Horizon scanning report 2020-21

January 2021

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Supergen
Energy Networks

Engineering and Physical Sciences Research Council

1. Introduction

The international aspiration to reach net zero carbon in energy systems by 2050 is growing. In the UK, the government has set a target of 'Net Zero' Greenhouse Gas (GHG) emissions by 2050 in order to reduce contribution to global warming [1]. This necessitates improved understand of the intrinsic properties of the key components of the Integrated Energy System (IES), from natural resources and energy import to the final energy user as well as the interdependencies within each layer/section [2]. These interdependencies and interactions occur between different energy vectors including natural gas, electricity, cooling and heating. Energy networks are vital enablers of the whole energy system, which connect the natural resources and import to the final energy user. Energy networks also exploit and enable the temporal and spatial diversity in energy production and energy use. They play an enabling role in the net zero GHG target, and in delivery of the complex challenges of a fair, cost effective and secure transition to a future energy system.

Currently, there is a lack of research in energy networks which takes a whole systems, or integrated systems, approach, and so knowledge of the interconnected and interdependent nature of energy network infrastructure is lacking. Therefore, it is believed that there is a need for step change in research and development in energy networks and their interdependencies, through Integration Energy Network (IEN) analysis, in order to facilitate the path to achieving the carbon reduction targets.

Energy networks (including gas, electricity and district heating/cooling networks) used to be planned and operated separately. However, there are several drivers for integrated planning and operation of energy networks including reduction of the use of primary energy, increasing integration of Renewable Energy Resources (RESs) and facilitating a low carbon economy [3]. The synergies between energy networks [4,5] and the interdependencies and interactions between these networks have brought several benefits to the integrated planning, optimal dispatch and operation of the energy networks including increasing energy conversion efficiency, maximised utilisation of primary energy sources, improving the energy system flexibility, resilience and security and carbon emission reduction [3,6,7].

Modelling of IEN is crucial for understanding the energy networks, their interaction and interdependencies and the benefits of their integrated operation. Several energy system models have been developed, which have been presented and discussed in the literature [3,6,8,9]. Moreover, Information and Communication Technologies (ICTs) have a substantial role in integrated energy systems since they support the coordinated operation of the system by integrating different parts of the energy system through information sharing frameworks [7]. Consequently, there are several complexities associated with planning, management and operation of integrated energy networks, which needs close collaboration of several fields of expertise including computing science and several engineering disciplines to address the challenges of this multi-disciplinary field of knowledge.

Facing pressure to be fit for a net zero GHG future, energy networks in the UK, and across the globe, are undergoing modernisation and investment. In order to ensure this investment is effective, energy network integration is a high priority for the UK regulator OFGEM, and hence the work of the Supergen Energy Networks Hub is urgent and timely.

This report summarises key academic literature with regards integrated energy network modelling across multiple vectors. This review will enable the Supergen Energy Networks Hub to address gaps in the review, and thereby contribute to the sector. This review was first published in Renewable and Sustainable Energy Reviews [10].

2. The review sample

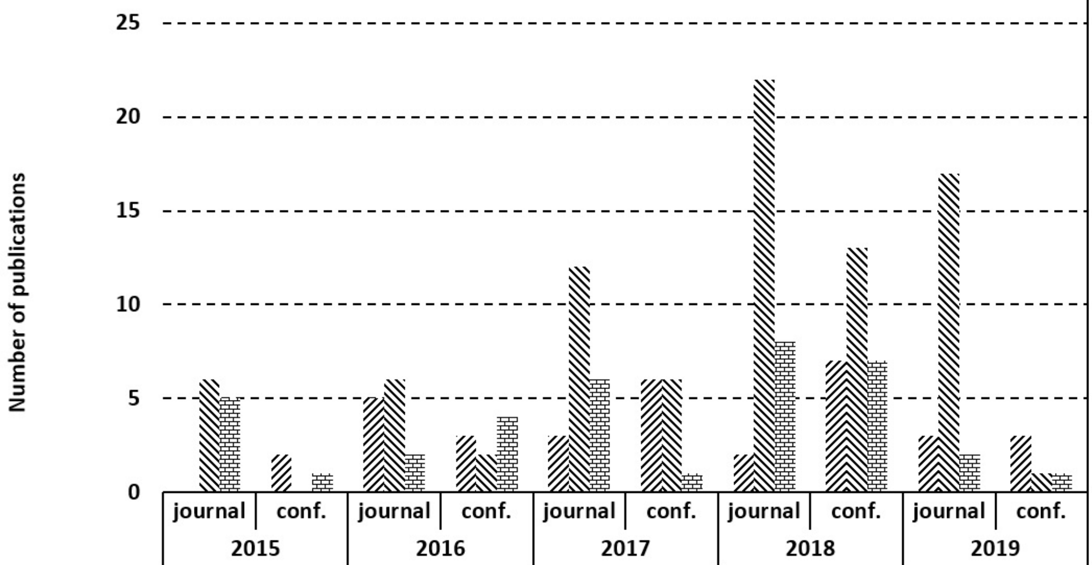
Research databases (including IEEEXplore, Sciencedirect and Scopus) were searched with the following key words in their title or keywords:

