LDES NODE WP3 and WP4 Model Methodology and Outputs

Final Report

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electricity north west

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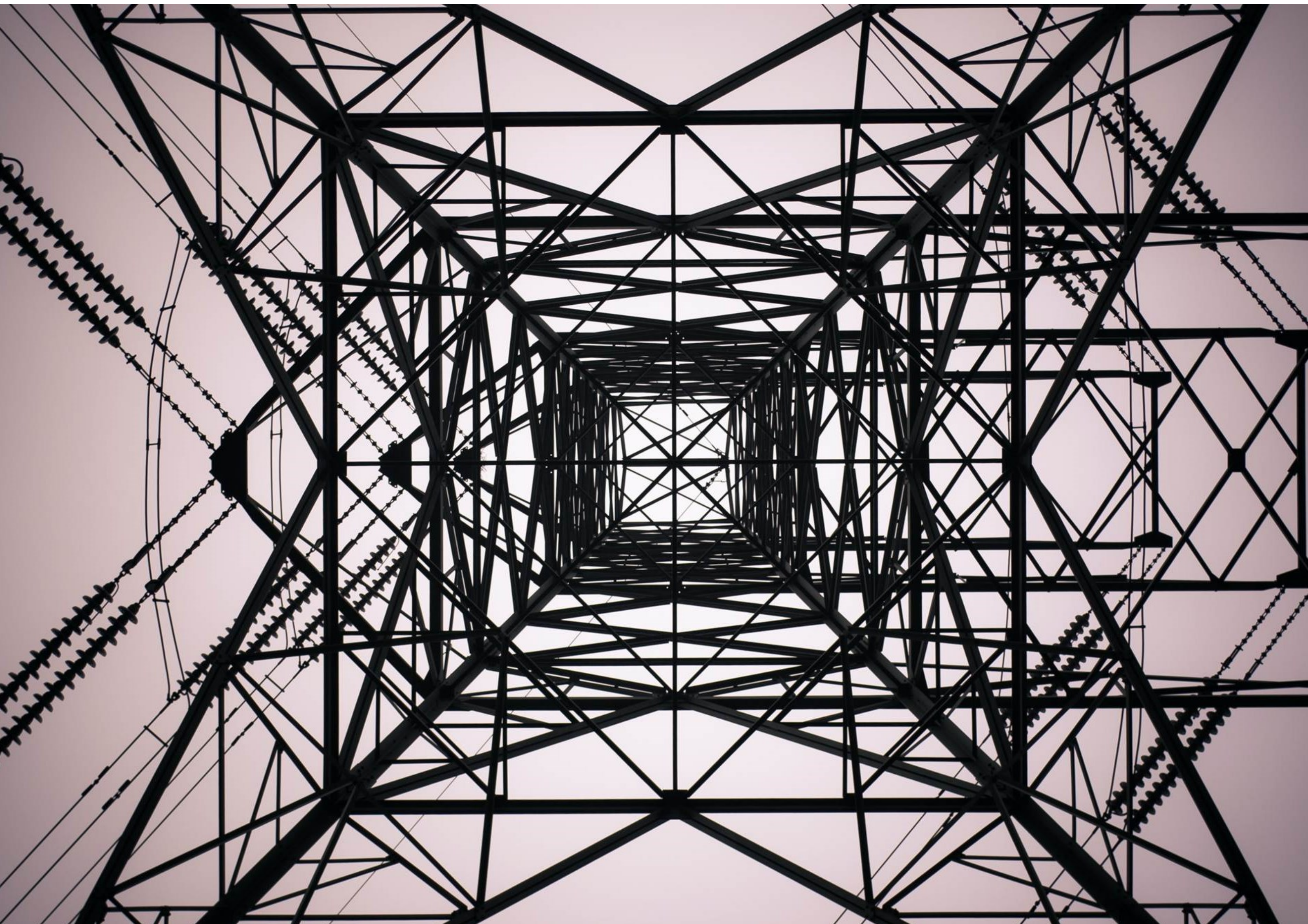

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ACRONYMS AND ABBREVIATIONS

Acronyms	Description
DFES	Distribution Future Energy Scenarios
DNO	Distribution Network Operator
ENWL	Electricity North West Ltd
GB	Great Britain
LDES	Long Duration Energy Storage
LDES-NODE	Long Duration Energy Storage – Network Optimisation, Decarbonisation and Efficiency
LSOA	Lower layer Super Output Area
SIF	Strategic Innovation Funding
WP	Work Package

EXECUTIVE SUMMARY

This report covers the overview of the model design specification, as well as the model output structures for the Long Duration Energy Storage for Network Optimisation, Decarbonisation and Efficiency (LDES NODE) project, funded through Strategic Innovation Fund (SIF).

