Developing an Energy Security Monitoring Framework Fit for UK Net Zero

UKERC Working Paper

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Executive Summary

Background and objectives

There has been a dramatic rise in wholesale and retail energy prices in the UK since 2021 following the war in Ukraine. This has revealed energy security vulnerabilities in the UK and neighbouring states – at least in terms of their ability to secure energy at an affordable price for homes and businesses and the huge cost to public finances of protecting consumers from higher bills. Despite energy security now being a high-profile priority for UK Government, the UK is not well placed for measuring, monitoring and therefore managing its energy security.

There is limited consensus on how best to usefully define and measure energy security and it has been described as 'black box' (Cox, 2016). The way in which energy security is best measured is also likely to change as the UK energy system continues to decarbonise, digitalise and decentralise. As this happens, we will need to define and measure energy security in ways that are fit for UK net zero energy futures - for example, measuring and tracking risk and progress related to system flexibility. With intense interest in energy security, and ongoing scrutiny of net zero strategy and energy costs, a more evidence-based and transparent approach is needed.

This working paper addresses the question of how the UK's energy security can be better measured, managed and communicated over the course of the transition. Drawing on a review of energy security indices and literature, plus a stakeholder workshop, this work has explored: conceptualisations of energy security; existing indicator-based approaches to tracking energy security; and the UK net zero context. *It offers a new draft monitoring framework for UK energy security on the path to net zero, which we call the '4+4 Framework'.*

Chapter 2 explores the themes and variation within existing definitions of 'energy security' and proposes a shift in focus from what it means to how to measure it – from conceptualisation to *operationalisation* using an indicator dashboard approach.

Chapter 3 considers a number of issues that could inform the choice of indicators in a dashboard approach to measuring energy security. It discusses limitations in the indicators used to date, emerging 'transition risks', and the challenges to be met by an indicators approach. The Smart Systems and Flexibility Plan (SSFP) Monitoring Framework is presented as an example of a systematic approach that identifies indicators and data, which we suggest should be expanded across energy security to create a framework that is both holistic and detailed.

Chapter 4 discusses the vital role data will play in any indicators-based approach to tracking energy security and outlines some existing frameworks for data quality assessment (DQA).

Chapter 5 presents in some detail our '4+4 Framework', an original draft framework for monitoring UK energy security. It lays out our approach to themes, indicators, data and offers guidelines for its use and presentation in two dashboards, as outlined below.

Approach to themes, indicators and data in the '4+4 Framework'

- '4+4' refers to our eight themes:
  - The four 'A's that are familiar in energy security literature and frameworks - *Availability, Accessibility, Affordability,* and *Acceptability.*
  - Plus four more - *Sustainability, Independence*, *Governance* and *Data & Metrics*.

  We define these eight themes and give our rationale for their inclusion. *Sustainability* has its own theme because there are legal obligations to cut UK emissions. UK Government strategy documents clearly indicate 'British' and homegrown' energy to be a key energy security goal, so we include *Independence*. Themes for *Governance* and for *Data & Metrics* have been included, as poor measurement or poor management add risks to energy security that have been neglected by many dashboards. *Governance* indicators require further development but draw on existing work and cover plans, reporting and decision-making processes for policymaking and implementation.
- Themes have several vital roles to play in an energy security framework: they help to generate a comprehensive set of indicators for security goals; they give structure to these indicators; and they are key for communicating various aspects of energy security to stakeholders. However, we suggest that the key priority and challenge for developing a useful and useable energy security monitoring framework is not in just laying out a preferred set of 'themes' or 'dimensions' but in systematically and comprehensively identifying specific indicators, metrics and data that together can operationalise energy security. This level of detail is necessary and should be done with transparency, so we have attempted this from the start.
- We take a somewhat novel approach to themes that recognises the inherent issue of fuzzy boundaries. We have not attempted to devise a set of dimensions that neatly cover all aspects of energy security without any overlaps. Instead, we allow for where indicators are relevant to multiple themes and highlight this to help manage risks of double-counting. For this reason, we favour the term 'theme' over 'dimension' as the latter may suggest that they are mutually exclusive or orthogonal when in fact many indicators and data are relevant to more than a single theme. Overlapping themes raise the issue of potential double-counting. In many cases multiple impacts should be counted separately to reflect multiple types of risks that may have a common origin. By making visible where indicators are relevant to multiple themes, the framework can hopefully help to manage risk of double-counting errors and inform thinking about trade-offs and synergies.
- Our approach to themes is illustrated in **Table I**, below. The table is a matrix that presents the themes in eight coloured columns and shows indicators in rows: each indicator is tagged as being relevant to one or more themes. Some indicators have more obvious multiple impacts across multiple themes: for example, energy efficiency in housing can reduce demand to improve security of supply (*Availability*), reduce imports of gas (*Independence*), and reduce consumers' bills (*Affordability*) – see **Table I**. All indicators are tagged as relevant to the *Data & Metrics* theme (see below). In **Table I**, two example indicators are used for illustration, but a full table with all 72 indicators can be found in **Table C**, **Appendix 4**, which is the key summary

of the framework. Our matrix approach means that an indicator does not need to be 'siloed' within a single theme. There is flexibility to add more themes or sub-themes, according to evolving policy goals, public concerns or communication needs, without disrupting the structure of the framework. In terms of **Table C** (Appendix 4), this would be a matter of adding additional theme columns.

- Poor metrics and data jeopardise energy security – limiting awareness of risks, confidence in risk assessments, and the ability to respond and manage them effectively. We attempt to incorporate these potential risks into our framework in three ways:
  (i) Our choice of indicators was not constrained by current data availability. Some energy security indexes have chosen or filtered dashboard indicators based on existing data availability. Our aim is to devise a holistic set of 'ideal' indicators (for which data is available, or data collection is at least potentially feasible).
  (ii) We take a systematic and detailed approach to identifying data sources for each indicator, as illustrated in **Table I**, below (and listed in full in **Table C**, **Appendix 4**).
  (iii) The availability and quality of existing metrics and data for each indicator (for all themes) is assessed and guides activity to improve data and metrics. This assessment is done using criteria defined by indicators within a *Data & Metrics* theme. Accordingly, in **Table I** (and **Table C**) a*ll* indicators and data are tagged as relevant to the *Data & Metrics* theme and, in that sense, this theme is unique.

TABLE I: The '4+4 Framework' for monitoring energy security (illustration using two example indicators) †

Indicators are tagged as relevant to one or more of eight themes within energy security. *All* indicators are relevant to a *Data & Metrics* theme that assesses the availability and quality of data and metrics.

INDICATOR † (or groups of indicators)	**DATA SOURCES**	**Energy security THEMES** (relevant indicators marked with '**X**')							
		Availability	**Accessibility**	**Affordability**	**Acceptability**	**Sustainability**	**Independence**	**Governance**	**Data & Metrics**
Loss of Load Expectation (LOLE) for gas and electricity	UK Energy in Brief (2023), Reliability, (p.17) UK Energy in Brief (2022), (p. 8) 'Total Inland Primary Energy Consumption' Statutory Security of Supply Report (2021) NESO - Winter Outlook Report UK Historic Energy Demand Data DESNZ Energy and emissions projections Meteorological data: Met Office	X							X
Energy Efficiency in Housing	National Energy Efficiency Data Framework (NEED) Non-Domestic National Energy Efficiency Data Framework (ND-NEED) Household Energy Efficiency Statistics Green Homes Grant Voucher & Installation Statistics Green Homes Local Authority Statistics Energy Savings Opportunity Scheme (EOS) Energy efficiency of Housing, England and Wales, country and region Energy efficiency of Housing, England and Wales, cumulative financial years Energy efficiency of Housing, England and Wales, local authority districts Scottish Domestic Energy Performance Certificates Scottish Non-Domestic Energy Performance Certificates Energy Performance of Buildings Certificates in England & Wales	X		X			X		X

† The full table with all 72 indicators can be found in **Table C**, **Appendix 4.**

Using the framework

The intended purpose of the '4+4 Framework' is to better support four activities:

i. Identifying and assessing risks to energy security
ii. Identifying, assessing and improving metrics and data for monitoring risks
iii. Managing energy security, including policy decision-making and trade-offs
iv. Communicating energy security to the UK public and other stakeholders.

The steps below outline how the draft framework could be used to support the above aims.

Step 1: Assess data and metrics

The first step is to assess current metrics and data for each indicator (the full list of 72 indicators is in **Table C**, **Appendix 4**) using the *Data & Metrics* indicators, which cover three criteria:

- Metrics (fitness for purpose, validity, accuracy, reliability and transparency)
- Data availability and access
- Data Quality (DQA).

This cataloguing and assessment exercise should produce a rating for the quality of data and metrics for each indicator across all themes. This should reflect both current and future data needs. These assessments of metrics (under '*fitness for purpose*') and data (under '*user needs*', within DQA) should also include evaluating if they support decision-making for a Just Transition, i.e. how well data and metrics support analyses of the distribution of costs and benefits geospatially, socio-economically and with respect to other characteristics.

The assessments of data and metrics may be presented as a **Data Dashboard** - at either the level of individual indicators or at the level of themes. **Table II**, below, is an illustrative example of a dashboard at the level of the eight themes.

These assessments and Data Dashboards can serve two purposes:

(i) to inform activity to improve metrics and data for all indicators;
(ii) to inform energy security risk assessments for all indicators (see Step 2, below).

Step 2: Assess energy security risks

The second step is to assess energy security risks using existing indicators and available data. This should reflect both short and long-term perspectives and take note of potential double-counting. Risk assessments should also reflect the strength of the data and metrics for that indicator (assessed in Step 1). For example, an indicator may have excellent metrics and high-quality data available that indicate, with high confidence, a low level of risk; in terms of a traffic light rating for a dashboard, the indicator could be rated green for risk. If, instead, that indicator appeared to be a low risk but had very poor metrics or data, the overall risk assessment should have a low confidence that should be reflected by an amber risk rating at best.

This assessment should produce a rating for the level of risk for each indicator across all themes and may be presented as a **Risk Dashboard** - at either the level of individual indicators or aggregated to the level of themes (as illustrated in **Table II**). Aggregating ratings to the theme level does lose important and useful detail. While the use of weightings to aggregate indicators may be unproblematic for a sub-category of indicators (e.g. security of supply indicators), we do not, at this stage, recommend quantitative weighting to aggregate assessments (of data or risk) across whole themes. Instead, we concur with previous work that suggests using stakeholder involvement and panels of experts to combine multiple indicators into overall assessments (such as red/amber/green ratings) while reflecting the shifting relative importance of different risks through the transition. Otherwise, specific methods for producing and aggregating ratings are left for future work.

These energy security risk assessments and Risk Dashboards can serve three purposes:

(i) To inform decision-making in policymaking and implementation

(ii) To support communicating energy security issues, policy and progress to UK public and other stakeholders with greater transparency

(iii) To further inform activities to improve metrics and data (as priority should be given to areas where metrics or data are poor and where risk level also appears significant).

Notes for Table II:

- The table below gives an example of what a combined Data Dashboard and Risk Dashboard at the level of themes could look like. The traffic light ratings and grey text in **Table II** are purely illustrative – a proper assessment of data, metrics and risks is for future work. In practice, each individual indicator would first be assessed in a much more detailed dashboard.
- The 'Data & Metrics Rating' indicates the strength of existing metrics and data for measuring risks in each theme; they do not indicate energy security risk levels (see Step 1, above).
- The 'Risk Rating' indicates the level of energy security for each theme, as we can assess them currently (see Step 2, above).

TABLE II: Data and Risk Dashboard for the '4+4 Framework' for monitoring energy security

**** Mock example ****

Energy Security THEME	DATA & METRICS RATING using *Data & Metrics* indicators	RISK RATING using available data (and the *Data & Metrics* assessments)	REASONS for current Data and Risk ratings
Availability			DATA & METRICS: A wider set of reliability metrics will be needed as system flexibility develops. More data also needed for DSR (both deployment and performance indicators and including the potential for heat pump loads to provide reliable flexibility). RISK: Good security of supply in short-term but changes in both generation and demand may disrupt this in longer-term.
Accessibility			DATA & METRICS: Need better metrics and data for distribution network capacity in context of new heat pump and EV-charging loads and their degree of flexibility. Need for better visibility of pipeline/timelines for grid development projects. RISK: Transmission network needs investment for wind and grid-level storage. Risks for distribution network capacity and connections for heat pumps and EV-charging.
Affordability			DATA & METRICS: Clear data for Government support for bills. Limitations in fuel poverty metrics and costs relative to incomes and cost-of-living. Energy efficiency (EE) data limited and savings from DSR not included. RISK: Support for consumer bills has been very costly for UK Government. Building EE is poor and the cost-of-living context challenging. Higher cost of electricity compared to gas is a risk to other energy security goals (themes).
Acceptability			DATA & METRICS: Generally good data on public attitudes but should be expanded to wider issues. Better data needed on consumer engagement with key technologies and services, including DSR. RISK: Generally good public support for a move to a high-renewables system and more energy independence. Stronger consumer engagement with key technologies and services needed, including DSR, and data lacking.
Sustainability			DATA & METRICS: Good data on carbon. Some specific gaps in other indicators and data (e.g. sustainability of biomass). RISK: Good past progress in cutting the carbon intensity of grid electricity. Keys challenges include reducing gas consumption for heat in buildings.
Independence			DATA & METRICS: Indicators and data sources generally good with several overlaps with *Availability*. RISK: Substantial energy dependencies including power interconnectors and imports of biomass and LNG. Synergies with *Acceptability*; synergies and trade-offs with *Availability.*
Governance			DATA & METRICS: Work is needed to further develop clear metrics and high-quality data for the four categories of *Governance* indicators. RISK: Clear broad goals exist for an energy security strategy but lacking detail for delivery and use of clear, measurable and transparent indicators and processes to support tracking, decision-making and reporting for energy security.
Data & Metrics			DATA & METRICS: † Criteria exist for DQA (e.g. DAMA) but lack clarity for data accuracy, gaps and access, the quality and use of metrics. RISK: A full assessment of data and metrics has not been done but some known limitations. Cybersecurity is a potential threat to *all* data.