- a combination of two of: ‘gas’, ‘heat’, ‘power’/‘electric’
- ‘multi-energy’, ‘multi-vector’, ‘integrated energy systems’, or ‘integrated energy networks’
- ‘energy system’ or ‘energy network’

Results were filtered to ensure the body of literature was from high quality sources. Several papers had performed analysis of a single vector (i.e. gas, electricity or heat) as well as the point(s) of connection to the network of other vector(s) and the impact of those networks without considering the operation of those coupled network(s). Those papers were excluded. The resulting 186 papers were classified into each of the groups below according to their models (as shown in Figure 1), research questions and scenarios:

- Papers on operational analysis
- Papers on optimal dispatch
- Papers on optimal planning

The majority of these papers were published in the last five years (see Figure 1).



	2015 journal	2015 conf.	2016 journal	2016 conf.	2017 journal	2017 conf.	2018 journal	2018 conf.	2019 journal	2019 conf.
operational analysis	0	2	5	3	3	6	2	7	3	3
optimal dispatch	6	0	6	2	12	6	22	13	17	1
optimal planning	5	1	2	4	6	1	8	7	2	1

operational analysis   optimal dispatch   optimal planning

Figure 1. Number of publications in the last five years on Integrated Energy Network analysis.

A full evaluation of the literature in this space has been published [10], and this report is therefore a short summary of the key findings.

3. Operational analysis

Operational analysis research involves calculation of the values of state parameters in IENs, i.e. voltages in electricity, pressures in gas and mass flow rates and temperatures in heating/cooling networks. Topics discussed in previous work on operational analysis of IENs are shown in Figure 2.