At a high level, the model aims to map pre-defined Long Duration Energy Storage (LDES) technologies to specific network infrastructure based on network metadata, along with geographical constraints for LDES technology deployment.

The LDES NODE project successfully created a methodology and proof-of-concept model for mapping LDES technologies to specific network primary locations, as well as creating both CSV outputs and visual outputs that overlay the allocated LDES technologies to network infrastructure, overlaid with Local Authority boundaries that can feed directly into Local Area Energy Plans.

The mapping of LDES technologies in done through three aspects. The first aspect is the model uses annualised network metadata to identify network requirements (network use cases); the second aspect is the model technology use cases, identified in WP2 – Techno-economic Analysis, which state which requirements specific LDES technologies meet to assign a list of LDES technologies to each node; the final aspect is the model takes in geographical land datasets along with LDES technology land requirements, and constrains LDES technologies to only be deployed in the correct land dataset.

The report begins by covering the inputs to the model and the references used to source these inputs. It then progresses into covering the model methodology and concludes with an overview of the structure of outputs from the model.

The final outputs have been made available and can be found on the ENA Smarter Networks Portal, and on the innovation pages of the ENWL website, or on request from ENWL.

1. INTRODUCTION

The Long Duration Energy Storage for Network Optimisation, Decarbonisation, and Efficiency (LDES NODE) project, funded through the Strategic Innovation Fund (SIF)[1], aimed to better understand the role of LDES technologies within the electricity distribution network and support Local Area Energy Plans (LAEPs).

As part of the Discovery phase[2], a techno-economic analysis was conducted to compare the levelised cost of storage of various technologies and map technologies to use cases relevant to the Distribution Network Operator as well as Local Authority boundaries to feed into LAEPs. The methodology and outputs of the WP2 techno-economic analysis are described in the LDES NODE WP2 Final Report.

In addition, a separate work package (WP3) was conducted to produce a proof-of-concept model which combined publicly available network and geospatial data with the use cases and associated LDES technologies from WP2 to allocate LDES technologies to network substations. This report describes the methodology developed to produce the proof-of-concept model and its accompanying outputs.

2. MODEL METHODOLOGY

2.1 MODEL INPUTS

The input data used within the model can be classified into four broad categories:

- Network metadata – this data characterises the network substations, and includes information such as location, rated capacity, annual generation and demand headroom forecasts. The primary source for network asset data was the ENWL DFES outputs, which contained annual forecasts for primary substations
- Geospatial data – these geospatial datasets describe the land usage of the regions within the network area, and includes information such as roads, green space, and salt cavern locations. Furthermore, this includes DNO license areas and Local Authority Boundaries.
- LDES technology data – these data define the LDES technology use cases and the associated technologies, and are derived from WP2.
- Auxiliary data – this category is a catch-all for any additional data used within the model that does not fit the above three categories.

The full list of data sources used within the model is outlined in Table 1 below.

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[1] Strategic Innovation Fund (SIF) | Ofgem
[2] The Discovery phase intends to define the problem and the value in solving the problem. It will also facilitate a common understanding of what energy consumers and network users need from the innovation and identify any constraints that may impact on solution of the problem and options for the management of those constraints.

