, the prototype does not account for how regulatory incentives under RIIO-ED1 (or in the future under RIIO-ED2) may influence a particular decision. Meaning that it does not consider the possibility that poorly targeted regulatory arrangements could create circumstances under which a company may face a financial incentive to choose a solution (whether a flexibility product or network reinforcement) that is more expensive in the long run instead of some cheaper alternative. As such, the prototype presumes a world where the regulatory framework is well targeted and incentivizes cost minimization effectively.

5 APPLICATION TO A CASE STUDY

5.1 In this section we set out the experience of applying the prototype to a real world example, using actual data from when a flexibility solution was considered at a location, Drayton, on the SSEN network.

5.2 SSEN's Bulk Supply Point (BSP) at Drayton supplies demand to Milton, Fulscot, Cholsey and Air Products by four 33 kV circuits. As of 2017, the demand at Milton, Fulscot and Cholsey was forecast to increase so that the First Circuit Outage (FCO) capacity of the 33 kV circuits supplying these substations from Drayton may have been exceeded during 2020.

Figure 19 Drayton 33kV network in 2017 (before investment decisions)



Source: SSEN

5.3 In order to meet this increase in demand, SSEN considered two options:

- **Reinforce the network using traditional methods:** SSEN considered constructing various new circuits from Drayton to the various demand areas. The most cost effective of these was to install a new 33 kV circuit (approximately 5 km in length) from Drayton substation to the Air Products tee point, creating a Drayton – Air Products circuit and a Drayton – Milton circuit. The proposed plan also included the installation of a new feeder bay at Drayton 33 kV substation for the new circuit. These works were required to be completed by 2020.
- **Use a constrained management zone alternative:** Alternatively, SSEN also undertook a CMZ assessment to avert overloads on the 33 kV network from Drayton BSP due to FCO conditions on various circuits. The first year in which an FCO results in an overload on this 33 kV network was 2020/21. It was determined that injecting power on one of the circuits (the amount of which was calculated based on historic breach durations) could reduce the overloads on the remaining circuits, and avert the need for traditional network reinforcement.

Figure 20 Summary of CMZ specification

Contract start year	2020/21
Contract end year	2023/24
Service windows	01:40 hrs from 16:30 hrs to 18:10 hrs for the month of November.
CMZ power injection	5 MW
CMZ energy requirement	0.14 MWh
Preferred locations	Milton 11 kV bus

Source: SSEN

5.4 The prototype model was tested with inputs from the above context to test its effectiveness in making an investment decision between traditionally reinforcing the 33kV network and entering into a 4-year CMZ contract. We outline below the various inputs and assumptions that were used as part of the case study.

Inputs

States of the world

5.5 The states of the world are constructed based on three sets of demand growth scenarios, based on the 2019 Future Energy Scenarios (FES) set out by National Grid[5]. The FES outline several pathways for the future of energy based on the speed of decarbonisation and extent of decentralisation. For the Drayton case study, demand growth states were determined using a combination of National Grid's FES and SSEN's internal load growth scenarios.

- **State 1 (S1) – Steady state:** This state includes base load growth along with any committed new connections, less any connections that drop-off.
- **State 2 (S2) – S1 + FES Consumer Evolution:** In this scenario, there is a shift towards local generation and increased consumer engagement, largely from the 2040s. Alternative heat solutions are taken up in the interim, mostly where it is practical and affordable, e.g. due to local availability. Consumers choose electric vehicles and energy efficiency measures. Cost-effective local schemes are supported but a lack of strong policy direction means technology is slow to develop, e.g. for improved battery storage.
- **State 3 (S3) – S1 + FES Two Degrees:** In the Two Degrees scenario, large-scale solutions are delivered, and consumers are supported to choose alternative heat and transport options to meet UK's previous target of achieving an 80% reduction in greenhouse gas emissions by 2050 as compared to 1990 levels[6]. UK homes and businesses transition to hydrogen and electric technologies for heat. Consumers choose electric personal vehicles and hydrogen is widely used for commercial transport. Increasing renewable capacity, improving energy efficiency and accelerating new technologies such as carbon capture, usage and storage are policy priorities.