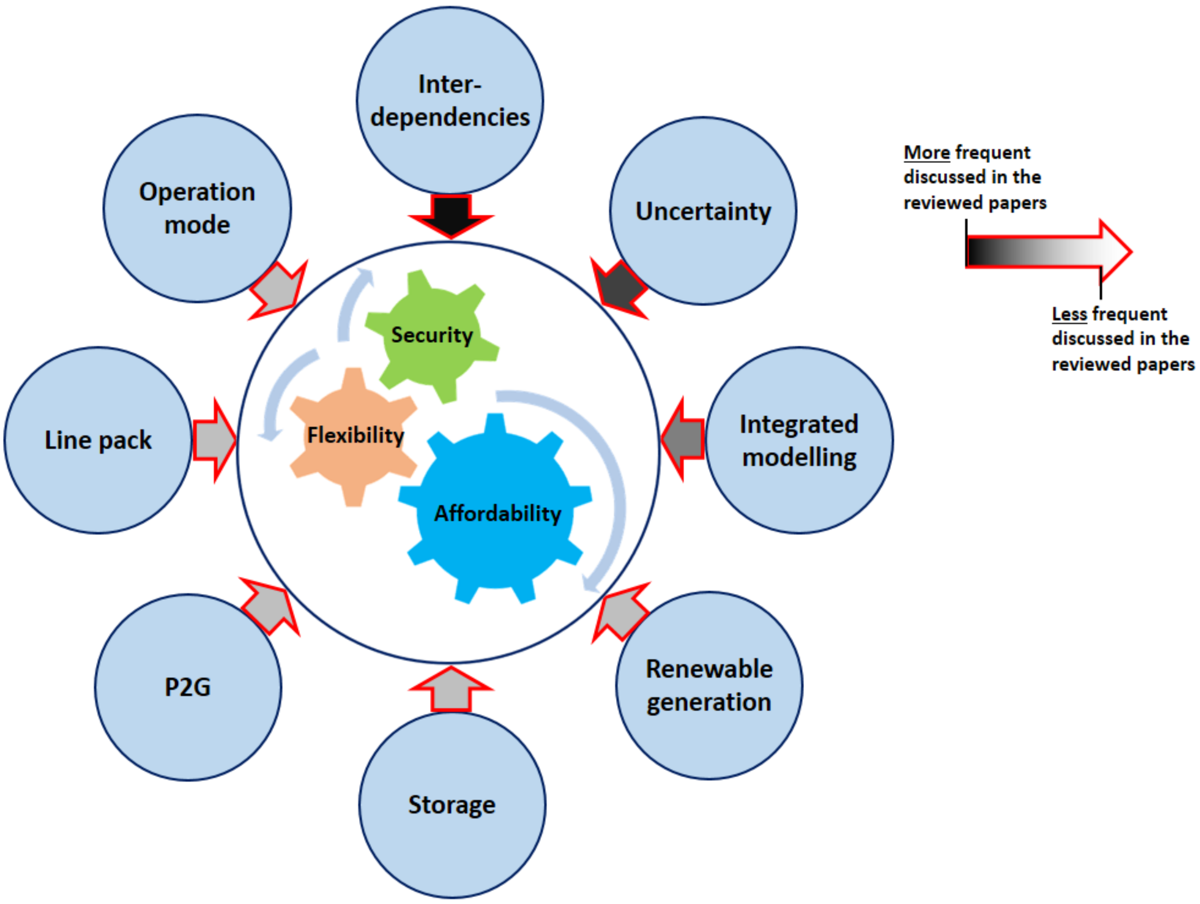


Figure 2. Topics discussed in the papers on operational analysis of IENs.

Flexibility has been discussed in previous work. There are several options that provide flexibility to the operation of IEN: line pack storage, power-to-gas (P2G), storage devices, and compressors (see Table 1). These devices can be used in gas, electricity and heat networks, and provide flexibility to the operation of networks. Storage, in particular, can provide flexibility to coupled network(s) through the quasi-dynamic[1] interactions, which can be used in security enhancement.

[1] 'Quasi-dynamic' in [11] refers to an integrated model of electricity and heat networks in which the electricity network has been modelled using steady-state formulations, however, time-dependant (dynamic) equations have been used for modelling the heat network.

Security, or resilience, is a frequently investigated issue in previous work, particularly with regards interdependencies and uncertainty. Interdependencies and coupling components of IENs allow for an IEN to have interactions through these components. Disturbance from one network transmits to the other coupled networks through these conversion components. However, IENs can also provide support across component networks in the case of occurrence of faults. There are several sources of uncertainty within IENs including renewable energy output, the random outage of generator units, and the random fluctuation of the loads. It was shown that any increase in the uncertainty range of these factors leads to more significant fluctuation of the state variables of the nearby buses/nodes.

Therefore, there is a need for IEN studies, to appropriately investigate system resilience and security, and/or system flexibility.

Table 1. Different types of energy storage systems utilised in IENs.

Gas network	Electricity network	District heating network
Gas tank Line pack	Batteries Pumped hydro storage Compressed air energy storage Liquid air storage Electric vehicles* Flywheel storage system Hydrogen**	Hot water tank Geothermal storage Air source heat pump*** Ground source heat pump***

*: through vehicle-to-grid

**: produced from surplus RES, using electrolyser, stored in the gas network and burnt at the time of need

***: acting as the heat supplier to the energy centre (source) of the DHN

4. Optimal dispatch

The problem of optimal dispatch in IENs is normally formulated as a classical optimisation problem with the objective of minimisation of operational costs or equivalently maximisation of social welfare subject to operational constraints. Topics discussed in previous work on optimal dispatch of IENs are shown in Figure 3. Comparison of co-ordinated scheduling showed that this approach to optimal dispatch across the IEN can lead to lower emissions and operational costs.

Flexibility of operation of IENs was the most frequent aspect investigated in previous work. It was shown that co-optimisation of IENs, rather than optimisation of individual networks, improves the economy and flexibility of the IEN. Line pack was shown as providing flexibility to gas networks, and to associated IENs, and thereby can have an important role in balancing production and consumption and more economical dispatch.

With regards **security and resilience**, previous work has found that combining gas and electricity networks is important to evaluate energy conversion between networks to minimise risk, ensure IEN security, and match supply with demand whilst minimising cost for transmission. Storage in IENs was shown to decrease load curtailments and improve IEN resilience against contingencies. P2G units were found to contribute to cost-effective scheduling by avoiding the curtailment of surplus wind generation. A number of papers investigated the impact to IEN resilience of uncertainty in wind generation, and found that increased levels of uncertainty of wind generation can lead to increased levels of uncertainty of operational costs of the IEN and hence to the higher system generation costs.