TABLE 1 DATASETS USED WITHIN THE LDES NODE MODEL

Dataset	Category	Source
GB local authority boundaries	Geospatial data	Open Geography Portal - Local Authority Districts (May 2022) UK BFE V3
GB LSOA boundaries	Geospatial data	Open Geography Portal - Lower layer Super Output Areas (December 2021) Boundaries EW BFC V8
Salt cavern locations	Geospatial data	Williams et. al. "Does the United Kingdom have sufficient geological storage capacity to support a hydrogen economy? Estimating the salt cavern storage potential of bedded halite formations", Journal of Energy Storage, Volume 53
Industrial cluster locations	Geospatial data	National Atmospheric Emissions Inventory - Emissions from NAEI large point sources
High-potential heat network zones	Geospatial data	This data was generated by ERM, details on how this was generated are covered in Appendix A
Network substation locations	Network metadata	Provided by ENWL
Network substation rated capacities	Network metadata	ENWL heat map tool - Heatmap tool
DFES outputs (by asset) • Peak demand • Minimum demand • Connected generation • Total annual consumption	Network metadata	ENWL DFES data - ENWL DFES

Dataset	Category	Source
Generation and demand headroom (by asset)	Network metadata	Provided by ENWL
LDES technology use cases and associated technologies	LDES technology data	LDES NODE WP2
LDES technology development requirements	LDES technology data	LDES NODE WP2
Hourly demand and renewable generation profiles for all of GB	Auxiliary data	Demand – ELEXON Rolling System Demand Generation – Grid Watch
GB DNO licence area boundaries	Auxiliary data	National Grid ESO - GIS Boundaries for GB DNO License Areas

2.2 MODEL OVERVIEW

A high-level process diagram for the LDES NODE proof-of-concept model is shown in Figure 1, a full step-by-step walkthrough of the model methodology can be found in Appendix B. The aim of the model is to allocate LDES technologies to network assets according to need, which is achieved by considering the following:

- LDES use cases – use cases for LDES technologies identified in WP2 are simplified and mapped to the available network metadata. Metrics are defined for each use case and threshold values are applied to determine use case eligibility. Each use case has an associated list of viable LDES technologies which get mapped to the asset. LDES use cases are described in further detail in Section 2.3.
- LDES technology development requirements – if geospatial constraints are defined for LDES technologies, filtering the resultant technology list produced by the use case analysis based on the geography surrounding the network asset. LDES geospatial filtering is described in further detail in Section 2.4.

All LDES technologies will be considered for each network substation. The final output is a mapping of suitable LDES technologies and network use cases for each network substation. The outputs of the model are described in more detail in Section 3.

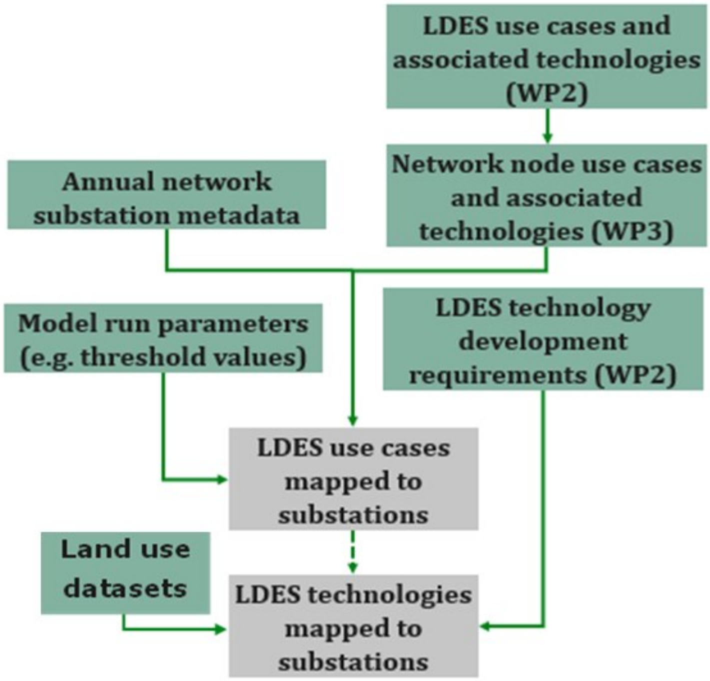

FIGURE 1 LDES NODE PROOF-OF-CONCEPT-MODEL DIAGRAM

2.3 LDES USE CASES

The outputs of the techno-economic analysis in WP2 produced a set of LDES technology use cases applicable to the distribution network, each of which had various associated LDES technologies, ranked by cost-effectiveness. Each use case was specific to a range of duration and frequency requirements. As the data granularity of the network substation metadata was restricted to annual forecasts, these use cases could not be directly utilised by the proof-of-concept model, which could not generate hourly storage profiles. As such, the use cases were simplified to align with the available data. Table 2 below shows the relationship between the LDES technology use cases identified in WP2 and those used in the proof-of-concept model.