5.6 As part of the SSEN estimates, loads for the FES scenarios only consider the heat pump and electric vehicles as Low Carbon Technologies (LCTs), connected using

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5 http://fes.nationalgrid.com/media/1410/fes-in-5-2019.pdf

6 This target was updated to a net zero emissions target at the end of June 2019.

4 kVA for Heat Pumps and the MW value for "EV charger" provided. Further, the loading forecasts only consider a peak in winter.

5.7 Given the challenge associated with ascribing a specific probability to each of the three demand scenarios, it was decided in discussions with SSEN to assume at least initially that the three scenarios were equally likely to materialize over the 2020-2052 period. The idea was to then use the probability sensitivities in the prototype to determine how the output would change as different demand scenarios are considered to be more or less likely relative to one another.

Set of actions

5.8 The four main options considered as part of the Drayton case study were the following:

- **Traditional network reinforcement:** The increase in demand estimated above implies that additional network reinforcement would be required (e.g. bigger conductors, cables, dual circuit OHLs). Where overloads were identified, the overloaded circuit type (cable or OHL) and length were costed for overlay within the sizes used by SSEN.
- **Constraint Managed Zones (CMZ):** An alternative would be to meet the overload through flexibility contracts. Under this option, the CMZ Prevent scheme would provide generation or load reduction at the Milton primary substation as this would benefit all overloads on the network.
- **Combination of network reinforcement and CMZ:** A third option identified was to partially reinforce the network, and meet the demand in other parts of the network through flexibility contracts.[7]
- **No intervention:** We also consider "doing nothing" as a third option available to SSEN in the Drayton case study, which leads to additional outage costs as a result of the network overload.

Costs considered

5.9 The assumptions underlying the computation of the various costs under each investment option are outlined below. These assumptions were developed by SSEN based on their current and projected future demand requirements.

Capex

5.10 For the Drayton case study, the costs of capital expenditure are assumed to be only relevant for traditional network reinforcement and the combined option of network reinforcement and CMZ.

5.11 These capex costs are based on internal SSEN estimates[8] of the cost at the following reinforcements at Drayton in each state of the world:

- **S1 – Low demand:** a 33kV reinforcement
- **S2 – Medium demand**: 2 separate 33kV reinforcements, one required in 2020-2021 and the other required in 2023-2024

7 The input cost assumptions for this option were not explicitly modelled by SSEN for the purpose of this case study, and were assumed to be a combination of the capex and opex costs of the previous two options.

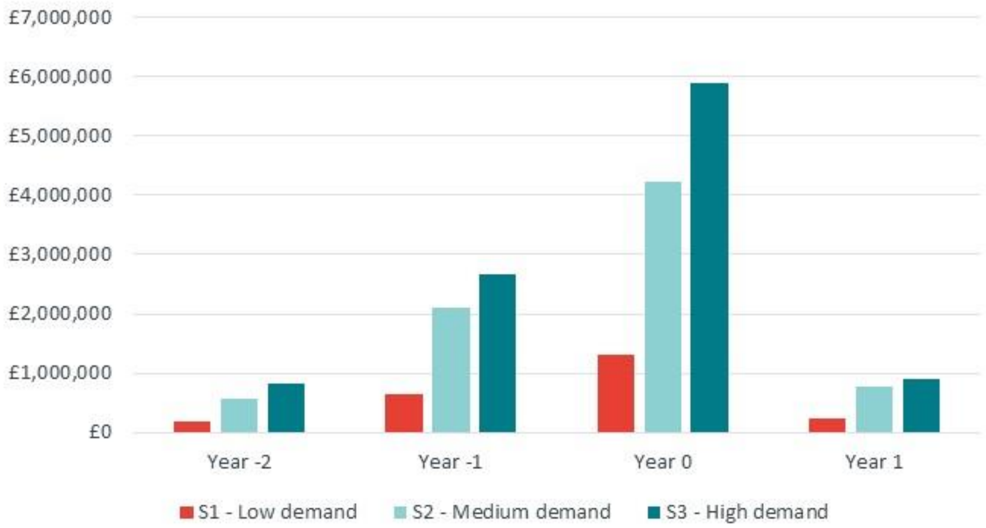
8 We understand that these are derived from the RIIO unit costs for the reinforced assets.