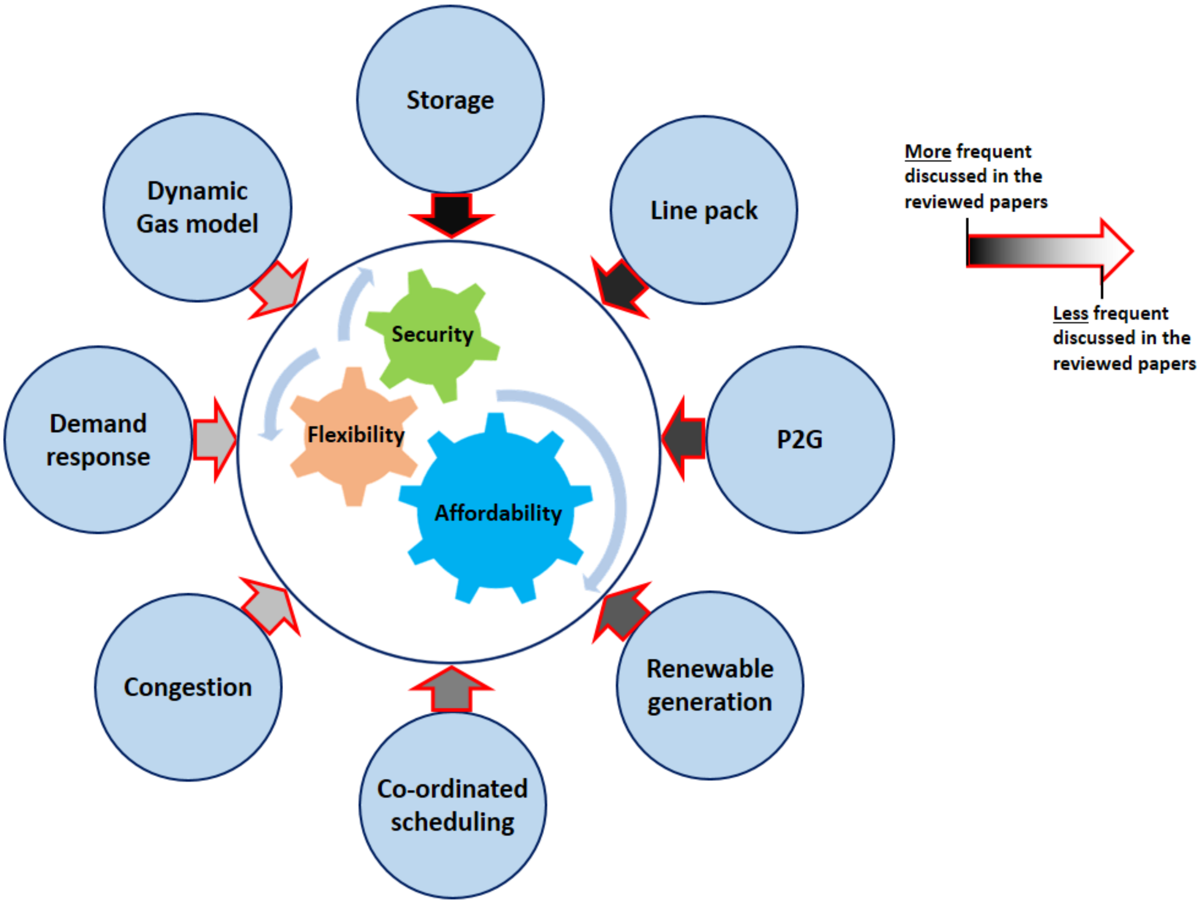


Figure 3. Topics discussed in the papers on optimal dispatch of IENs.

5. Optimal planning

The problem of optimal planning of IENs typically involves minimisation of Net Present Value (NPV) of a system, or maximisation of social welfare of a system, for a particular planning horizon and subject to some operational and investment constraints. Topics discussed in previous work on optimal planning of IENs are shown in Figure 4.

Flexibility in IENs is incorporated at the optimal planning stage, and previous work found that all the energy storage systems contribute in the long term to avoid energy deficit and hence contribute to increase economic savings. Demand uncertainty was found to impact operational cost, but not investment cost, of IENs. Stochastic solutions for demand and generation uncertainty were common methods in previous work.