TABLE 2 WP2 USE CASES AND THEIR EQUIVALENT USE CASE USED WITHIN THE MODEL.[3]

Techno-economic analysis use case (WP2)	**Proof-of-concept model use case (WP3)**
Increase renewable utilisation for regular load, e.g., the North West industrial cluster.	Reduce curtailment – industry.

[3] The column on the left provides LDES technology use cases i.e. the issues that are directly addressed by an LDES technology. The column on the right provides network use cases i.e. requirements from the network that are addressed by the LDES technology.

Techno-economic analysis use case (WP2)	Proof-of-concept model use case (WP3)
Increase new connection capacity on constrained distribution network.	Increase new connection capacity on constrained distribution network.
Active network management.	Active network management.
Assist in demand management and midday peak demand reduction.	Assist in demand management and midday peak demand reduction.
Absorb excess PV and help smooth PV generation profiles.	Reduce curtailment.
Absorb distribution network level wind oversupply – reduce curtailment.	Reduce curtailment.
Interseasonal renewable storage which reduces curtailment.	Reduce curtailment.
Store excess generation as heat for district heat scheme.	Store energy for district heat.
Reduce heating demand through district heating.	Store energy for district heat.

As calculating hourly storage profiles was not feasible, each model use case was assigned a metric, derived from the available network metadata. Each metric has an associated threshold value, which is defined by the user in the model run arguments, and any node[4] which falls within the critical zone (above or below the threshold, depending on the use case), the relevant use case is assigned to that substation. Table 3 describes the metrics associated with each model use case; depending on the metric definition, eligibility calculations were performed once (e.g., "Store energy for district heat" use case) or annually. Any node deemed eligible for a use case calculated annually would also be assigned a "earlier case year", which indicates the year by which LDES should be installed to meet the use case.

[4] A network node is any network asset (e.g. primary subsation)

TABLE 3 MODEL USE CASES AND ASSOCIATED METRICS

Proof-of-concept model use case (WP3)	**Associated metric(s)**
Reduce curtailment	Total curtailed energy relative to total annual consumption, is obtained as follows: • Calculate normalised generation and demand profiles using GB-wide data. • Apply to generation capacity and total annual consumption at substation. • Calculate total curtailed/unused energy and validate if it falls above the threshold as defined in the model input arguments. Calculated for each year in the forecast.
Reduce curtailment – industry	• For substations that meet threshold for "Reduce curtailment" – check proximity to industrial clusters.
Increase new connection capacity on constrained Distribution Network.	• Generation and/or demand headroom below X% (set by user) of rated capacity of the substation. • Calculated per substation for each year in the forecast.
Active network management	• Any substation in which the generation or demand headroom goes negative. • Calculated per substation for each year in the forecast.
Assist in demand management and midday peak reduction.	• All nodes with a peak demand higher than X% (set by user) of the average peak demand across all substations. • Calculated per substation for each year in the forecast.
Store energy for district heat	• All substations in proximity (distance set by user) to high heat demand clusters. • Calculated once per substation.

2.4 LDES LAND-USE REQUIREMENTS

Within the proof-of-concept model, geographical constraints for the deployment of LDES technologies were also considered. To achieve this, the model takes in three inputs:

Geographical polygon datasets of land use (e.g. salt cavern locations); a table defining any LDES technology land use requirements/constraints; and buffer values, defining the maximum distance (in metres) for LDES suitability.

The model then overlays each of the network node locations, with the land use polygons (with the corresponding buffers applied). Looping through each LDES technology with land use requirements, it marks each network node as to whether it is suitable or not for that LDES technology only based on geographical locations. Therefore, technologies with land use requirements can only be assigned to network nodes that fall within the acceptable distance threshold of the specified land use polygons.