- **S3 – High demand:** 2 separate 33kV and an 132kV reinforcement, one required in 2020-2021 and the other required in 2023-2024

5.12 For each of these investments, SSEN estimated the annual capex required over a 4-year period to build the necessary reinforcements, as shown in Figure 21. In situations (S2 and S3) where there were two investments forecast as required in 2020 and 2023, these were converted into a single investment required in 2022 and spread over four years. Finally, these capex costs were assumed to be the same irrespective of which time period the reinforcement was undertaken.

5.13 In addition, for future periods, the continued costs of maintaining the traditional reinforcement in future periods were assumed to be 1% of the total 4-year capex incurred in each of the three states. This is SSEN's estimate of the average annual maintenance costs that would follow a network reinforcement. In reality, these costs may be lower than this average soon after reinforcement occurs, and increase as the asset becomes older.

Figure 21 Reinforcement capex cost assumptions over a 4-year period



Source: SSEN

Note: Capex costs were assumed to be the same irrespective of when the reinforcement was undertaken

5.14 For the option involving a combination of network reinforcement and CMZ, the capex as well as the continued costs of maintaining the capex were assumed to be 50% of the respective costs computed above for the purposes of the current modelling, based on discussions with SSEN.

Opex

5.15 The costs of opex were assumed to be only relevant for the flexibility solution (that is, the CMZ option), and for the combined option of network reinforcement and CMZ.

5.16 The opex costs are an internal SSEN estimate of the likely CMZ requirement at Drayton, which has been determined by looking at the overload estimates over time and under each state. The specific assumptions are listed in Figure 22. The costs are then computed using a contract cost of £300 MWh, using the below formula:

Opex cost = MW injected * daily service duration * service days * cost per MWh

Figure 22 Opex assumptions in the Drayton case study

State of the world	Contract (MW)	Service duration	Service window
S1 - Low demand	5 (maximum)	1h 40m (daily)	30 days (Nov)
S2 - Medium demand	10	2h 30m	61 days (Nov - Dec)
S3 - High demand	15	3h	92 days (Nov - Jan)

Source: SSEN

5.17 The opex estimates for a CMZ solution are available for a five year period starting from 2022, that is, till 2026. In other words, the overload on the network is assumed to start two years into the investment decision period, raising the need for a CMZ solution. Starting from 2027, the opex costs are assumed to increase by 1% annually with expected increase in service duration due to growth in demand. This figure is broadly consistent with the demand growth assumptions in the 2019 FES scenarios, where the peak load growth estimates range from 0.4 – 1% depending on the scenario.[9] Figure 23 depicts the evolution of the opex costs under each of the three states.

Figure 23 CMZ opex cost assumptions over the investment horizon

Source: SSEN

5.18 The opex costs associated with the combined option of network reinforcement and CMZ were assumed to be 25% of the opex assumption for the CMZ only option, based on discussion with SSEN. These opex costs continue to be incurred alongside a partial reinforcement of the network through the decision-making horizon.

[9] Electricity peak demand GW (Tab 4.2) in the Future Energy Scenarios 2019 Data Workbook - http://fes.nationalgrid.com/media/1432/fes-data-workbook-v30.xlsx

CI/CML outage costs

5.19 The CI/CML outage costs are, as described above, costs due to lost consumer minutes and customer interruptions. These outage costs are assumed to be only relevant for the option that involves no intervention on the part of the decision maker.

5.20 The outage costs are based on a 2019-2020 internal SSEN estimate of customer interruptions and customer minutes lost for the SEPD licence area (see Figure 24) and total number of customers at the Drayton site.

- The outage is assumed to affect all customers on the network, and last for 50 hours for 33kV circuits and 75 hours for 132kV circuits, annually.
- The costs for CI/CML are calculated for a fixed failure rate (i.e., the duration which assets are beyond their rating for N-1), and then multiplied by a probability of the outage occurring in any given state.
- Finally, customer numbers affected by the outages were considered to remain constant across all periods when computing outage costs.