† *Data & Metrics* indicators/criteria could themselves be assessed though this may be somewhat circular/reflexive and requires more work.

Complexity

The 4+4 Framework work is relatively complex. We have attempted to assemble a comprehensive and holistic set of indicators and themes for the whole of energy security. It has a total of 72 indicators, plus data sources, tagged against eight themes, and produces separate dashboards for the quality of data and the level of risk. It is hoped that this greater complexity can help to avoid double-counting and significant risks being missed, and better support decision-making that takes account of trade-offs and synergies.

Complexity can be a barrier for users. But one of the aims of our framework is to enable continued improvement in data and governance. If an energy security monitoring framework fits too easily into existing policymaking processes, then perhaps it is not having enough impact in stimulating improvement. The complexity might be made more manageable if this framework was implemented in an interactive ICT interface that better supported use cases and user needs.

Future work

As with several previous frameworks, this draft framework is a work in progress and would require further work. We have attempted to identify indicators and data, but some are more developed than others and in some cases data sources have not yet been identified. We have not carried out the assessment of metrics and data, and have not assessed energy security risks (**Table II** is illustrative only). All these activities would be open-ended activities requiring regular updates.

We hope this draft framework can be the basis for review and, if it proves promising to potential end-users, iteration and further development. We suggest that the first steps would be a more thorough review of indicators, metrics and data, using the criteria in the *Data & Metrics* theme (as per *Step 1*, above), and establishing agreed methods for aggregating assessments of data and risk. The sooner limitations in metrics and data are addressed the sooner tracking change over time will be supported.

Further developing and implementing the framework would best be achieved through inclusive collaboration among stakeholders and experts. This would better manage the challenges we discuss and incorporate diverse perspectives, highlighted by previous work as important in risk assessments.

1. Introduction

There has been a dramatic rise in wholesale and retail energy prices in the UK since 2021 following the war in Ukraine. This has revealed energy security vulnerabilities in the UK and neighbouring states – at least in terms of their ability to secure energy at an affordable price for homes and businesses and the huge cost to public finances of protecting consumers from higher prices. An Oxford Institute for Energy Studies/UKERC paper on gas imports [1] argues that "*the time is ripe for a fundamental review, by the Government and Ofgem, of UK energy security to learn the lessons of the crisis and to ensure that both security and affordability are fully incorporated into policy design and regulation in the energy transition*" (p.vi).

Despite energy security now being a more visible priority for UK Government, the UK is not in a strong position for measuring, monitoring and therefore managing its energy security. The International Energy Agency's broad definition of energy security ("*uninterrupted availability of energy sources at an affordable price*" [2], p.13) is widely used but there is still a lack of clarity around the metrics and data that should be used to measure it. The British Energy Security Strategy [3] refers to "*secure, clean and affordable*" energy and "*reducing our dependence*" but gives no explicit definition, metrics or data on how these will be measured and how policy success will be evaluated against these goals. Policy announcements commonly appeal to 'improving energy security' without backing up claims with evidence. Energy security has been aptly described as "*slippery because it is polysemic in nature*" [4] (p.887) and as a "*black box*" [5].

There is limited consensus on how best to usefully define and measure energy security [6] [5]. Different approaches vary hugely in the number of dimensions and indicators of energy security. Some of these indicators will not be relevant for the UK context. The way in which energy security is best measured is also likely to change as the UK energy system continues to decarbonise, digitalise and decentralise. As this happens, we will need to define and measure energy security in ways that are fit for UK net zero energy futures - for example, measuring and tracking changes to system flexibility.

With intense interest in energy security, and ongoing scrutiny of net zero strategy and energy costs, there remain pressing questions about how the UK's energy security will be measured, managed and communicated, and policy success evaluated, over the course of the transition. A more evidence-based and transparent approach is needed but what should a framework for monitoring UK energy security look like?

This working paper draws on a literature review, stakeholder workshop and expert consultation to offer a draft framework of metrics and data for the improved measurement and communication of UK energy security during the transition to net zero.

Chapter 2 explores the variation, themes and limitations of existing definitions and conceptualisations of 'energy security'.

Chapter 3 reviews indicator dashboard approaches to energy security and gives an overview of the range of indicators and indices in use or recommended by the academic literature. It discusses limitations in the indicators used to date, emerging 'transition risks', and the challenges to be met by an indicators approach. Attention is drawn to data sources for indicators and to the user of the framework, with a discussion of ‘governance indicators’ within existing frameworks.

Chapter 4 further considers data and its use. It gives examples of current gaps and limitations in metrics and data and highlights risks from poor data availability and quality.

Chapter 5 presents in some detail an original draft framework – the ‘*4+4 Framework’* – and outlines how its dashboard of themes, indicators and associated data sources could be used in monitoring, managing and communicating energy security. It concludes with recommendations for future work and development of the draft framework presented, emphasising the need for a collaborative, inclusive approach to both developing and using any framework for monitoring energy security.

2. Defining Energy Security – from Conceptualisation to Operationalisation

2.1 The 4 A's

There is no categorical definition of 'energy security' and limited international consensus on how best to define and measure it [7] [8]. In 2011, the House of Commons Energy and Climate Change Committee noted that,

> "*Over the course of our inquiry, it became clear that there was no agreed definition of 'energy security*'. […] *Despite having a departmental priority to 'deliver secure energy on the way to a low carbon energy future'* […], *DECC does not appear to have a categorical definition of what 'secure energy' is. When asked to provide such a definition, the Minister told us that 'It is a combination of matters. It includes the resilience of our energy supplies, inevitably now it includes low carbon issues and it includes an affordability aspect'* ". ([9], Sections 3.9-3.10)

A number of UK Government documents relating to energy security have been published since 2011, these include: the UK Energy Security Strategy [10]; the *Net Zero Strategy* [11]; the *British Energy Security Strategy* [3]; and *Powering Up Britain: Energy Security Plan* [12]. With the establishment of the Department for Energy Security and Net Zero (DESNZ) in 2023, 'energy security' has become a more visible priority but a categorical definition is still elusive.

Energy security has been conceptualised or theorised in a number of ways. For a review of definitions and conceptualisations of energy security see [6], [13] and [14]. An influential scheme has been the "*Four 'A's*", proposed by the Asia Pacific Energy Research Centre (APERC) in 2007 [15] and used by others (e.g. [16] [17]).

The "Four 'A's" of energy security

Availability – the availability of energy (to a given nation state, region or territory) in sufficient amounts.

Accessibility – the degree to which available energy can be accessed where and when it is needed.

Affordability – the cost/price of the available and accessible energy.

Acceptability – concerned with the potentially negatively-valued aspects of providing available, accessible and affordable energy; can include environmental, political and justice issues.

Adapted from Jones and Dodds, 2017 [13]

A review of the literature by Ang et al. [8] provides partial support for the four 'A's. It identified seven commonly-used major energy security dimensions: Availability, Infrastructure, Prices, Societal effects, Environment, Governance, and Efficiency. Based on analysis of 83 energy security definitions, energy Availability is included in 82 of them, Infrastructure (which overlaps with Accessibility) in 60, and energy Prices (Affordability) in 59 definitions.

2.2 Summary of definitions used for energy security in government documents

As a first step to exploring the need for greater clarity and how to measure energy security, we review the explicit or implicit definitions of energy security in government strategy documents and those used by key international organisations. This is summarised in **Table 1**, below.

Table 1: Summary of definitions used for energy security in government documents		
	Source	**Definition and comments** highlighting key terms (in bold) and links to the 'four As'
1.	IEA (2014) *Energy Supply Security 2014: Emergency Response of IEA Countries* [2]	○ *"The uninterrupted **availability** of energy sources at an **affordable** price*." (p.13) ○ Separates energy security into long-term and short-term considerations, where: long-term deals with timely investments to supply energy in line with economic developments and environmental needs; and short-term focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance.
2.	European Parliament (2020) *Energy Security in the EU's External Policy* [18]	The European Parliament uses the above IEA definition [18] while the European Commission's topic page on Energy Security[1] is also mainly concerned with security of supply and energy infrastructure.
3.	HM Government (2023) *Powering Up Britain: Energy Security Plan* [12]	No explicit definition given but outlines the following objectives: ○ *"If we do not decarbonise, we will be less energy secure. We want our energy to be **cheap, clean and British"** (p.2);* ○ *"Energy security necessarily entails the smooth transition to **abundant, low-carbon** energy"* ○ *"A future of **cheap, clean and British** Energy";* ○ *"**Cheap, clean, and secure** energy"* (p.3); ○ *"The UK's energy security remains hugely dependent on a **reliable**, **resilient** and **affordable supply** of gas"* (p.4); ○ *"[T]he transformation of the energy system so it is **secure, low-cost and low-carbon**"* (p.3) ○ *"[I]ncreasing the overall share of domestic energy production and "**energy independence**";* ○ *"Securing our Gas **Supply"** and "maximising the **'vital' production of UK oil and gas**";* ○ *"Security through Strong **International Partnerships**"* (p.4); ○ Reducing energy demand.
4.	HM Government (2022) *British Energy Security Strategy* [3]	No definition given. Often refers to "**Secure, clean** and **affordable British** energy", which stresses Availability, Environment, Affordability and energy independence respectively. Has a strong emphasis on energy independence: ○ ***"[R]educing our dependence" on imported*** *oil and gas and hydrogen.* ○ *"We need a power supply that's **made in Britain, for Britain** – and that's what this plan is all about"* (p.3) Also: ○ *"[O]ur progress towards **Net Zero**, which is fundamental to energy security"* (p.6) ○ *"**Energy Efficiency** […] Every therm of gas saved grows our energy security"* (p.11)
5.	HM Government (2021) *Net Zero Strategy: Build Back Greener* [11]	No explicit definition given. Mentions "energy security" four times: ○ "*[O]ur plan for a strong **home-grown** renewable power sector to strengthen our energy security*" (p.96) (Availability) ○ "*The use of hydrogen to generate electricity can reduce reliance on unabated natural gas*." (p.98) (Availability) ○ The role of **smart technologies and flexibility** in providing energy security (Availability) ○ Electricity System Operator (ESO) reforms to maintain energy security and minimise consumer costs (Availability, Affordability)

[1] https://energy.ec.europa.eu/topics/energy-security_en

6.	HM Government (2020) *Powering Our Net Zero Future: Energy White Paper* [19]	Only two mentions of 'energy security': ○ *"The UK's **domestic** oil and gas industry has a critical role in maintaining the country's energy security"* (p.135) ○ *"[E]ffective **climate leadership** can be compatible with maintaining a strong economy and robust energy security"* (p.141) Also, ○ *"[W]e all rely on secure, **affordable** energy"* (p.20) ○ *"[E]nsure **security of supply** at low **cost**"* (p.44) ○ *"Security of supply will always be a priority, but our approach must also adapt to reduce **carbon** emission and **costs**"* (p.74)
7.	BEIS (2020) *Ten Point Plan for a Green Industrial Revolution* [20]	No specific use of the term 'energy security'
8.	HM Government (2017) *Clean Growth Strategy* [21]	○ *"Energy security is about ensuring **secure**, **reliable**, **uninterrupted** supplies to consumers, and having a system that can effectively and efficiently **respond** and **adapt** to changes and shocks. It is made up of three characteristics: **flexibility, adequacy and resilience**."* (p.154) ○ Emphasises a ***resilience*** perspective due to its emphasis on both *known* and *unknown* risks.
9.	DECC (2012) *UK Energy Security Strategy* [10]	○ *"[E]nergy security is about ensuring that we have **access** to the energy services we need (physical security) at **prices** that avoid excessive volatility (price security). […] Energy security also needs to be considered in the context of our other energy objectives of **sustainable** energy supplies (in particular reducing our **carbon** emissions)"* (p.13). ○ Uses three complementary approaches: (i). Horizon scanning for risk; (ii). Assessing the energy system using a framework of **four key characteristics or indicators of security** for each of the consumer fuels (electricity, gas and oil) - **Capacity, Diversity, Reliability,** and **Demand side responsiveness**; (iii). Stress testing. ○ *"This is the first time that a UK Government has produced an energy security strategy. It is intended to complement the Statutory Security of Supply Report, which provides a purely factual and technical account of energy security."* (p.12) ○ It also identifies **six policy areas**, that contribute towards the aims of the energy security strategy: **Resilience measures, Energy efficiency, Reliable network, Maximising UK production, Working internationally, Decarbonisation, Regulating for security** and **Competitive markets**.
10.	House of Commons Energy and Climate Change Committee (2011) *Eighth Report: UK Energy Supply: Security or Independence?* [9]	○ *"Our own suggestion is as follows: a secure energy system is one that is **able to meet the needs** of people and organisations for energy **services** such as heating, lighting, powering appliances and transportation, in a **reliable** and **affordable** way both **now and in the future**. We recommend that the Government adopts this definition."* (Section 3.11)
11.	Scottish Government (2023) *Draft Energy Strategy and Just Transition Plan* [22]	○ A formal definition of energy security is given in the Strategy: *"Energy security can be defined as having **sufficient** energy generation to meet the **volume and type of energy demand** at any point, and having **the means to get that energy to the point of use**"* (p.189). As such, Availability and Accessibility are stressed. The following other references to energy security are made:

		○ A commitment to improve energy security "*through [the]* ***development of our own resources*** *and additional energy storage*" (p.3) ○ "*Reducing our reliance on other energy sources*" (Section 3.2) These two quotes stress energy independence, but there is also: "*To ensure we deliver climate-friendly, affordable and secure energy supplies here in Scotland, we must look to* ***collaborate with others****, particularly our* ***neighbours around the North Sea****, in creating mutual energy security*" (p.3) ○ "*By 2030, Scotland's energy supplies will be* ***secure****,* ***reliable*** *and* ***affordable*** *for people and businesses*" (p.22) ○ "*Building in* ***flexibility*** *to respond to changing levels of supply and demand in our electricity system*" (p.128) ○ The Strategy document refers to a number of actions to ensure energy security and resilience: - exploring goal of fully **interconnected** North Sea grid - improving electricity system **operability and restoration** - improve **flexibility** of system through ancillary services.
12.	Wales	Wales is covered in the *British Energy Security Strategy* and has no separate strategy document relating specifically to overall energy security.
13.	Northern Ireland Executive (2021) *The Path to Net Zero Energy* [23]	The term 'energy security' appears only once but the document states: • "*Ensuring our energy is* ***secure****,* ***affordable*** *and* ***clean*** *for us now and future generations*" (p.3) • "*We want to* ***reduce our reliance on fossil fuels*** *and become more* ***self-sufficient****, strengthening our energy security*" (p.7)
14.	BEIS (2022) *Risk Preparedness Plan for the Electricity Sector in Northern Ireland* [24]	Does not explicitly use the term 'energy security' but describes "***security of supply***" issues and some consideration of mechanisms to limit **price** increases above a certain threshold in times of system stress.

2.3 Beyond the Four 'A's

Reviewing the definitions in **Table 1**, three main observations can be made. Firstly, in most cases an explicit definition of energy security is not given, even in the UK Government's (2023) *Powering Up Britain: Energy Security Plan* [12] and *British Energy Security Strategy* [3]. The *Scottish Energy Strategy and Just Transition Plan* [22] is the exception in giving an explicitly-stated definition of energy security.

Secondly, the stated goals or characterisations of energy security tend to reflect the themes of the four 'A's (availability, accessibility, affordability and acceptability) that are discussed more directly in the academic literature. For example:

- The IEA definition ("*…the uninterrupted availability of energy sources at an affordable price*") [2] clearly reflects Availability and Affordability. This definition is, broadly, also followed by the EU [18].
- Affordability comes through clearly in the UK Government documents in the stated goal of "*cheap*" or "*affordable*" energy [19] [3] [12].
- Availability and Accessibility are stressed in the Scottish *Draft Energy Strategy and Just Transition Plan*: "Energy security can be defined as having *sufficient energy generation* to meet the volume and type of energy demand at any point, and having *the means to get that energy to the point of use*" [22] (p.189; emphasis added).

Thirdly, these characterisations of energy security go beyond the four 'A's. A dimension of *environmental sustainability* is apparent in the stated goals of: "*cheap, clean and British*" energy [19] [12]; "*secure, clean and affordable*" energy [19] [3]; "*secure, affordable and clean*" energy [23]; and "*low-carbon energy*" [19]. In fact, alongside their "4 'A's", APERC [15] gives "*three fundamental elements of energy security*", which do include 'Environmental Sustainability'. A clearer addition to the four 'A's in UK Government documents is a theme of *energy independence*, as indicated in: "*British energy*" [19][12]; "*reducing our dependence on imported oil and gas and hydrogen*" [3]; "*homegrown*" energy [11]; and "*become more self-sufficient*" [23].

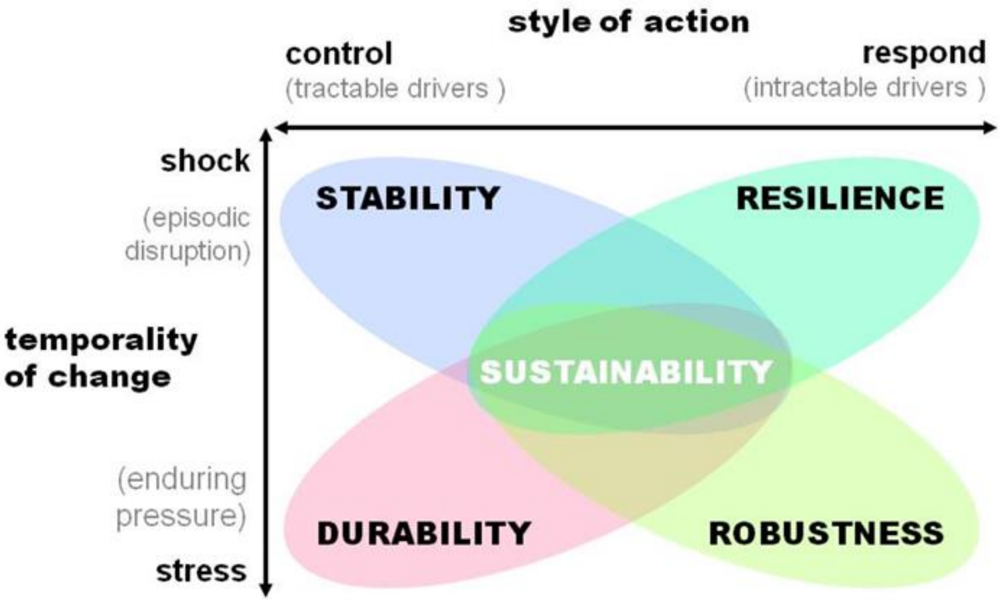
In the wider literature, there are many variations on, and departures from, the four 'A's. For example, in the academic literature some definitions include another 'A', 'Applicability' [25] [26], to reflect contextual factors of energy security. The idea that energy security is highly context dependent is generally accepted by the research and policy community [8].

2.4 Vulnerability, risk and resilience

Cherp and Jewell's [27] starting point for their critique of the four 'A's is that energy security is an instance of security in general. Drawing on security studies, they argue that the four 'A's fails to address three key questions: "*Security for whom?*", "*Security for which values?*", and "*Security from what threats?*". Instead, they propose a concept of energy security as 'low vulnerability of vital energy systems', which opens the way to more detailed specification of vital energy systems and their vulnerabilities in terms of 'risk exposure' and 'resilience'.

The edited volume, *New Challenges in Energy Security: the UK in a Multipolar World* [28], outlines challenges to energy security in a world in which power is distributed. Drawing on work by Stirling on vulnerability and sustainability [29] it presents two dimensions within the dynamics of energy security - the *temporality of the threat* (from long-term 'stresses' to short-term 'shocks'[2]) and the style of *action* (from 'control' to 'respond') – **see Fig. 1**. Long-term stress is typically associated with 'robustness', which focuses on protection from predictable factors such as resource scarcity, climate change and aging infrastructure. Short-term shocks are associated with 'resilience', which focuses on protection from less predictable factors such as political instability, extreme weather and pandemics.

Figure 1: Four dynamics of energy security. Source: Stirling [29]



This perspective also suggests a more systematic approach of identifying the sources of stress and shock and the actions to control or respond to them. However, such an approach still depends on what 'energy security' is deemed to include and, as we have seen, consensus on themes and scope is lacking.

Bradshaw and Solman [30] characterise existing approaches as emphasising either breadth (a 'dimensions approach' such as the 4 'A's) or depth (with a focus on sources of threats and risk). Similarly, Cox [31] notes the important distinction between narrower definitions of energy security that are large-scale and long-term, focusing on issues such as geopolitics, resource depletion and climate change, and typically come from within the social sciences, and those that take a micro-scale, short-term view and are associated with engineering and other physical science disciplines.

2.5 'Energy security' is evolving and expanding

The scope of energy security has also grown over time. Since its beginnings following the 1970s oil crises, energy security concerns have expanded to encompass various energy sectors and increasingly diverse issues [27]. The literature has noted that the traditional conceptualisation of energy security has been dominated by a focus on uninterrupted supply of the hydrocarbon fuels

[2] The IEA also separate energy security into long-term and short-term considerations.

we rely on and has tended to neglect the important roles that the demand side could play [32] [33] [8] [26]. Environmental sustainability has also received increasing attention [8].

Emerging 'transition risks' (e.g. [34]) are well-acknowledged and will become increasingly important and further expand the scope of energy security as the UK energy system continues to decarbonise, digitalise and decentralise. The transition will include profound changes on both the supply side (e.g. a shift to more intermittent renewable power generation) and the demand side (e.g. large new loads for the electrification of transport and heat in buildings). Strojny et al [14] highlight the future impacts of changing technology and smart grids. The UK's *Energy Security Plan* does include attention to both demand side management and the growing need for flexibility:

> "*We are developing the technology options for delivering flexibility on both the supply side, through power CCUS, hydrogen to power and storage, and the demand side, through electric vehicle charging or smart appliances (demand side response)*" [12] (p.28).

2.6 From conceptualisation to operationalisation

Strojny et al's [14] conceptual overview of energy security concludes that energy security is complex and evolving and requires a holistic definition that integrates various dimensions into a coherent concept. They also make a key point that,

> "In the literature, one can notice a trend of growing interest in the *operationalization* of energy security, which translates into the search for effective ways to quantify this abstract problem. These interests are reflected in numerous publications discussing *how energy security can be measured* through the use of a wide range of indicators relating to various aspects of this phenomenon." (p.8; emphasis added)

Sovacool and Mukherjee [35] also suggest that,

> "Summarizing the various dimensions and components of energy security is helpful in identifying major themes. However, more useful still is correlating these dimensions with *usable metrics and indicators* that can be utilized to assess national energy security policies and performance. Numerous studies on energy policy have noted that having comparative indicators is a prerequisite for setting energy targets as well as for evaluating future scenarios." (p.5346; emphasis added)

For a recent example, the Centre on Regulation in Europe (CERRE) [36], speaking about grid operators, also note "a particular challenge here is *to define criteria and metrics* that will reflect disruptions of varying scale and in a longer timeframe" (p.9; emphasis added).

We concur that what is needed is a shift in focus from what 'energy security' means to how to measure it in practice – a shift from conceptualisation to operationalisation. What, then, should be the indicators and metrics we use for quantifying and measuring energy security? There have been several attempts at an 'indicators approach' to energy security and many energy security indices exist. Chapter 3 explores indicator-based approaches to measuring energy security.

3. Indicator-based Approaches to Measuring Energy Security

In the previous chapter we saw that definitions and conceptualisations of energy security vary. Focussing on how to actually measure and monitor energy security would be a pragmatic approach but what should those measurable indicators be? This chapter explores indicator-based approaches.

3.1 Review of energy security indices and indicators

There have been numerous attempts to provide a given nation state, territory, region or bloc an energy security score. To do this, frameworks have been developed that provide metrics or indicators for the various dimensions of energy security. There are a range of existing energy security indices, or indexes, with considerable variation between them. These have been developed by both industry and academia. They are reported in grey literature (e.g. the *Global Energy Institute's International Energy Security Risk Index/IESRI* [37]) and academic literature (e.g. the Four 'A's Framework of Yao and Chang [25] and the ESRIA index [26]).

Table A, in **Appendix 2**, summarises over 30 energy security indexes, which attempt to 'score' a country's energy security, and other indicator-based approaches from academic literature. Our objective in this paper is to produce a draft framework for monitoring UK energy security throughout the transition. The purpose of this review exercise is to inform our choice of a set of indicators, themes, and how to structure them into a framework, by understanding the variety and consensus within indicator-based approaches to energy security. Combining this with insight from the wider literature and stakeholder consultation, we hope to better understand the challenges for indicators-based approaches and the pros and cons of different frameworks.