It is worth highlighting that at the start of the Discovery phase, it was thought that most if not all LDES technologies would have land use requirements. However, upon the completion of WP2 it was discovered that only two technologies have significant land requirements, as shown below in Table 4. If this project progresses to the Alpha phase, then a key area of focus would be to improve the understanding of publicly available geographical inputs and the land use requirements of LDES technologies.

TABLE 4 LDES TECHNOLOGY LAND USE REQUIREMENTS

Technology Name	**Land Use Requirements**
Compressed Air Energy Storage – Stored in a salt dome	Salt Cavern
Adiabatic Compressed Air Energy Storage – Stored in a salt dome	Salt Cavern
Salt cavern stored green H2 with fuel	Salt Cavern
Salt cavern stored green H2 with H2 turbine	Salt Cavern

3. MODEL OUTPUTS

The model produces three main outputs, this section provides an overview of the functionality and purpose these outputs provide.

3.1 CSV OUTPUTS

The CSV outputs provide a tabular format for users to interrogate the model results. These outputs are broken down into two files.

Summary CSV Output

Within the summary CSV output, each row corresponds to a single network node and intends to provide a quick summary of the top-ranked LDES technologies assigned to each network node alongside a list of other relevant technologies. It also provides an overview of the earliest year in which network node requirements become significant (the year in which metadata exceeds any thresholds as defined by network use cases which are described in Section 2.3 LDES use cases); as well as listing the network use cases that are being addressed by the attributed LDES technologies. An example of this output can be seen in Appendix C, as well as column definitions provided in Table 5 below.

TABLE 5 COLUMN DEFINITIONS FOR THE SUMMARY CSV OUTPUT

Column Name	Column Definition
Network Node	The network node name
Top Ranked LDES Technology	The most cost-effective LDES technologies are attributed to the network node, which could be multiple. LDES technologies are ranked at each node by the total number of times a specific technology has been attributed to the node (i.e. that LDES technology is meeting a greater number of the network use cases). The higher this number the higher ranked the LDES technology is.
Other Relevant LDES Technologies	Other LDES technologies that are attributed to the network node.
Earliest Network Node Requirement Year	The earliest year in which the network node has significant requirements for the installation of any LDES technology.

Column Name	Column Definition
Network Node Use Cases	All network node requirements that have been attributed to the network node.
Total Network Node Use Cases	The total number of network node use cases, for a given network node.

Appendix CSV Output

Within the appendix CSV output, each row corresponds to a single LDES technology within each network node and intends to provide a more detailed breakdown of the information associated with each of the LDES technologies assigned to network nodes. An example of this output can be seen in Appendix C, as well as column definitions provided in Table 6 below.

TABLE 6 COLUMN DEFINITIONS FOR THE APPENDIX CSV OUTPUT.

Column Name	Column Definition
Network Node	See Table 5 for column definition.
LDES Technology Mapped to Network Node Use Case	The most cost-effective LDES technology attributed to a single network node, that resolves a single network node requirement (network node use case).
Network Node Requirement Year	The year in which the network node requirement (as defined in Network Node Use Case Addressed by Technology) becomes significant for the installation of the LDES technology.
Total Network Node Use Cases Addressed by Technology	The number of network node requirements that a single technology meets.
Total Network Node Use Cases	See Table 5 for column definition.

3.2 VISUAL OUTPUTS

The visual outputs created as part of the model intend to provide an overview of the locations of network nodes (primary substations), overlaid with the ENWL license area and Local Authority boundaries. This allows for ease of use for the consideration of what LDES technologies are recommended within each Local Authority, which in turn can directly support the rollout of LDES technologies as part of Local Area Energy Plans (LAEPs).

There are two visual outputs, that are intended to show different slices of the same data. Each of these outputs and their intended purpose are discussed in further detail below. The screenshots below show the outputs for the model, which will change depending on the results of the model. Currently the outputs of the model see a minimum number of use cases of 1 and a maximum of 5; it also allocates the following top ranked technologies:

1. A-CAES
2. CAES
3. Gravitational
4. Lion
5. Hot water storage with a heat pump

3.2.1 NUMBER OF NETWORK USE CASES

As previously described in Section 2.3, a network use case was used to determine from the metadata whether a particular network node has a requirement for LDES technologies. Each network node can have multiple network use cases, the greater the number of these use cases, the larger its need for LDES technologies.