Figure 24 CI and CHL costs for SEPD license area 2019/20

OFGEM IIS Penalties - SEPD licence area 2019/20 | £ per CI = **£12.46** | £ per CHL = **£18.20**

Time Off-Supply: Duration of interruption (hrs/mins)		Number of Customers Affected: 10	50	100	500	1000	5000	10000	50000
18	hours	£3,401	£17,003	£34,006	£170,030	£340,060	£1,700,300	£3,400,600	£17,003,000
17	hours	£3,219	£16,093	£32,186	£160,930	£321,860	£1,609,300	£3,218,600	£16,093,000
16	hours	£3,037	£15,183	£30,366	£151,830	£303,660	£1,518,300	£3,036,600	£15,183,000
15	hours	£2,855	£14,273	£28,546	£142,730	£285,460	£1,427,300	£2,854,600	£14,273,000
14	hours	£2,673	£13,363	£26,726	£133,630	£267,260	£1,336,300	£2,672,600	£13,363,000
13	hours	£2,491	£12,453	£24,906	£124,530	£249,060	£1,245,300	£2,490,600	£12,453,000
12	hours	£2,309	£11,543	£23,086	£115,430	£230,860	£1,154,300	£2,308,600	£11,543,000
11	hours	£2,127	£10,633	£21,266	£106,330	£212,660	£1,063,300	£2,126,600	£10,633,000
10	hours	£1,945	£9,723	£19,446	£97,230	£194,460	£972,300	£1,944,600	£9,723,000
9	hours	£1,763	£8,813	£17,626	£88,130	£176,260	£881,300	£1,762,600	£8,813,000
8	hours	£1,581	£7,903	£15,806	£79,030	£158,060	£790,300	£1,580,600	£7,903,000
7	hours	£1,399	£6,993	£13,986	£69,930	£139,860	£699,300	£1,398,600	£6,993,000
6	hours	£1,217	£6,083	£12,166	£60,830	£121,660	£608,300	£1,216,600	£6,083,000
5	hours	£1,035	£5,173	£10,346	£51,730	£103,460	£517,300	£1,034,600	£5,173,000
4	hours	£853	£4,263	£8,526	£42,630	£85,260	£426,300	£852,600	£4,263,000
3	hours	£671	£3,353	£6,706	£33,530	£67,060	£335,300	£670,600	£3,353,000
2	hours	£489	£2,443	£4,886	£24,430	£48,860	£244,300	£488,600	£2,443,000
60	mins	£307	£1,533	£3,066	£15,330	£30,660	£153,300	£306,600	£1,533,000
45	mins	£261	£1,306	£2,611	£13,055	£26,110	£130,550	£261,100	£1,305,500
30	mins	£216	£1,078	£2,156	£10,780	£21,560	£107,800	£215,600	£1,078,000
25	mins	£200	£1,002	£2,004	£10,022	£20,043	£100,217	£200,433	£1,002,167
20	mins	£185	£926	£1,853	£9,263	£18,527	£92,633	£185,267	£926,333
15	mins	£170	£851	£1,701	£8,505	£17,010	£85,050	£170,100	£850,500
10	mins	£155	£775	£1,549	£7,747	£15,493	£77,467	£154,933	£774,667
5	mins	£140	£699	£1,398	£6,988	£13,977	£69,883	£139,767	£698,833
<3	mins	£0	£0	£0	£0	£0	£0	£0	£0
Duration of interruption (hrs/mins)		10	50	100	500	1000	5000	10000	50000
		Number of Customers Affected							

These are the costs of every fault on our network based on the number of customers and duration.

None

Under £1,000

£1,000-£10,000

£10,000-£100,000

£100,000-£802,000

Over £802,000 (Penalties are limited to about £802,000 , providing OFGEM accept thay are an Exceptional Event and are outside our control, and we have taken all reasonable steps to avoid/minimise effect).

Source: SSEN

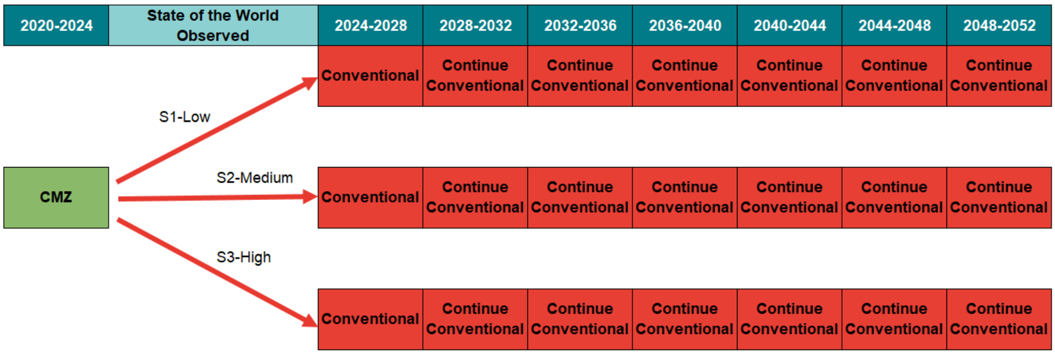
Outputs

5.21 As described previously, the model gives the decision maker the optimal investment decision today (covering period 2020-2024) and the optimal decision at each future four-yearly decision points (2024, 2028, 2032, 2036, 2040, 2044 and 2048) given the observed state of the world in period 2020-24. The model output based on the Drayton case study cost assumptions is shown in Figure 25.