Co-planning of IENs results in a solution with the following characteristics:

- Lower total costs, or equivalently higher total social welfare, due to the co-planned IEN having lower transmission stress, deferred investment capital cost and lower operational cost
- Lower carbon emissions
- Lower load curtailment
- Higher reliability levels, even in situations of uncertainty
- Greater flexibility
- Lower losses and better efficiency

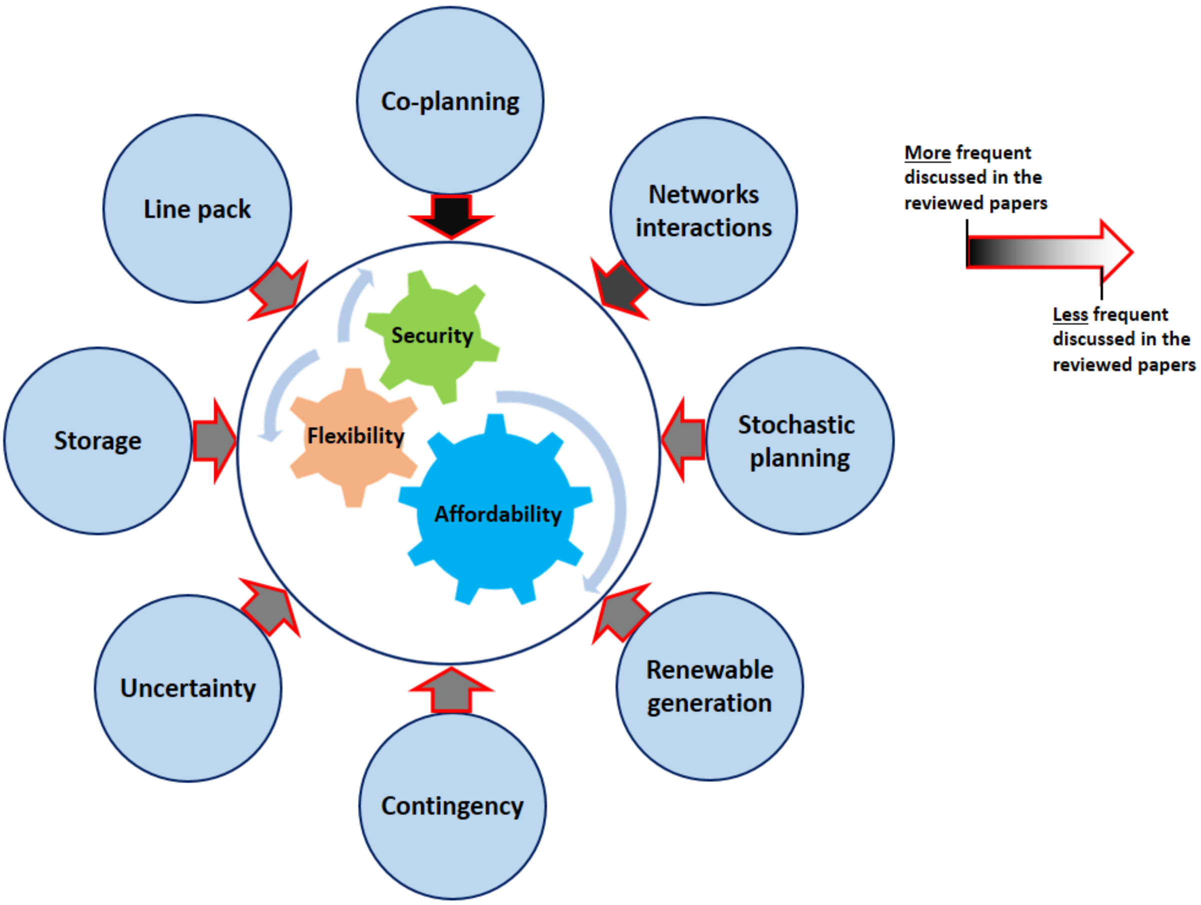


Figure 4. Topics discussed in the papers on optimal planning of IEN.

6. Network Architectures Working Group

In light of the work presented above, regarding the previous work, the Supergen Energy Networks Hub has commissioned a Network Architectures Working Group. This community of industry and academic experts are now in place. Through the Working Group, we are able to access a wide pool of expertise for future updates to this horizon scanning report.

Members: ABB, Energy Systems Catapult, Engie UK, Wales and West, Brunel University, Imperial University, Cranfield University, University of Strathclyde, Newcastle University, Cardiff University, Birmingham University, Bristol University, Oxford University, Aston University, UCL, Keele University, Durham University, Loughborough University, Leeds University.

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