This visual output slices the data based on the value of the total number of network node use cases (i.e. how much of a need for LDES technologies each network node has). This allows the user to focus on areas that are perceived as having the highest requirements. The technologies shown in the pop-up box on the network node as ordered in ranking (i.e. the top ranked LDES technology is the first in the list). An example of this visual output can be seen in Figure 2 below.

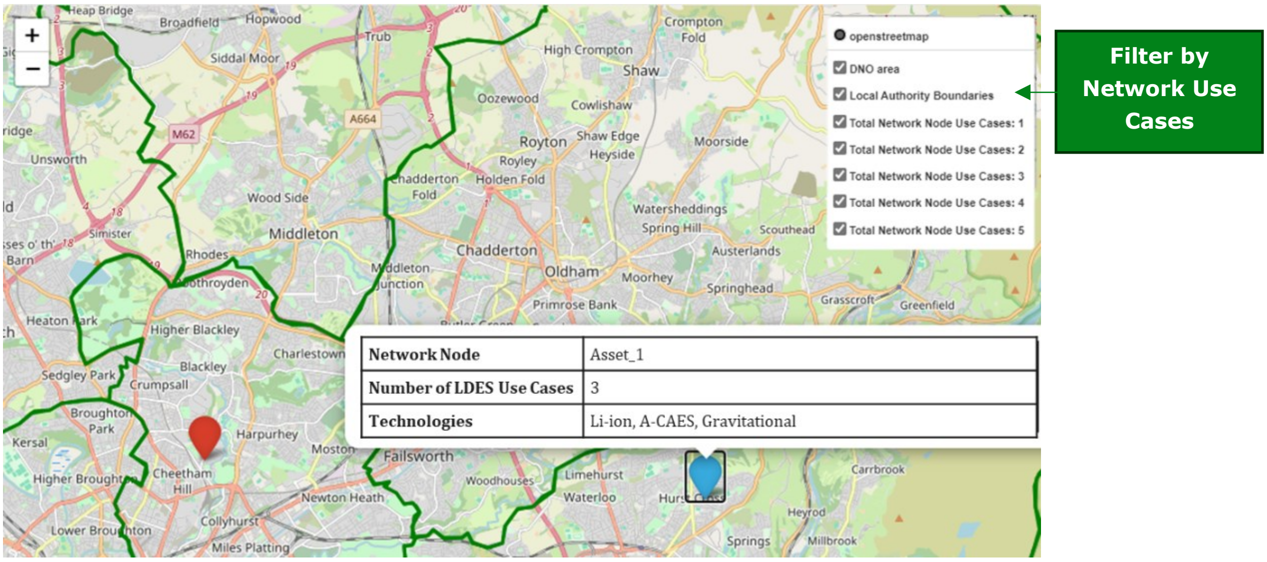

FIGURE 2 EXAMPLE OF HTML VISUAL OUTPUT FOR NUMBER OF NETWORK USE CASES

3.2.2 TOP RANKED TECHNOLOGY

Another way the visual outputs have been sliced is what top-ranked LDES technology has been assigned to each network node. This allows the users to filter for specific technologies that have been allocated and identify any regional hotspot locations where they are assigned. The technologies shown in the pop-up box on the network node as ordered in ranking (i.e. the top ranked LDES technology is the first in the list).