3.1.1 Method

We adopted the following methodology to review the breadth of indices and literature related to energy security indexes. For searches we used Scopus, for academic literature, and Google, for grey literature, collecting examples of indices and sets of indicators for energy security as whole (rather than one aspect of energy security). See **Appendix 1** for details of search protocols and search terms used. These searches were supplemented by following citation trails, ad hoc expert consultation, and input from a stakeholder workshop (held in December 2023). Workshop participants were drawn from UK Government departments, regulators, advisory bodies, NGOs and industry working on energy security issues. Workshop discussion topics covered:

i. Users and use cases for how energy security indicators and data could be used. What would help make them more useful or impactful?
ii. Existing metrics and indices of energy security (definitions, scope, frameworks)
iii. How to choose indicators relevant for UK and net zero? What effect would this have on international comparisons?
iv. What are the emerging 'Transition Risks' for UK net zero energy security?

v. Data for energy security metrics (availability, quality and access).
vi. Priorities and challenges for defining a dashboard of energy security metrics for UK net zero.

Input received from this workshop will be referred to where relevant throughout this paper.

3.1.2 Note on nomenclature and terminology

Axon, Darton and Winzer [32] and others note problematic inconsistencies in nomenclature used within energy security literature, partly due to variation in definitions of energy security. Clarity in terminology will be important to for understanding and comparing existing indices and indicator approaches.

Axon, Darton and Winzer suggest that the term 'index' should be reserved for systems of rankings or scoring of simple or aggregate indicators (e.g. as in the Human Development Index). DiXi Group [38] distinguish three types of indicators: binary indicators (e.g. compliance/non-compliance with legislative requirements); quantile indicators, for example, 0 (non-compliance), 2 (partial compliance), or 4 (full compliance); and multi-dimensional indicators.

Consistently applying a standard nomenclature across all indicator approaches is challenging, given the variation and limited transparency but, drawing in part on the literature, we suggest the following working terminology that outlines a number of levels within a 'framework'.

Table 2: Suggested working nomenclature for indicator-based energy security monitoring frameworks	
Term (level)	**Definition or Example**
'Framework'	The set of indicators and guidance on their use for a defined purpose such as monitoring or comparing nations' energy security (e.g. the '4 'A's framework' of Kruyt et al, [16]; after APERC [15]). An index (plural 'indices') that produces a rating, score or ranking would count as a framework. Some indices use the term 'sub-index' that may correspond to the next level, dimensions (below), or may not (e.g. 'Risk assessment' sub-index and 'Mitigation assessment' sub-index).
'Dimension' or **'theme'**	Examples of dimensions or themes are Availability (within the 4 'A's), or Environmental sustainability. Some literature uses the term 'perspective'.
'Indicator'	An example of an indicator is Loss of Load Expectation (LOLE). Individual (simple) indicators may be grouped into categories or combined to produce composite indicators – e.g. besides LOLE there are several other reliability standards that could be used as indicators then grouped to form a composite indicator of reliability. Another example is fuel poverty which may be composed of multiple indicators.
'Metric'	The distinction between 'metric' and 'indicator' may be blurred but metrics are closer to data analysis methods (e.g. formulae) than indicators. An example of a metric is the LILEE (low income, low energy efficiency) metric used in English fuel poverty assessment. We include both quantitative and qualitative metrics.
'Data source'	Data is a level below indicators and metrics. An example would be the Digest of UK Energy Statistics (DUKES) [39] or specific datasets on household income or on the energy performance of housing. The boundary between data and metrics may be blurred where datasets are strongly associated with specific metrics that guide data collection, assumptions and usability.

3.2 Indicators-based approaches to UK energy security

There have been considerable efforts to review and evaluate the spectrum of energy security indicators [40]. Reviews have noted the absence of a standardised instrument or method to measure energy security (e.g. [41]) and the complexity and intersectional nature of energy security [8]. According to several analyses, there is also a considerable lack of transparency, in particular regarding the selection of indicators, the normalisation methods, indicator weightings and aggregation functions [42]. This lack of transparency is a barrier for attempts to review, assess and compare.

We are interested here in how a review of past/current indicator-based approaches might inform an alternative framework and we begin with some broad observations from the summary table (**Table A**, in **Appendix 2**). Input from a stakeholder workshop, held in December 2023, helped to populate the summary table and inform the observations drawn from it. The table lists over 30 indices or frameworks along with the dimensions and the number of indicators used, where known.

In terms of content, the 4 A's are commonly represented in the dimensions used by the frameworks. Many additional dimensions are also seen, some notable ones are: geopolitical risk, environmental Impact, investment risk and governance. Workshop participants also indicated that the dimensions used is highly dependent on context, on who developed the index, and on the target audience. We discuss other indicators and relevance to the UK and net zero context in sections 3.4 and 3.5 respectively

Regarding the structure and complexity of the frameworks:

The number of dimensions used in the indexes and frameworks: Most frameworks found have between four and seven dimensions. The simplest frameworks are Watson et al [43] with just two dimensions (Availability and Reliability) and the World Energy Trilemma Index [44], with three dimensions (Energy security, Energy equity and Environmental sustainability[3]). In contrast, academic work by Vivoda [45], intended for the Asia-Pacific context, proposes 11 dimensions (Energy supply, Demand management, Efficiency, Economic, Environmental, Domestic socio-cultural and political factors, Human security, Military–security, Technology, International, Policy).

The number of indicators used in the frameworks: Our summary table points to wide variation in the number of indicators used to develop index scores, a view shared by workshop participants. At the lowest end of the spectrum several have less than ten indicators: Watson et al [43] has seven and DECC's *Energy Security Strategy* [10] only four 'key characteristics or indicators of security' for each of the consumer fuels: Capacity, Diversity, Reliability, and Demand side responsiveness. At the high end, Sovacool and Mukherjee [35] list 320 simple indicators and 52 complex indicators.

More complex structures are also seen (often by institutes rather than within academic literature), such as use of sub-indexes that are assessed using the same indicators or different indicators. For example, the International Energy Security Risk Index (IESRI) by the Global Energy Institute [37], comprises four 'sub-indexes' (Geopolitical Risk; Economic Risk; Environmental Impact; Energy Reliability) and eight categories of metrics (Global Fuel; Fuel Imports; Energy Expenditure; Price and Market Volatility; Energy Use Intensity; Electric Power Sector; Transportation; and Environment), with each category made up of between two and six metrics.

Below are some snapshots of influential dashboard approaches to illustrate some of the breadth, in the structure and content, of these frameworks.

The DECC [10] *Energy Security Strategy* was the first time that a UK Government had produced an energy security strategy. The indicators covered Capacity, Diversity, Reliability, and Demand side responsiveness (for electricity, gas and oil) with the caveat that, "*the indicators we have used do not provide a straightforward measure of how great a risk exists, or when change is needed: they are rather a way of flagging potential issues and a stimulus to debate*" (p.11). A dashboard produced by the 'Energy in a Multi-Polar World' programme add a further 16 indicators to those used by DECC without using weightings [46]. Cox [5] reviewed literature to create a 'dashboard' of 22 quantitative and qualitative indicators, across four dimensions, that can be used without aggregation – see **Figure 2**.

[3] See also the Energy Trilemma Online Tool at https://trilemma.worldenergy.org/

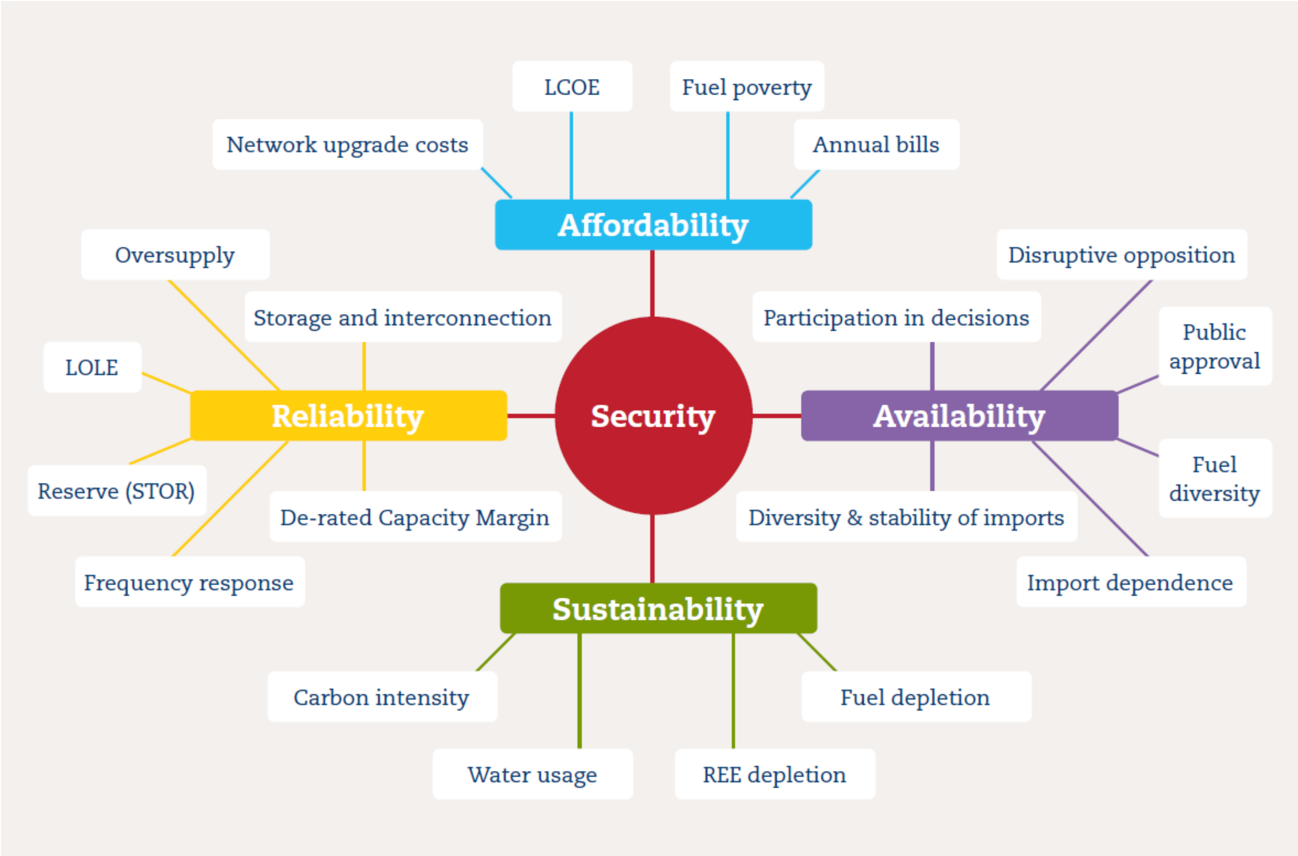


Figure 2: Energy security framework. Source: Watson et al [43], adapted from Cox [47]

Watson et al [43] build on Cox [5] [47], to offer a dashboard of seven indicators across two categories (Availability indicators and Reliability indicators) and use this to show how each indicator may change between 2016 and 2050 for six energy scenarios – see **Figure 3**.

Figure 23: Energy security indicators for 2050, compared to 2016

	Energy Island	Slow De-carbonisation	Low Carbon	Low Carbon (no CCS)	Low Carbon (no BECCS)	Technology Optimism
Risk of public opposition to electricity mix	↑	↓	↓	↑	–	↓↓
Domestic fossil fuel and biomass production	–	↓	↓	↓	↓	↓↓
Energy diversity	↑	↑	–	↑	↑	–
Electricity diversity	↓	–	–	↓	↓	–
Biomass imports	↓	↑	↑	↑	↑	↑
Oil imports	↓↓	↑	–	↓	↓	↓
Gas imports	↓	↑	↑	↓↓	↑	–
Electricity LOLE	↑	↑	↑↑	↑↑	↑	↓↓
Gas LOLE	–	↑	↑↑	–	–	–
Electricity interconnector capacity	–	↑	↑	↑	↑	↑
Demand side flexibility: electric vehicles	–	–	–	↑	↑↑	↑↑
Demand side flexibility: heat pumps	↑	↑	↑	↑↑	↑↑	↑

Figure 3: Dashboard showing change in energy security indicators 2016-2050 for six scenarios. Source: Watson et al [43]

Figure 4 shows the Global Energy Institute's *Index of U.S. Energy Security Risk*. Here, a total of 37 metrics are grouped into nine categories and mapped to one or more of the four sub-indexes that identify the major areas of risk to U.S. energy security (geopolitical, economic, reliability, and environmental). The sub-indexes are weighted and combined to produce a total Index Score, where scores of 100 suggest a very high degree of risk.

Figure 4: Structure of the Index of U.S. Energy Security Risk
Source: The Global Energy Institute [48]

3.3 Challenges for a holistic dashboard of energy security indicators

Watson et al [43] highlight trade-offs in different approaches and choice of indicators for assessing energy security. Attempts to assemble a set of energy security indicators face many challenges, which we attempt to outline below.

3.3.1 Composite indicators

As Le Coq and Paltseva [49] note, aggregation results in a loss of useful information. Composites of aggregated indicators can be opaque and are heavily dependent on the aggregation methodology. Single indices are not suitable for assessing the security of the energy system as a whole or understanding how energy system change will affect security. Our workshop participants also suggested that a UK-wide index which evaluates or scores the entire energy system would not be sufficiently sensitive to measure the impact resulting from individual policy. While a single aggregated index for energy security would be unlikely to be useful for guiding policy, a dashboard of multiple indicators can offer more useful assessments that identify which aspects and areas of the energy system pose different levels and types of risk to energy security.