5.22 If the decision maker were to be agnostic between the three states of the world (i.e., they think it is equally likely that each of the states manifest in reality), the output in Figure 25 indicates that:

- In the first period, it is optimal to delay the reinforcement of the network and to ensure an energy balance through flexibility solutions.
- Then, in the second period, it becomes optimal to invest to reinforce the network, irrespective of the state of the world.
- In subsequent periods, no further investment is required as the network has been reinforced to accommodate higher demand levels. The model thus chooses the option ‘Continue Conventional’.

Figure 25 Output of the Drayton case study – decision tree



Source: Frontier Economics

5.23 The expected and maximum cost of the optimal decision path for each state of the world observed in 2020-2024 are as shown in Figure 26 below.

Figure 26 Output of the Drayton case study - Expected and maximum costs of the optimal decision path

	2020-2024	Scenario 2020-2024	2024-2028	2028-2032	2032-2036	2036-2040	2040-2044	2044-2048	2048-2052	Total net present cost
Expected Cost	£54,476	S1	£5,217,349	£179,695	£153,604	£131,302	£112,237	£95,941	£82,011	£6,026,614
		S2	£5,217,349	£179,695	£153,604	£131,302	£112,237	£95,941	£82,011	
		S3	£5,217,349	£179,695	£153,604	£131,302	£112,237	£95,941	£82,011	
Maximum Cost	£108,875	S1	£7,924,278	£272,898	£233,274	£199,404	£170,451	£145,703	£124,547	£9,179,430
		S2	£7,924,278	£272,898	£233,274	£199,404	£170,451	£145,703	£124,547	
		S3	£7,924,278	£272,898	£233,274	£199,404	£170,451	£145,703	£124,547	
Standard Deviation	£39,603	S1	£2,539,274	£87,446	£74,749	£63,896	£54,619	£46,688	£39,909	
		S2	£2,539,274	£87,446	£74,749	£63,896	£54,619	£46,688	£39,909	
		S3	£2,539,274	£87,446	£74,749	£63,896	£54,619	£46,688	£39,909	

Source: Frontier Economics

5.24 Finally, the value of optionality, that is, is the reduction in expected net present cost compared with having a fixed investment decision for the full time-horizon, is equal to £1.04 million in this case.