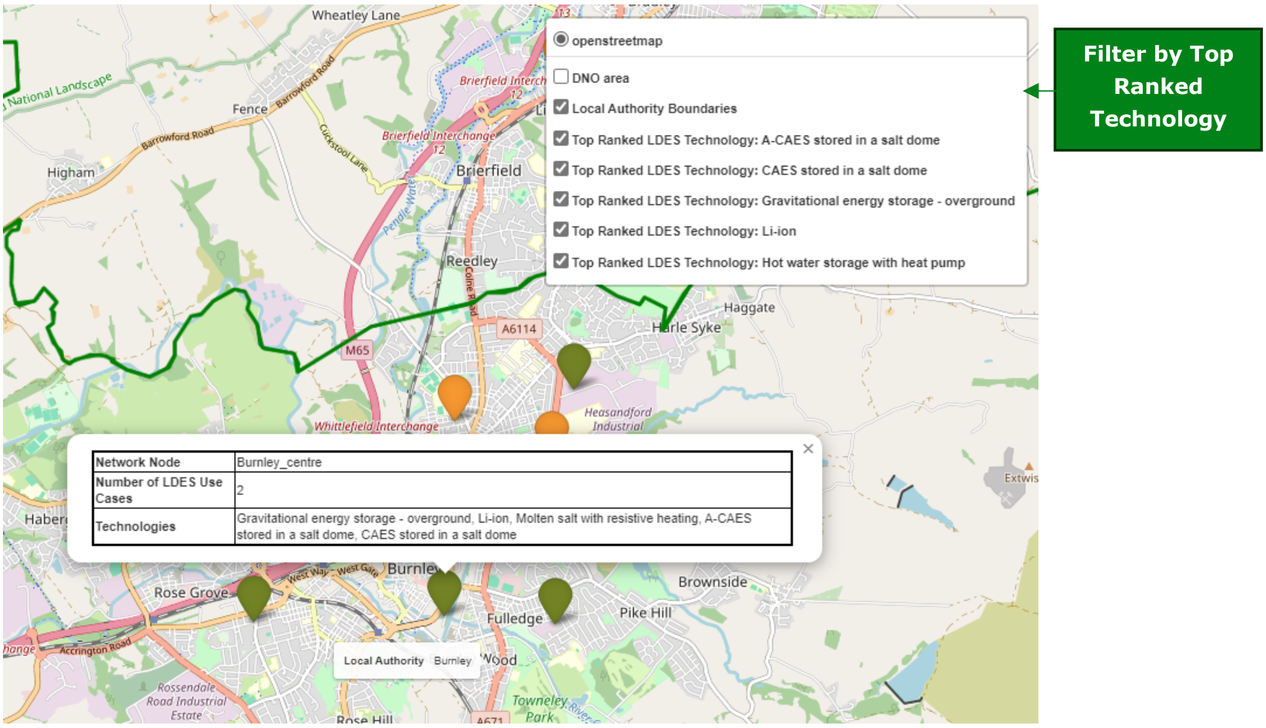

FIGURE 3 EXAMPLE OF HTML VISUAL OUTPUT FOR TOP-RANKED LDES TECHNOLOGY

3.3 GEOJSON OUTPUT

The model also provides a geojson output, which contains the same data as seen in the Summary CSV, except in a geographical dataset format. The intended purpose of this output is to allow the user to utilise any GIS of their choice to further interrogate the outputs of the model as well as overlay any other geographical datasets of their choice.

APPENDIX A - HIGH POTENTIAL HEAT NETWORK ZONES INPUT CREATION

This Appendix covers the methodology used by ERM when creating the input that defines areas within ENWL's license areas that are considered a high potential for heat networks to be installed. The basis of the inputs and their sources were:

- Building polygons – Ordnance Survey Topographic Layer
- Lidar data 1m Digital Terrain Model – DEFRA Lidar Survey Data Download

These two inputs provide an estimated volume (m^3) for each building. This was then fed into a heat demand estimation tool that uses a support vector machine, which is a supervised machine learning algorithm that is trained on input data of building volume vs annual heating demand, to forecast annual heating demand. The output of this is building polygons with an annual estimated heating demand.

The next step was to convert the building polygons into centroids and run it through a kernel density estimation (KDE) algorithm, which taking the X and Y coordinates in a spatial plane, finds the probability density of heat demand. The output of the KDE algorithm is then filtered, where the density is above a set threshold (i.e. the heat density is greater than a pre-defined value), giving polygons of areas where there is a high potential for the installation of heat networks.