3.3.2 Weightings

The Global Energy Institute *Index of U.S. Energy Security Risk* [48] uses a weighted average of four sub-indices to produce a single score using the following weightings: 30% each for Geopolitical and Economic; 20% each for Reliability and Environmental. However, the justification for these weightings is brief: "*The weightings used to create the Index […] give slightly more weight to the geopolitical and economic risks that, for good reason, tend to dominate much of the public debate on energy security*." (p.13). Axon, Darton and Winzer [32] argue that "*aggregated indicators and indices are inherently subjective as there is no fundamental basis for the assignment of weights*" (p.230). Weightings for an overall energy security rating would inevitably be contested and could produce unintended consequences or be gamed but may be much less problematic within a sub-group of indicators.

Moreover, in GEI's *Index of U.S. Energy Security Risk*, "*these weightings are unchanged over the entire 70-year period the Index covers*" (p.11). However, as the transition in energy systems advances, the sources and levels of risk are expected to evolve. For example, we have seen acknowledgement that energy security indicators should, and have, begun to shift from a focus on supply to give greater consideration (i.e. weight) to more demand-side aspects. As the UK grows its wind generation the potential risk to reliability from insufficient flexibility in the system will rise. To monitor risks, such changes would therefore need to be reflected in any weightings for indicators, sub-indices or dimensions.

3.3.3 Measurement, risk and uncertainty

Indicators for monitoring energy security should be clear, measurable and, where possible, quantitative. Axon, Darton and Winzer [32] distinguish between simple or aggregate indicators and between indices that are predominantly quantitative and those that involve qualitative expert assessments and reserve the term 'metric' for quantitative measures. An alternative to formal quantitative metrics, or weightings, could be to use an expert group to make more qualitative judgements (or combine multiple indicators into an overall assessment) such as red/amber/green ratings.

Axon, Darton and Winzer also distinguish between indicators of observed data versus indicators that project into the future, which they deem to be in the domain of a model. We share an interest in monitoring energy security over time using *ex-post* assessment and other observed data rather than modelling. However, the distinction may not be clear cut: measuring energy security often involves assessing risk and so involves uncertainty over future events, e.g. the impact of weather. During the net zero transition, the scale and nature of changes in the energy system will be hard to anticipate [50] and uncertainty over how multiple changes will interact will make measuring energy security even more challenging (we consider some specific emerging 'transition risks' in Section 3.5.2).

The UK *National Risk Register* [51] measures risk using Likelihood and Impact. A likelihood approach is also relevant for a number of aspects of energy security, including the likelihood of meeting targets for emissions, investment, deployment of technologies, and generation capacity. Likelihood, or probability, is also implicit in expert ratings - for example ratings of being 'pessimistic' (red), 'uncertain' (amber) or 'optimistic' (green) used by Nedd and Bell [52]. The *UK Climate Change Risk Assessment* [53] uses a method that also considers likelihood but differentiates between negative risks and positive opportunities, and these are assessed and reported separately [54].

3.3.4 Data availability and choice of indicators

As Axon, Darton and Winzer [32] note, frameworks should not include indicators "*simply because data is available*" (p.209). However, some frameworks acknowledge they allow currently available data to guide their choice of indicators. The Energy Charter Secretariat's *Energy Investment Risk Assessment* (EIRA) framework [55] uses five criteria for developing its indicators, one of which is Data availability (the others are Functionality/Actionability, Measurability, Comparability and Objectivity). Similarly, for their *US Energy Security Index* and *International Energy Security Index*, GEI [48] give, "*a list of the main sources of the data used to compile the metrics*" (p.13) (although they do not map these datasets or sources to individual metrics, categories of metrics, or sub-indexes).

There are risks with the choice of indicators being determined by available data. Taken too far, this could reflect an observational bias known as the 'streetlight effect'. This refers to a cautionary tale of a drunkard looking for a lost house key under a streetlight, where it is easy to see, despite him knowing that he dropped his key on the other, darker, side of the street. It has been used in an academic context since Kaplan [56] to refer to "*the tendency for researchers to focus on particular questions, cases and variables for reasons of convenience or data availability rather than broader relevance, policy import, or construct validity*" [57] (p.137).

Further, one valuable role for an energy security monitoring framework would be to guide improvement over time in the indicators and data used. Mitchell and Watson [58] highlight that there may be a reliance on data with weak and varying collection methodologies. Sovacool and Mukherjee [35] also acknowledge that data reliability and accuracy will be paramount issues to contend with but also recognise that, "*[t]he process of collecting data for an energy security index itself might reveal pressing energy concerns, or gaps in institutional capacity, that need addressed. […] the logical next step is to begin collecting data on these indicators*" (p.5353). We suggest that potential feasibility of collecting data, rather than current availability, should be used as a criteria for choosing indicators.

3.3.5 Fit for purpose

The above discussion of the pros and cons of a single composite, weighted index versus a dashboard of indicators illustrates a broader point that energy security frameworks should be *"fit for purpose"* [32] and should be clear about what that purpose is. Cox [47] also advocates identifying a specific aim and developing indicators for that (in their case, assessing security of UK low-carbon electricity). The choice of indicators should also depend on the definition of energy security, energy security goals, and energy security policies of the government [13]. We advocate transparency in the purpose of frameworks, choice of indicators, assessments and assumptions. As part of an argument for transparency in assessments, Valentine [59] further recommends assessment should also disclose and explicate any critical ideological assumptions that influenced analyses.

Some frameworks focus on enabling countries to be compared and ranked on energy security relative to each other. For example, Vivoda [45] is interested in comparative analysis of energy security characteristics across the Asia-Pacific region, noting the potential value for cooperation and learning between countries. Participants in our stakeholder workshop indicated that enabling inter-country comparison was a low priority and that helping to manage energy security, guide energy policy, and deliver a just transition were much more important. Similarly, we focus in this paper on how to develop a holistic dashboard of indicators for the UK context and net zero transition. Focussing on one country also has the advantage of reducing issues around the availability of data and the applicability or relevance of indicators being dependent on context.

The purpose of a monitoring framework can be expressed in terms of its intended use cases and end-users. In our workshop discussion, the key end-users for energy security monitoring frameworks were considered to be central and local government, who would use the framework to develop, evaluate and implement policy (including managing trade-offs) and to communicate with stakeholders. A range of other potential end-users were also given: 'arms-length' bodies, NGOs, trade associations, industry, and regulatory agencies, consumers and voters - for these users, the framework could support participation in a more democratic process for managing energy security, such as supporting Government accountability, public debate and engagement, and contributing data.

3.3.6 Overlapping and fuzzy boundaries

Global Energy Institute's (GEI) *U.S. Index of Energy Security Risk* and *International Index of Energy Security Risk* have metrics grouped into nine categories but neither metrics nor categories map neatly onto their four sub-indices: "*four areas of concern were identified […] While there are no "bright lines" delineating these categories, they nonetheless provided a reasonable framework around which to develop Sub-Indexes*" (p.11) [48]. Sovacool and Mukherjee [35] note that in their framework, *"[s]ome of these indicators do overlap, making the table complicated*" (p.5353). Axon, Darton and Winzer [32] stress that any framework will need to take account of "*fuzzy boundaries*" and that overlapping indicators would give rise to double-counting.

3.3.7 Double counting, multiple impacts and secondary effects

Double-counting may occur for several reasons.

- As noted above, impacts in overlapping categories might be summed leading to double or triple counting - e.g. the financial savings from energy efficiency could be counted under reduced bills, reduced cost of Government financial support, and avoided network reinforcement costs.
- Similarly, indicators may be nested within each other. Using an example from public health epidemiology, if cardiac events and all-cause deaths are aggregated then fatal cardiac events will be counted twice [60]. Energy-related examples: counting reduced fuel bills across all households and also reduction in fuel poverty depth; or summing individual indicators of DSR performance (e.g. aggregating smart EV-charging) with overall DSR observed.
- Counting at different geospatial scales – e.g. if power outages counted locally and nationally and then summed.
- Measuring the same impact/phenomenon using multiple different indicators/metrics: Counting traffic noise pollution in decibels and also in terms of health impacts could result in double-counting.

Assessments of financial value, carbon emissions and cost-benefit analyses may be especially prone to double-counting as they are converting impacts into a common unit. There is, though, a good level of awareness of double counting in carbon emissions calculations (including life cycle assessment/LCA) due to accounting methods, different spatial and temporal resolutions, or when accounting boundaries overlap. The literature on co-benefits that considers approaches to double-counting may be useful for energy security frameworks. Discussing the risk of incurring double counting, Ürge-Vorsatz et al [61] provide a systematic account of the challenges to assessing multiple impacts (MI) and highlight methodological pitfalls (see also [62]). They recommend taking a conservative approach to quantification in order not to undermine the credibility of the assessment and offer a framework for rigorous MI evaluations that includes a granular approach to additionality.

However, in many cases multiple impacts should be counted separately to reflect multiple types of risks that may have a common origin. For example, extreme weather events pose multiple risks that all need to be represented, including potential impacts on system balancing, damage to infrastructure, and impacts on public acceptance of the energy system or services. Similarly, low system flexibility could increase risks in availability, reliability, affordability, energy independence, and acceptability. These multiple impacts may simultaneously increase some risks while reducing other risks - for example, a policy to increase gas plant capacity may lead to improved Availability and energy Independence but negatively affect other dimensions such as Environmental Sustainability or Affordability. Building new transmission grid may increase Accessibility and Availability but decrease Acceptability. Visibility of these multiple impacts is important to inform thinking about trade-offs and may be unproblematic, especially if they are not aggregated into a single score.

Impacts may also have secondary effects. For example, extreme weather damage to infrastructure, or rising energy costs, may have a knock-on effect of reducing consumer approval for the energy mix or technologies.

3.3.8 Assessing policy

These issues of fuzzy and overlapping boundaries, multiple impacts, secondary effects and double-counting are challenging for monitoring energy security and also for assessing what impact policies and actions are having on energy security. One policy or action may have impacts on multiple indicators, across multiple dimensions of energy security. One dimension or indicator may be impacted by multiple policies/actions. These impacts may also interact in complex ways.

A notable activity for monitoring progress related to net zero and energy policy is the UK Government's *Smart Systems and Flexibility Plan (SSFP) Monitoring Framework* [63], which "*provides a systematic approach for identifying the outcomes we expect to deliver and selecting monitoring indicators to measure progress*" (p.5). It identifies a range of indicators and datasets that it will track in order to monitor progress on the SSFP. The Monitoring Framework concludes,

> "*The impacts from many of these actions are overlapping and complex; multiple actions will contribute to a single outcome. There are also factors outside of direct policy control that will affect […] outcomes […]. We therefore do not consider it appropriate to track separate indicators for every policy action, and it is not possible to robustly attribute changes in outcomes to individual policy interventions*" (p.5). [63]

So, instead of being able to evidence one-to-mapping between a specific policy and a specific indicator of energy security, the measurable impact on a group of co-impact indicators may be attributable to a group of policies.

3.3.9 Complexity vs simplicity

The need to consider multiple dimensions of energy security and diverse stakeholder perspectives, over both the short-term and long-term, and to manage the various challenges outlined above, means that an effective framework for monitoring energy security is unlikely to be simple.

Greater simplicity is likely to mean less consensus. Cox [5] discussed a set of 22 energy security indicators with 25 experts from across the energy sector in the UK: "*The results from the interviews show that there is a real need to attempt to take into account multiple competing and context-specific views on energy security, instead of trying to close the discussion down around a small number of simple quantifiable indicators or metrics*" (p.1).

The scope of energy security indicator approaches is broad and expanding. Our review of indices and frameworks includes many with a large number of indicators. Yu, Li and Yang [40] reviews indexes for quantifying energy security levels and observe that energy security indexes have become more complex and their scope has broadened from simple energy market issues to include environmental, technological, and social issues.

Some academic work advocates for simplicity on the grounds that a simpler framework is more likely to be navigable and used by policymakers. Mitchell and Watson [58] observe that an argument is often put forward for simplicity in policy design but highlight the inter-related nature of goals and policies, trade-offs and synergies. They recommend that the inevitable complexity is dealt with by holistic, interdisciplinary analysis and appropriate institutions including "*a cross-government inter-department forum on energy which meets regularly; it would include senior civil servants and external experts*" (p.252). This body would provide oversight of energy policy decision-making and ensure transparency in how trade-offs are made. Axon, Darton and Winzer [32] also draw attention to Stirling's statement that "*his framework requires intelligent operation and interpretation by policymakers*" (p.227).

This raises the issue, again, of the purpose of a framework, who would used it, and how. Some frameworks for measuring energy security include indicators for 'governance' that scrutinise the user and their management of energy security – these are discussed below.

3.4 The use of frameworks

3.4.1 Governance indicators

Several of the indices and frameworks listed in **Table A** (**Appendix 2**) include a dimension of 'Governance'. The WEF's [64] *Energy Transition Index* includes a sub-index of 'Transition Readiness', with three 'enabling dimensions': Capital & Investment; Regulation & Political Commitment; Institutions & Governance. In academic work, Ang et al's [8] literature review included 'Governance' among seven major dimensions of energy security. Governance indicators are also included in the frameworks proposed by Zhang et al [65], Song et al [66]; Zaman and Brudermann [67]; and Axon, Darton and Winzer [32] cite several other works.