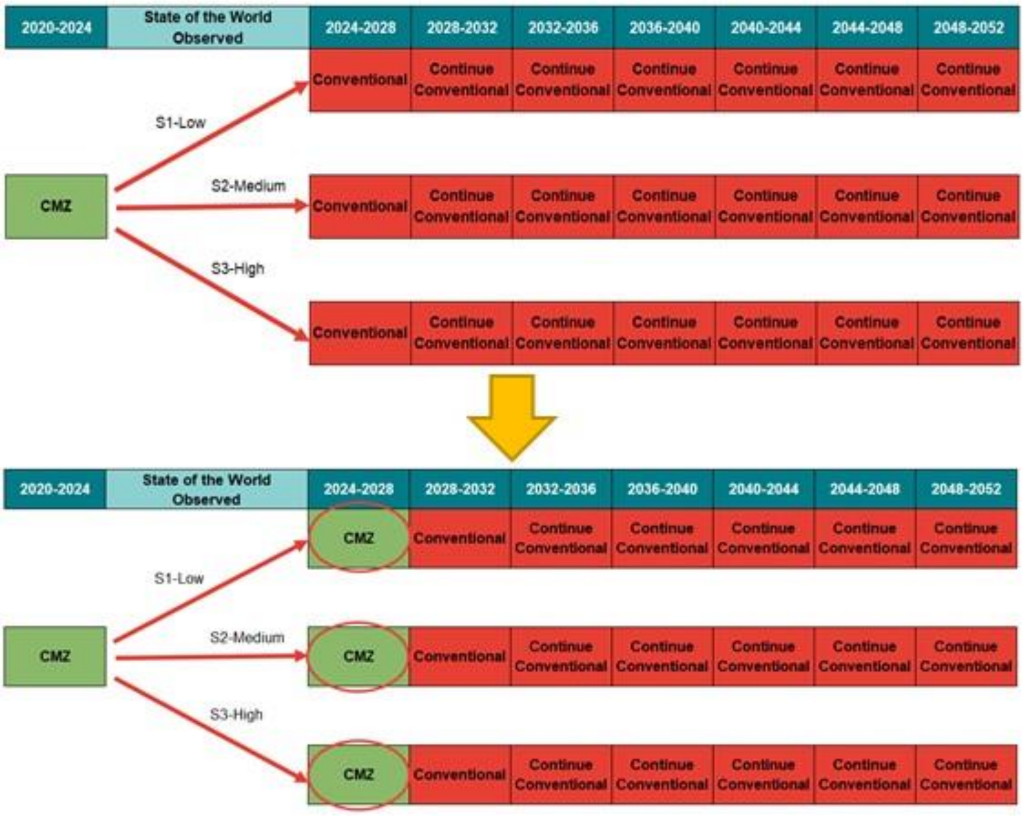
Sensitivity analysis

5.25 We tested the sensitivity of the optimal decision to varying input assumptions. The results are set out below.

5.26 The “Sensitivity Sliders” allow the user to observe the point at which the optimal decision switches. For instance, if we decrease the opex associated with the CMZ option by 16%, the optimal decision for the 2024-2028 period switches from

‘Conventional reinforcement’ to ‘CMZ’, and the optimal point to invest to reinforce the network is postponed by one period. This example is illustrated in Figure 27. Increasing the capex by 18% or more leads to a similar result.

Figure 27 Change in model output with a 16% decrease in CMZ opex



Source: Frontier Economics

5.27 However, the optimal decision in 2020-2024 is largely invariant under a wide range of input assumptions. Figure 28 shows that for the Drayton case study, the 2020-2024 optimal decision to ensure an energy balance through flexibility solutions is robust across all the sensitivities considered in the default threshold analysis.

Figure 28 Optimal decision in 2020-2024 with a range of input sensitivities

											Central Assumptions										
Deviation from central CMZ Opex Assumptions	-50%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Optimal 2020-2024 option	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ
Deviation from central network reinforcement Capex Assumptions	-50%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Optimal 2020-2024 option	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ
Change in probability of low demand scenario	-10%	-9%	-8%	-7%	-6%	-5%	-4%	-3%	-2%	-1%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
P (Low demand)	23%	24%	25%	26%	27%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	41%	42%	43%
P (Medium demand)	38%	38%	37%	37%	36%	36%	35%	35%	34%	34%	33%	33%	32%	32%	31%	31%	30%	30%	29%	29%	28%
P (High demand)	38%	38%	37%	37%	36%	36%	35%	35%	34%	34%	33%	33%	32%	32%	31%	31%	30%	30%	29%	29%	28%
Optimal 2020-2024 option	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ
Change in probability of high scenario	-10%	-9%	-8%	-7%	-6%	-5%	-4%	-3%	-2%	-1%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
P (Low demand)	38%	38%	37%	37%	36%	36%	35%	35%	34%	34%	33%	33%	32%	32%	31%	31%	30%	30%	29%	29%	28%
P (Medium demand)	38%	38%	37%	37%	36%	36%	35%	35%	34%	34%	33%	33%	32%	32%	31%	31%	30%	30%	29%	29%	28%
P (High demand)	23%	24%	25%	26%	27%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	41%	42%	43%
Optimal 2020-2024 option	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ

Source: Frontier Economics

5.28 The model also allows one to observe the changes to the optimal decision in periods other than the starting period, and in each state of the world, as the input assumptions are varied. Figure 29 below shows that the optimal decision for 2024-2028 switches to CMZ when:

- the opex of the flexibility solutions is decreased by 20% or more; or
- the capex of the network reinforcement option is increased by 20% or more.