APPENDIX B - DETAILED MODEL METHODOLOGY

1. Load all inputs, these include:
    a. Network node locations.
    b. Land use datasets.
    c. Network node metadata.
    d. Technology metadata.
    e. Average hourly demand and generation.
    f. Industrial cluster locations.
    g. Heat network locations.
2. Calculate the intersection and difference of land use datasets. This takes the land use polygons and splits them into the intersection and difference polygons of all land use datasets. Returns a single GeoDataFrame with all the datasets, intersected and difference calculated with a column added that states the land use type.
3. Calculate the normalised generation and demand hourly profile from the average UK hourly demand and generation profile:
    a. The demand is normalised by dividing all hourly demand values by the sum of the yearly demand values. This is done as the network node demand data is in MWh.
    b. The generation is normalised by dividing all hourly generation values by the max of the yearly generation values. This is done as the network node generation data is in MW.
4. Map LDES technologies (that have land use constraints, e.g. CAES) to land use polygons (generated in step 2), based on the land use requirements of each LDES technology (contained within the technology metadata). This results in only LDES technologies with land use constraints being mapped to where they are suitable i.e. CAES for all salt cavern locations.
5. Loop through each network node:
    a. Looking at the metadata of that single network node, across all years, consider what network "use cases" it meets (see Section 2.3 LDES use cases for further details on how these are calculated). Furthermore, the earliest year in which the network node has a network use case is recorded.
    b. Using the land use polygons with appropriate LDES technologies mapped onto them (generated in step 4), mark whether each network node is appropriate or not to deploy the LDES technology by calculating a geospatial intersection.

6. Filter (if provided in the input arguments) for the top X number of network nodes. This is determined by sorting network nodes by the total number of network use cases as defined in step 5a.
7. Map LDES technologies to network nodes, this is done in a two-step process:
    a. Using the network node "use case" (from WP3) to the technology "use case" (from WP2) mapping, attribute the technology to the network node that is meeting the network node requirements.
    b. If any of the technologies have geographical constraints, check if the network node is within the geospatial boundary of the land use input (as calculated in step 5b).
8. Post-processing outputs:
    a. Calculate the top-ranked LDES technology by taking the LDES technology that meets the most amount of network node requirements.
9. Generate the following outputs:
    a. Summary CSV output
    b. Appendix CSV output
    c. Summary geojson output (the same as the summary CSV, just geospatial)
    d. HTML visual output sliced by the number of network use cases
    e. HTML visual output sliced by the top-ranked LDES technology.

APPENDIX C - TABULAR OUTPUT EXAMPLES

TABLE 7 SHOWING THE EXAMPLE OUTPUT FORMAT FOR THE SUMMARY CSV RESULTS [5]

Network Node ID	Network Node	Top Ranked LDES Technology	Other Relevant LDES Technologies	Earliest Network Node Requirement Year	Network Node Use Cases	Total Network Node Use Cases
1	Asset_1	Li-ion	A-CAES, Gravitational	2029	Reduce curtailment, industrial cluster, Constrained network	3
2	Asset_2	Li-ion	Gravitational	2034	constrained network, reduce curtailment	2

TABLE 8 SHOWING THE EXAMPLE OUTPUT FORMAT FOR THE APPENDIX OUTPUT [6]

Network Node ID	Network Node	LDES Technology Mapped to Network Node Use Case	Network Node Requirement Year	Network Node Use Case Addressed by Technology	Total Network Node Use Cases Addressed by Technology	Total Network Node Use Cases
1	Asset_1	Li-ion	2029	Reduce curtailment, Industrial cluster, Constrained network	3	3
1	Asset_1	A-CAES	2045	Constrained network, Reduce curtailment	2	3
1	Asset_1	Gravitational	2032	Constrained network	1	3

[5] Please note the data in this table is indicative and does not represent actual outputs from the model
[6] Please note the data in this table is indicative and does not represent actual outputs from the model

Network Node ID	Network Node	LDES Technology Mapped to Network Node Use Case	Network Node Requirement Year	Network Node Use Case Addressed by Technology	Total Network Node Use Cases Addressed by Technology	Total Network Node Use Cases
2	Asset_2	Li-ion	2034	Reduce curtailment, Constrained network	2	2
2	Asset_2	Gravitational	2040	Industrial cluster	1	2

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ERM London
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