Benamirouche et al [26] argue that *"[…] and the instability of energy sector governance constitute some issues that could affect negatively the performance of energy security*" (p.233). The five major dimensions of their ESIA framework includes 'Governance', which has ten indicators:

1. Availability of National Energy Policies
2. Extent of Implementation of National Energy Policies
3. Adequacy Energy Institutions
4. Public-Private Partnerships in Energy Sector
5. Efficacy of Institutions for Delivery of Energy Services
6. Availability Various Acts Related to Energy
7. Energy Efficiency Standards
8. Availability of Enabling Framework for Private Sector Participation
9. Ease of Access to Finance for Energy Project Financing
10. Energy Efficiency/Renewable Energy for Households.

3.4.2 Institutional and strategic preparedness

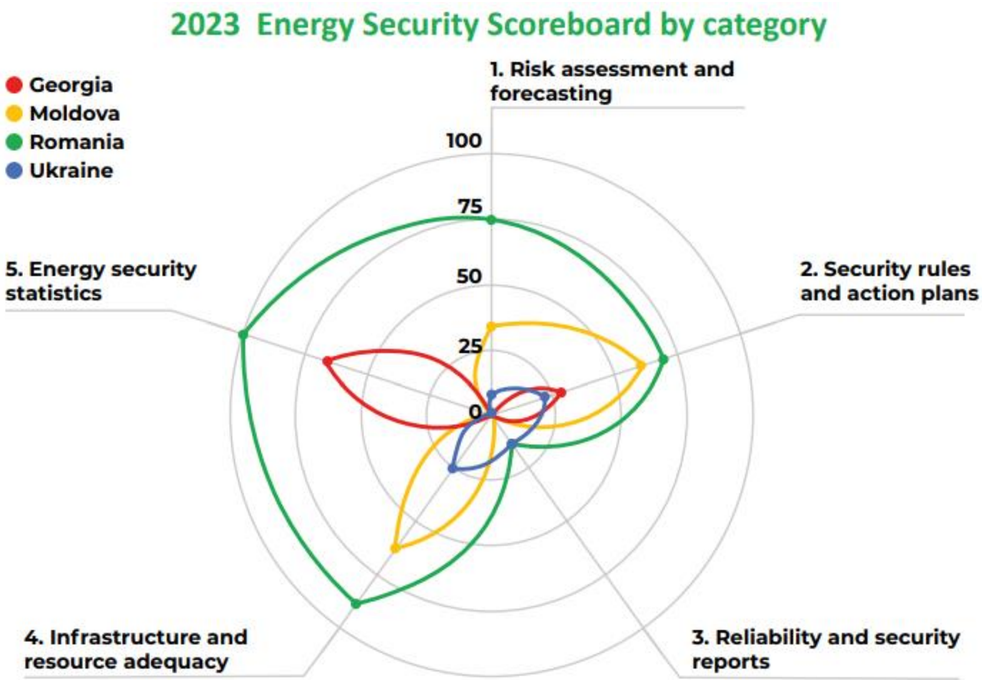
Work by DiXi Group [38], collaborating with the Black Sea Trust and the EU, presents an interesting energy security framework. Their *Energy Security Scoreboard* is, "*an analytical tool that addresses one yet important aspect of energy security – the institutional and strategic preparedness of countries to indicate, assess, mitigate, prevent, and withstand energy security risks while remaining energy resilient and sustainable*" (p.5).

Here, the authors do not give dimensions or themes for energy security threats, risks or outcomes[4] but their pilot Scoreboard comprises 40 indicators divided into five categories for "*institutional preparedness*", reflecting the main stages of policymaking in energy security:

1. **Risk assessment and forecasting**: aimed at determining the level of implementation of risk assessment procedures.
2. **Security rules and action plans**: includes action plans; standards and definitions; procedures and investment planning.
3. **Reliability and security reports**: the availability of reports and other instruments confirming the implementation of plans and compliance with standards
4. **Infrastructure and resource adequacy**: compliance with specific objectives, targets, and standards related to infrastructure and resource adequacy.
5. **Energy security statistics**: the level and quality of data disclosures on indicators essential for assessing energy security.

These indicators are assessed using six 'transparency criteria', we discuss these and the role of data (highlighted in DiXi Group's fifth category for institutional preparedness, 'Energy security statistics') in Chapter 4. Scores are converted into a 100-point scale and given a rating A+ to F. An example scoreboard for four Black Sea states shown in Figure 5, below.

[4] "*The Energy Security Scoreboard cannot be used to assess: energy security of the country as such, which is a more broad and dynamic phenomenon in its nature*" [38] (p.36)



Category	Georgia		Moldova		Romania		Ukraine*	
	Score	Rating	Score	Rating	Score	Rating	Score	Rating
1. Risk assessment and forecasting	0	F	33	F	75	B	7	F
2. Security rules and action plans	27	F	60	C	69	C+	21	F
3. Reliability and security reports	0	F	0	F	13	F	13	F
4. Infrastructure and resource adequacy	0	F	63	C	88	A-	25	F
5. Energy security statistics	67	C+	0	F	100	A+	0	F
Total score	**15**	F	**31**	F	**58**	C-	**14**	F

Score	Rating	Characteristic
95...100	A+	absolute preparedness
90...94	A	excellent preparedness
85...89	A-	
80...84	B+	good preparedness
75...79	B	
70...74	B-	
65...69	C+	medium preparedness
60...64	C	
55...59	C-	
50...54	D+	insufficient preparedness
45...49	D	
40...44	D-	
0...39	F	unacceptable preparedness

Figure 5: 2023 Energy Security Scoreboard by category for Georgia, Moldova, Romania and Ukraine. Source: DiXi Group [38]

3.4.3 Management of decision-making processes

Another index that does not aim to provide a comprehensive framework for energy security as a whole but includes interesting governance indicators is the *Energy Investment Risk Assessment* (EIRA) Framework, by the Brussels-based Energy Charter Secretariat [55]. EIRA's goal is to facilitate the clean energy transition by helping countries to improve the investment climate for the energy sector. EIRA adds to the energy security literature by exclusively assessing countries' legal and regulatory risks that can be managed and mitigated through government action. It applies five indicators (each with sub-indicators) to identify and track these risks and develop the corrective measures countries must take to mitigate them:

1. Framework for a sustainable energy system
2. Foresight of policy and regulatory change
3. Management of decision-making processes

4. Rule of law (compliance with national and international obligations)
5. Regulatory environment and investment conditions

Especially relevant to governance of energy security broadly is the third indicator, 'Management of decision-making processes', which addresses the importance of quality and accountability in policy planning and decision-making. It is made up of two sub-indicators:

- **Institutional governance**: This sub-indicator measures how well governments coordinate the decision-making processes for policy design and implementation. The importance of a central body with responsibility for reconciling diverging perspectives and intra-governmental coordination is stressed.
- **Transparency and anti-corruption measures**: This sub-indicator measures the inclusiveness, fairness, consistency and predictability exercised by governments in designing and implementing their laws, policies and regulatory frameworks.

We concur with the above work that poor energy governance and poor use of any framework constitutes a risk to energy security and that therefore governance indicators - assessing the policymaking and decision-making processes - have an important place within a holistic framework for monitoring energy security.

3.5 UK context and transition risks

We have so far discussed the choice of indicators for monitoring energy security in general, while acknowledging that energy security is contextual and evolving. Our focus in this paper is on designing a framework suited to monitoring energy security in the UK throughout the transition to a low-carbon energy system. In this section we consider this context and the implications for choice of indicators, drawing on insights from literature and a workshop conducted with experts drawn from UK Government departments, regulators, advisory bodies, NGOs and industry, who work on energy security issues and who could be potential end-users of energy security monitoring frameworks.

Key points of workshop discussions on UK context and the net zero transition are summarised below. In addition to these issues, the UK is, of course also affected by many risks that have an international impact (for example, global markets and supply chains including those for fuels and critical minerals).

3.5.1 Energy security in a UK context – input from workshop

i. Workshop participants reported that the most appropriate indicators within an energy security framework are determined by the users and their use cases and so there is a need to consider likely or intended users and stakeholders in the UK.
ii. Similarly, the 'optimum' metric will vary with use case and is likely to vary by scale, from a 'single' metric at system-level to the use of more granular 'sub-indicators'.
iii. Generally, participants supported the use of monitoring frameworks based on indicators to track progress. Monitoring is likely to be incorporated into their work more in the future as it is fundamental to net zero thinking.

iv. Some participants commented that they typically approach the issue of indicators by using a Theory of Change (ToC) approach (see [68]), a methodology for planning, monitoring, and evaluation that guides identification of: (a) priority actions; (b) risks associated with these changes; and (c) associated indicators and specific target metrics.
v. The group noted limitations with current monitoring of fuel poverty, which fails to reflect retail price volatility for electricity and fossil-fuels and so has under-estimated fuel poverty in recent years.

3.5.2 Transition risks – input from workshop

Workshop discussion topics included the fitness of current indicators of energy security over the long-term and emerging 'Transition Risks'. Comments are summarised below.

Emerging risks:

i. More aspects of the system are outside direct control/dispatch - e.g. greater reliance on variable renewables.
ii. Increased variability in both demand and supply.
iii. Annual variation in renewable output leads to greater challenges for forecasting.
iv. Risk of insufficient investment in network infrastructure and capacity, e.g. lack of investment in power transmission grid or a declining gas network.
v. New/emerging risks from digitalisation such as cybersecurity risks.
vi. Planning considerations and risk of 'lock-in'.
vii. Risk of/from imposing costs at individual/business level (e.g. for energy efficiency improvements).
viii. Risks of/from changing climate and increased extreme weather.
ix. Volatility of global oil and gas supplies/markets as investment declines.
x. (Un)affordability of housing which is net zero-ready.
xi. Risk of unfair distributional impacts and increasing inequity. E.g. distributional impacts of demand-side response: we must ensure that energy security isn't provided by relying on those least able to 'flex' their demand. Who pays for a changing system and how is that managed fairly?
xii. Risk that we deliver energy security at the aggregate (e.g. national) level but not at the household level. E.g. loss of resilience at individual-household level by having only one energy vector (electricity) instead of electricity and gas for heating/cooking.
xiii. Successfully managing the phase-out of UK oil and gas production and the refining industry.
xiv. Job insecurity and the mismanagement of (re)skilling associated with the transition.
xv. Balancing needs of/for hydrogen versus gas in the Transition.
xvi. Uncertainty over the success or failure of innovation.
xvii. Risks associated with either reduced or improved interconnectedness with European energy markets (e.g. improved energy independence versus higher availability of fuels with more vulnerability to shocks).
xviii. Greater volatility of electricity prices, including seasonal variations (cheap renewable generation in the summer but expensive winters).
xix. A faster and accelerating pace of changes in the system impacting energy security.

xx. Increasing complexity of system operation means more actors and assets (for supply, demand and storage) involved in the provision of security.
xxi. Risks associated with changes in fuel supply chains, e.g. biomass and hydrogen in place of gas and oil.
xxii. Late 2020s-early 2030s will see closure of some electricity plants and the phasing out of unabated natural gas which could lead to security of supply risks before new technologies come online.
xxiii. Delivery risks affected by acceptability, such as consumer/voter backlash about pylons.
xxiv. Impact of planning decisions, e.g. frequently locating wind in rural northern Scotland affects energy supply costs, energy infrastructure planning etc.

New indicators needed for:

xxv. Energy security metrics are often based on primary energy production and use. However, as we move towards higher percentage of electricity in the energy mix, it becomes increasingly relevant to provide metrics on the energy services delivered (e.g. flexibility), rather than simply the primary energy used to generate those services.
xxvi. Indicators/metrics which measure energy system interconnectedness should be a focus for the transition to net zero.
xxvii. Selected conventional indicators may become less appropriate as we move towards net zero. An example is, energy storage rather than energy 'stocks' or 'reserves': Over time UK stocks of fossil fuels have declined whilst energy storage (e.g. batteries) has increased; whilst battery storage still accounts for a relatively small part of the picture, it provides significant reductions in fuel mix carbon intensity as well as additional energy system services not provided by energy stored in conventional fossil fuels.
xxviii. There is an important distinction between indicators which simply measure and track the current situation (e.g. current reserves of a given fuel vector) and those which forecast. These are both important but forecast metrics are likely to be of growing value to ensure energy availability over the medium- and long-term during the transition to net zero.
xxix. Some suggested future indicators for electricity: consumer participation in demand side response; technological diversity of generation; locational diversity of weather-dependent generation; level of interconnection to energy/electricity systems in other geographies. The improved tracking of these metrics could help reduce the length and frequency of low generation periods.