Figure 29 Optimal decision in 2024-2028 with a range of input sensitivities

Decision period 2024-2028

Central Assumptions

Deviation from central CMZ Opex Assumptions		-50%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Optimal 2024-2028 option	Low demand	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional
	Medium demand	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional
	High demand	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional

Deviation from central network reinforcement Capex Assumptions		-50%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Optimal 2024-2028 option	Low demand	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ
	Medium demand	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ
	High demand	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	Conventional	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ	CMZ

Source: Frontier Economics

5.29 As discussed above, all three demand scenarios were assumed to occur with equal likelihood based on discussions with SSEN. A key functionality of the prototype model however is to test how the optimal decisions vary by changing these probability assumptions, based on a pre-defined set of "belief states" about the probabilities in the first period, and the update of probabilities thereafter.

5.30 For example, instead of assuming equal likelihood of all states of the world, if the decision maker chooses the "New Connections Unlikely" scenario[10] for the probabilities in Period 1 (2020-2024), and then picks a belief state that indicates that the probabilities in Period 1 are likely to manifest again ("Strong" probability updating), then the optimal decision switches away from conventional reinforcement. Specifically, the optimal choice in such a scenario would be to:

- undertake investments in CMZ in all decision periods, including in 2020-2024 under the "Low" scenario; and
- in the medium and high demand scenarios, undertake investments in CMZ in the first period (2020-2024) followed by a combination of conventional network reinforcement and CMZ solutions.

5.31 This is illustrated in Figure 30, and indicates that under a scenario which places a higher likelihood on the "Low" demand scenario occurring, it is optimal to defer investment in traditional network reinforcement for longer (and in this case, not undertake network reinforcement at all) as compared to a scenario where all three states are equally likely. On the other hand, under the same assumptions about probabilities in the first period, if the decision maker assumes that future probabilities are likely to resemble the first period only in the high demand growth

[10] In this scenario, the probability of the "Low Demand" state occurring is significantly higher than the other two states.

scenario ("Asymmetric" probability updating), the model output indicates that both the "Low" and "Medium" demand scenarios should consist of CMZ solutions throughout the decision-making horizon.

Figure 30 Change in model output with a change in probabilities of demand scenarios

Source: Frontier Economics

6 POSSIBLE REFINEMENTS AND NEXT STEPS

6.1 The prototype model is a starting point to understand the various investment options available to a decision-maker, and the numerous drivers that can influence the choice of the optimal investment. As discussed above the prototype was by construct a simplified application of the decision-making framework designed to keep the problem tractable, e.g. by considering fewer possible alternative actions, fewer possible states of the world, fewer time periods. However, it is possible to further refine the prototype model to provide for more robust decision-making by considering a broad set of parameters. We list a few such possible refinements below.

6.2 **More frequent decision-making.** The current version of the prototype model allows a decision-maker to update their choice every 4 years, which also implicitly assumes they enter into CMZ contracts of 4-year lengths. In reality, the flexibility solutions available to DNOs range from 1-week long (specially for low voltage network solutions) to 7-year long contracts. The model can be updated to allow for more frequent decision-making like annual or six months instead of four years, to improve alignment with demand forecast updates (annual) or to suit specific projects on lower voltage networks.

6.3 **Expand option space.** The set of options available to a decision-maker could be expanded to consider different types of reinforcement (e.g. uprating vs circuit reinforcement), different sizes/types of flexibility solutions, and combinations thereof.

6.4 **Provide for other costs.** A possible refinement to the current version of the prototype model is allowing for other costs/benefits of investments, that may additionally need to be taken into consideration to determine the relative merits of the actions being evaluated. These could range from operational factors, like electrical losses, to societal factors (like carbon costs) to more directly take into consideration the carbon footprint of the actions being proposed. It could also be possible for the scope of the evaluation to not be limited to a particular issue at a specific point on the network (say if the action has broader impacts).

6.5 **Provide for regulatory incentives**. The prototype in its current form does not consider the possibility that poorly targeted regulatory arrangements could incentivize a company to choose a solution (whether a flexibility product or network reinforcement) that is more expensive in the long run instead of some cheaper alternative. As such, the prototype presumes a world where the regulatory framework is well targeted and incentivizes cost minimization effectively. This seems a reasonable approach, in anticipation that future DSO regulation will be designed with sufficient care. Alternatively, it may be possible to switch the decision-making mechanism from minimising costs to maximizing profit taking into consideration any relevant regulatory arrangements.

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