The above points included the limitations with existing UK metrics for fuel poverty. Further limitations in indicators and metrics may become more obvious as the energy transition progresses. Once such example are the indicators and metrics used for reliability standards. Hoggett, Eyre and Keay [33] note the need for broader reliability indicators than Loss of load expectation (LOLE). A report for DESNZ examined whether the current Reliability Standard metric for Great Britain remains an appropriate metric for capacity adequacy as we transition to a net zero electricity system with a flexible, low carbon capacity mix, and conclude that, "*A combination of metrics could be better at targeting more complex system stress events*" DESNZ [69]. They note that empirical analysis could help in deciding on the optimal combination of metrics but suggest a combination of

LOLE (Loss of Load Expectation), LOLD (Loss of Load Duration), LOLP (Loss of Load Probability), and EEU (Expected Energy Unserved) - see **Figure 6**.

	Average
Frequency of events	LOLE or LOLP
Duration of event	LOLD
Size of events	EEU

Figure 6: Potential future metrics for reliability standards in the GB context
Source: DESNZ [69]

Another potentially important limitation in the capacity to monitor energy security is poor-quality data for indicators. This is discussed in Chapter 4.

3.6 Key points

- This chapter has considered a number of issues that could inform the choice of indicators in a dashboard approach to measuring energy security.
- We have presented an overview of existing indices, indicators and frameworks for measuring energy security and outlined a range of challenges for assembling a holistic set of measurable energy security indicators.
- Drawing on findings from a stakeholder workshop, we have also explored the UK context and emerging 'Transition Risks' that could help inform choice of indictors.
- Chapter 2 argued for operationalising energy security by using measurable indicators. This chapter has further argued that how a framework is used is another source of risk to energy security and that operationalising energy security requires that indicators also assess the nation's capacity to manage energy security. Attention was drawn to such 'Governance indicators' within existing frameworks.
- Chapter 4 goes on to consider indicators' dependency on data and the need to also assess this in any monitoring framework.

4. Data for Monitoring Energy Security

Tracking energy security through the transition will require a holistic set of measurable indicators that cover the range of risks. Indicators require sources of data. Some previous work that highlights the role of data within energy security frameworks are outlined below.

4.1 Identifying data sources

Few indicator approaches to energy security give a list of data sources, still fewer identify data for each indicator in a transparent way. The GEI US Index [48] gives "*a list of the main sources of the data used to compile the metrics*" (p.13) but does not map data to individual metrics, categories of metrics, or sub-indexes.

Bradshaw and Solman [30] is a rare example of a paper that makes a one-to-one mapping between indicators (here a dashboard of 12 'measures of gas security') and 'method' (in most cases a methodology or model but sometimes a dataset) - for example the Digest of UK Energy Statistics (DUKES) is given as the data source for 'LNG Utilisation Levels'.

An important piece of work that considers data in the context of energy security is the Smart Systems and Flexibility Plan (SSFP) Monitoring Framework [63] and related work [70] [71] [72]. The framework has a clearly-defined purpose: it *"provides a systematic approach for identifying the outcomes we expect to deliver and selecting monitoring indicators to measure progress*" [71]. Specifically, it aims to:

- Track technology deployment and performance;
- Understand where flexibility is successfully performing in markets;
- Understand high-level trends;
- Reassure that progress is as expected;
- Highlight areas where more detailed analysis may be needed;
- Identify priorities for unblocking remaining barriers. [63]

It identifies a range of indicators and maps them to specific datasets that it will track in order to monitor progress on the SSFP (the indicators and datasets identified in this work are shown in **Table B**, **Appendix 3**). Its remit is confined to outcomes that demonstrate the overall progress of flexibility in the electricity system, but the approach could be applied consistently across the entire breadth of energy security issues.

4.2 Data gaps and limitations

Below we illustrate limitations and issues in the data for two areas of energy security: flexibility and fuel poverty.

4.2.1 Example 1: Flexibility data

The SSFP acknowledges that existing public data does not capture all the information that will be needed to track the progress of flexibility going forward. The Government aims to work with stakeholders to develop the flexibility monitoring framework by identifying new indicators and data sources and has highlighted a number of areas where further monitoring data would be valuable:

- Consumer tariffs and behaviour
- Domestic and small-scale smart technologies
- Aggregated services
- Carbon intensity of flexibility markets. [63]

The framework also aims to address data *access* issues: "*We will use the monitoring framework as a tool for improving the accessibility of data by working with stakeholders to identify and publish new data where appropriate*" (p.6). [63]

Additional indicators, evidence and datasets to better monitor demand response (DR) include ongoing work on Automatic Asset Registration as part of Ofgem's Flexibility Digital Infrastructure vision [73]. For example, the LCT Connect project [74] is developing an automated asset registration process and a central asset register to provide visibility of low carbon technology *deployment*.

Other possible indicators and data on the *performance* of DSR assets include:

- An application developed by Ryan Jenkinson, to visualise the flexibility provided by the Demand Flexibility Service (DFS) aggregated across all participating households [75].
- Measuring the scope for flexibility within large new loads for EV-charging and heat pumps. Trials to test this with various flexibility services are on-going (e.g. Equinox project [76]).
- A metric and data collection to track not only how energy efficient UK homes and buildings are but also their scope for being flexible in the time of electricity consumption from the grid will be of growing value. The Climate Change Committee's recommendations for EPC reform [77] suggested inclusion of indicators for DSR. Work in its early stages in this area includes the development of an energy demand flexibility metric for residential buildings [78]; demand flexibility certificates [79]; Centre For Net Zero's *Smart Buildings Rating* [80] (which focusses on low carbon technologies); and metrics to assess the smart readiness of buildings (e.g. the EU's *Smart Readiness Indicator for Buildings* [81]) now being proposed by the UK Government as one of four headline metrics within EPCs [82].

4.2.2 Example 2: Fuel poverty data

In Chapter 3, the summary of workshop discussions noted some limitations to the current UK fuel poverty metrics. The data collection methodology for fuel poverty introduces further limitations. Data are collected from the English Housing Survey (EHS) [83] and the Scottish House Condition Survey (SHCS)[84]. Where data are missing, it is modelled when appropriate. Concerns about sample bias in house condition survey data have been raised [85]. The accuracy and reliability of the data using sampling and modelling could be improved if supplemented by more measurement-based data. Fuel poverty measures are affected by limitations in measuring energy efficiency, for which greater measurement-based data has also been recommended (see later, Section 5.3.8).

Including a broader set of indicators and data could also give a more rounded picture of fuel poverty: e.g. the number of households in arrears with fuel bills [86], or capturing underheating via measured indoor temperature or thermal comfort [87] [88] [89], not currently recorded via official statistics. Similarly, although data for energy efficiency and fuel poverty at a number of levels (UK, national, regional and local authority) is publicly available via government sources, it would be valuable to see more data provided by local authorities and other non-government stakeholders. For example, the NEA publishes an annual UK Fuel Poverty Monitor report [90] and Energy Action Scotland produces reports and resources on fuel poverty.

Changes are needed to improve accuracy and uniformity across the UK nations. However, changing metrics may also have negative impacts on data availability and usability. Annual sub-regional fuel poverty data for the LILEE (Low Income Low Energy Efficiency) metric are only available from 2019, when LILEE replaced the previous LIHC (Low Income High Costs) metric. The impact of moving from LIHC to LILEE is shown in **Figure 7**, below[5]. Future changes to fuel poverty and other metrics and methodologies, to improve them or bring UK nations into alignment, would have similar consequences for using the data to make like-for-like comparisons and track change over time. Such changes to standardise or improve metrics for energy security should preferably be done as soon as possible to permit a continuous dataset to start accruing.

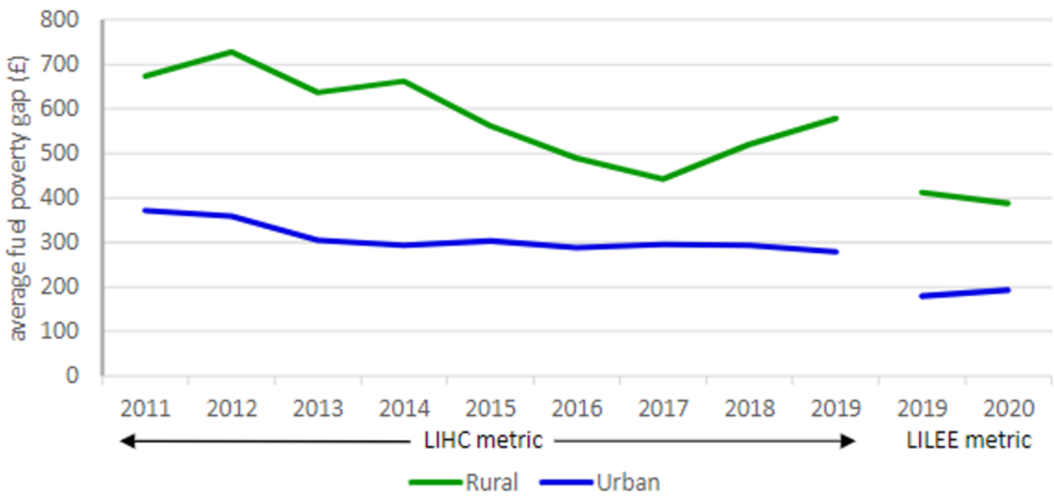


Figure 7: Annual fuel poverty gap (£), by settlement type, Low Income High Costs (LIHC) 2011-2019, Low Income Low Energy Efficiency (LILEE) 2019-2020
Source: DEFRA [91]

4.2.3 Data for UK energy security - key points from workshop

Data for energy security more broadly was discussed in the stakeholder workshop, key points from which are summarised below.

Oil and gas data:

- Much of the data related to future energy supply is likely to be private, proprietary, or related to commercial activity; consequently data availability is poor.
- Global data on oil and gas production is private and must be accessed through services like Rystad. It is also difficult to use, and more open/public data is needed.

[5] A similar issue arises due to past revisions to the EPC and SAP methodology.

- Even where data is available and accessible, some of the data upstream of emissions (e.g. on flaring) are not very reliable, making it even harder to analyse interactions between energy security and net zero targets.
- Oil and gas data for UK (e.g. from *Energy in Brief* or the *Digest for UK Energy Statistics*) is complex and heavily nested in the petroleum refining industries, which makes understanding it very challenging.
- Apart from the IEA, there is limited data on oil and gas production and, where data exists (e.g. from the North Sea Transition Authority), it is hard to distinguish between actual and forecasted supply.

Other data:

- Participants noted that more meteorological data is required. For example, the metrics of Loss of Load Expectation (LOLE) and 'Expected Energy Unserved' (EEU) are very much defined against one or two 'challenging' years. Participants noted that they currently have around 34 years of historical data and so if just one or two of these years effectively set the definition of 'challenging' then the data are not especially robust for defining LOLE and EEU. We therefore need a more complete and detailed weather dataset to improve forecasting scenarios. In addition, we also need more granular weather data that would be more aligned with the granularity increasingly used to balance the energy system (e.g. half-hourly).
- More data is needed related to future energy vector development, e.g. hydrogen and its expected potential.

The above limitations underline the need for efforts to improve the identification and mapping of data sources to indicators and to catalogue and assess these, with scrutiny of the associated metrics where appropriate. The following section reviews some existing frameworks for data quality assessment (DQA).

4.3 Data quality assessment (DQA) frameworks

4.3.1 Global Energy Institute's *Index of U.S. Energy Security Risk*

In developing the *Index of U.S. Energy Security Risk* [48], The Global Energy Institute's (GEI) established some criteria that would ensure the data used possessed several crucial characteristics. The data for each metric had to be:

- **Sensible**: The data had to relate to common-sense expectations.
- **Credible**: The data source had to be well-recognized and authoritative.
- **Accessible**: The data had to be readily and publicly available.
- **Transparent**: Data derivations and manipulations had to be clear.
- **Complete**: The data record had to extend back in history for a reasonable amount of time, preferably back to 1970.
- **Prospective**: The historical data had to dovetail cleanly with forecast data that extend to 2040 where these are available.

- **Updatable**: The historical data had to be revised each year, with a new historical year added and new forecast outlooks prepared.

As discussed in Chapter 3, using such criteria to help select or filter the choice of indicators can have a detrimental impact on designing a holistic set of strong energy security indicators but such criteria could instead be used for assessing data after indicators have been chosen. Some other frameworks for data quality assessment (DQA) are outlined below.

4.3.2 DiXi Group's 'Transparency Criteria'

The DiXi Group Energy Security Scoreboard [38] is specific to the Black Sea region but has an unconventional approach that is potentially useful for thinking about data in the UK context. They set out five categories of indicators for 'institutional preparedness', reflecting the main stages of policymaking in energy security (discussed in Chapter 3 with respect to governance indicators). One of these categories is 'Energy security statistics' – this assesses the level and quality of data disclosures on indicators essential for assessing energy security. Their scoreboard scores available data related to energy security on the basis of six 'Transparency Criteria':

1. **Availability:** Availability of the information;
2. **Accessibility:** The degree of access to information;
3. **Relevance:** Availability of information for the most recent reporting period or the moment of assessment;
4. **Frequency:** Whether information is updated according to requirements and available for past periods;
5. **Usability:** Convenience of using the information (e.g. is machine-readable);
6. **Completeness:** Availability of the information within the required period.

4.3.3 DAMA's *Data Quality Framework*

As part of the UK's *National Data Strategy* [92], the UK Government has developed a *Data Quality Hub* [93] which takes forwards several methodologies, frameworks and standards for managing and working with data. One such component is the *Government Data Quality Framework* [94], developed by the Data Management Association UK (DAMA UK), and recommended by the Government Data Quality Hub [95]. The purpose of the framework is to provide a set of practical tools and techniques which can be used to assess, communicate and improve data quality. The framework offers: five data quality principles; six data quality dimensions; and guidance on data quality action plans and metadata.

Data quality dimensions

According to DAMA, data quality dimensions are 'measurable features or characteristics of data' that can be used to make data quality assessments and therefore identify any issues or weaknesses with datasets. Whilst not exhaustive in nature, DAMA provide a list of six core quality dimensions [94], which are defined as follows:

1. **Completeness**: Data is considered complete when all the data required for a particular use is present and available to be used. i.e. contains all the records it should have, and all essential

values in a record are populated. Completeness is distinct from accuracy, as completed fields may contains inaccurate data (the criteria used by DiXi Group also include ‘Completeness’.)

2. **Uniqueness**: Uniqueness measures the number of duplicates. Data is unique if it appears only once in a data set. A record can be a duplicate even if it has some fields that are different – e.g. data for two people which should be unique but is identical, such as a National Insurance Number.
3. **Consistency**: Consistency is achieved when data values do not conflict with other values within a record or across different data sets - e.g. a mother’s date of birth cannot be earlier in time than that of her child.
4. **Timeliness**: indicates whether the data is available when expected and needed for a given use case (e.g. energy consumption data at half-hourly granularity) and that the data and its values are up to date (the DiXi Group criteria ‘Completeness’ and ‘Frequency’ are very similar.)
5. **Validity**: the extent to which the data conforms to the expected format, type, and range. For example: an email address must have an ‘@’ symbol; month should be between one and twelve.
6. **Accuracy**: data is accurate when data reflects reality, i.e. the ‘closeness between an estimated result and the (unknown) true value’.

The framework also stresses **‘user needs and trade-offs’:** ensuring that data meets user needs as closely as possible, whilst recognising that perfect data does not exist. Trade-offs between quality dimensions might be necessary (and desirable), depending on user needs - such as timeliness over completeness where a user would rather receive frequent data than it be complete with every release.

The Government *Data Quality Framework* guidance documents acknowledges that “*concerns have been raised over the quality of data collected, created and used by government*” and that “*at present, we lack a consistent approach to managing data quality across government*” [94]. The Government Statistical Service (GSS) document, *Quality Statistics in Government* [96], states that accuracy, in particular, is a fundamental data quality dimension and that information on accuracy should be monitored and reported regularly. Despite this, the guidance does not set absolute standards for criteria such as accuracy, and states that what is appropriate to ensure fitness-for-purpose will depend on context and is a matter of professional judgement and that accuracy should be considered through data bias evaluation, i.e. an assessment of whether the data comes from a trusted source. A clear methodology for data bias evaluation is also lacking, suggesting a subjective judgement of whether the data is ‘trustworthy’, rather than measuring the extent to which data represents the real world.

Data quality action plans

A data quality action plan helps to identify and understand the strengths and limitations of your critical data: whether the data is fit for purpose and where to put resource to improve its quality. The Government *Data Quality Framework* guidance on how to create a data quality action plan has nine steps [94]:

1. Identify your critical data
2. Identify your data quality rules

3. Perform an initial data quality assessment
4. Document your findings
5. Identify and prioritise potential improvements.

When you have assessed your data, identify which areas require improvements and prioritise the most pressing ones.

6. Define goals for data quality improvement
7. Identify the root cause and take action to address this
8. Report on your data quality
9. Repeat measurements of data quality over time.

4.3.4 Other data best practice guidance

DAMA and the Government *Data Quality Framework* focus primarily on assessing and improving the quality of input data *rather* than the quality assurance of analytical outputs. Other resources for DQA and data handling include: The ONS Data Quality Management Policy [97] and the UK Statistics Authority's *Code of Practice for Statistics* [98] (consistent with the *European Statistics Code of Practice* [99]).

Also of note for data quality assessment is the Energy Systems Catapult *Data Best Practice Guidance* [100], which identifies the following principles:

1. Identify the roles of stakeholders of the data
2. Use common terms within Data, Metadata and supporting information
3. Describe data accurately using industry standard metadata
4. Enable potential users to understand the data by providing supporting information
5. Make datasets discoverable for potential users
6. Learn and understand the needs of their current and prospective data users
7. Ensure data quality maintenance and improvement is prioritised by user needs
8. Ensure that data is interoperable with other data and digital services
9. Protect data and systems in accordance with Security, Privacy and Resilience best practice
10. Store, archive and provide access to data in ways that maximise sustaining value
11. Ensure that data relating to common assets is Presumed Open
12. Conduct Open Data Triage for Presumed Open data.

It could also be worthwhile to assess data using Open Data principles, which might be helpful for promoting data quality, transparency and trust in energy security data. For example, Tim Berners-Lee's 5-Star Open Data [101] criteria:

★	Available on the Web (whatever format) under an open license
★★	Available as structured data (e.g., Excel instead of image scan of a table)
★★★	Available in a non-proprietary open format (e.g., CSV instead of Excel)
★★★★	Use URIs to denote things, so that people can point at your stuff
★★★★★	Link data to other data to provide context.

4.3.5 Data for a Just Transition

There appears to be growing attention within government on monitoring and evaluation. In addition to the monitoring frameworks within DESNZ [63] [72], Scottish Government is currently developing a framework for monitoring and evaluating the Just Transition in Scotland [102]. A report for ClimateXChange [103] concludes with recommendations that include: linking National Performance Framework outcomes to Just Transition Outcomes; measuring the social impact of net zero policies using indicators from the NPF; assessing the indicators' ability to capture regional impacts; and further developing process indicators to capture empowerment and participation. A recent report on monitoring and evaluation for the Just Transition Commission [102] stresses the value of a Theory of Change for assessing Just Transition progress and enumerates several key outcomes and mechanisms. It also recommends that public reporting of monitoring for just transition should begin immediately, including development of an annual dashboard for tracking and presenting the Scottish progress to Just Transition KPIs (an initial dashboard is given using current data).

As a first step to monitoring Just Transition goals alongside energy security goals, we suggest that data and metadata should support analyses of the distribution of costs and benefits (financial and non-financial) and be evaluated against this standard. This would require datasets to include geospatial data, socio-economic data, and data on vulnerabilities and other characteristics relevant to energy security (the latter might include health conditions, type of tenancy, building type).

4.4 Key points

- Data will play a vital role in any indicators-based approach to monitoring energy security. Poor or lacking data limits awareness of risks and the ability to manage them, and so is itself a potential source of risk to energy security.
- We have argued that data sources need to be identified and catalogued for each and every energy security indicator. We have reviewed some existing work within energy security that include data sources. The *Smart Systems and Flexibility Plan Monitoring Framework* [63] was highlighted as an example of a systematic approach to identifying and tracking data sources for each measurable indicator. This work also acknowledges that identification of data sources is incomplete and is an ongoing activity best done collaboratively. We recommend this as an approach that could be applied across the much broader scope of energy security as a whole.
- Further, we have argued that assessment of the availability and quality of energy security data also needs to be built into a monitoring framework. Data availability and quality should not limit the selection of indicators. Rather, a holistic set of indicators should be the basis for doing an inventory, or stock-taking exercise, that catalogues existing data, metrics and analytic methods, and identifies limitations. It should act as a springboard for improving data collection, access and use. We have highlighted some previous work within energy security that considers data assessment (e.g. [38]) and have summarised some Data Quality Assessment (DQA) frameworks beyond energy (e.g. the DAMA Data Quality Framework) that could help inform DQA for an energy security dashboard.

Chapter 5 presents a draft monitoring framework for UK energy security through the transition.

5. The ‘4+4 Energy Security Monitoring Framework’

This chapter lays out our approach for a draft framework for monitoring UK energy security through the transition including a holistic set of dimensions, indicators and data and a guide to its use. It draws on the discussions of energy security conceptualisations, choice of indicators, and use of data in Chapters 2, 3 and 4 respectively.

5.1 Recap on challenges and requirements for a UK energy security monitoring framework

As a prelude to presenting our draft framework and rationale, the following is a brief recap of the design criteria and considerations discussed in Chapter 3. i.e. the characteristics an optimal framework for monitoring UK energy security should have, and the challenges it would have to overcome or manage. An energy security monitoring framework should:

1. Be fit for purpose and useful for key stakeholders. The specific characteristics required will be determined by the users and use cases but should include the following.
2. Help guide policy assessment and decision-making to manage risks, including supporting making trade-offs between multiple goals.
3. Include a broad and holistic range of energy security risks.
4. Include both long-term stresses and short-term or sudden shocks.
5. Include emerging transition risks as the UK energy system continues to decarbonise, digitalise and decentralise.
6. Take account of fuzzy boundaries and double-counting risks.
7. Take account of all relevant stakeholders.
8. Help monitor and guide delivery of a Just Transition.
9. Help identify data sources for all indicators.
10. Help assess the quality of metrics and available data and guide necessary improvements in both.
11. Be transparent at all stages: from intended use cases and choice of indicators through to data collection, analysis, assessment and decision-making.
12. Use clear, consistent nomenclature.
13. Be useable and impactful in a practical policymaking environment.
14. Avoid needless complexity.

5.2 Key features of our '4+4 Framework'

We summarise, below, the key distinguishing features of our '4+4' monitoring framework for energy security and the approach it takes to themes, indicators and data.

5.2.1 Approach to themes

'4+4' refers to our eight themes:

- The familiar four 'A's - *Availability, Accessibility, Affordability, and Acceptability,*
- Plus four more - *Sustainability, Independence*, *Governance* and *Data & Metrics*.

Definitions, precedents and rationales for choosing each of these themes are given below in Section 5.3.

Themes have several vital roles to play in an energy security framework: they help to generate a comprehensive set of indicators for security goals; they give structure to these indicators; and they are key for communicating various aspects of energy security to stakeholders. However, we suggest that the key priority and challenge for developing a useful and useable energy security monitoring framework is not in just laying out a preferred set of 'themes' or 'dimensions' but in systematically and comprehensively identifying specific indicators, metrics and data that together can operationalise energy security. This level of detail is laborious but necessary and should be done with transparency, so we have attempted this from the start.

We take a somewhat novel approach to themes that recognises the inherent issue of fuzzy boundaries. We have not attempted to devise a set of dimensions that neatly cover all aspects of energy security without any overlaps. Instead, we allow for where indicators are relevant to multiple themes and highlight this to help manage risks of double-counting.[6] For this reason, we favour the term 'theme' over 'dimension' as the latter may suggest that they are independent, mutually exclusive or orthogonal when in fact many indicators and data are relevant to more than a single theme.

Our approach to themes is illustrated in **Table 3**, below. The table is a matrix that presents the themes in eight coloured columns and shows indicators in rows: each indicator is tagged as being relevant to one or more themes. Some indicators have more obvious multiple impacts across multiple themes: for example, energy efficiency in housing can reduce demand and reduce consumers' bills (*Affordability)* and carbon emissions *(Sustainability)* and also improve security of supply (*Availability*)[7] and reduce imports of gas (*Independence*) – see **Table 3**. All indicators are tagged as relevant to the *Data & Metrics* theme (see 'Approach to data', below). Two example indicators are used here for illustration, but a full table with all 72 indicators can be found in **Table C**, **Appendix 4**, which is the key summary of the framework.

As discussed in Chapter 3 (Section 3.3.7), overlapping themes raise the issue of potential double-counting. Double-counting may occur for several reasons but, in many cases, multiple impacts

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[6] This appears to share similarities with the approach used for Sub-Indexes within the Global Energy Institute's *Index of U.S. Energy Security Risk*, in which a single 'metric' can be used to contribute to calculations within one or more of four 'sub-indices', depending on relevance and interpretation of data, though transparency in this process is low.

[7] Cox reports that, "*A majority of respondents suggested that reduction of overall energy demand can in theory improve availability, affordability and sustainability*." [5] (p.5).

should be counted separately to reflect multiple types of risk that may have a common origin. For example, extreme weather events (risk to *Availability* due to impact on demand, risk to *Accessibility* and *Acceptability* due to damage to infrastructure) and system flexibility (impacts on *Availability*, *Affordability*, energy *Independence*, and *Acceptability*). These multiple impacts may simultaneously increase some risks while reducing others – e.g. building new transmission grid may increase *Accessibility* but decrease *Acceptability*. Some of these overlaps may be handled by clarifying primary versus secondary effects (for discussion see the Final Report of the UKERC *Win-Window* [104] project on tracking net zero co-benefits). When multiple risks are expressed in a common unit (e.g. metric tons of carbon dioxide equivalent/MTCO2e, for carbon emissions, or GBP, for financial valuations) then risks of double counting may be greater. Visibility of these multiple impacts is important to inform thinking about trade-offs and may be unproblematic, especially if they are not aggregated into a single score or unit of measurement. By highlighting overlaps, the framework can hopefully help to better inform thinking about trade-offs and manage risk of double-counting errors.

Nevertheless, in **Table C** (**Appendix 4**) we have colour-coded indicators to one theme. This is done to help the reader navigate the long table of 72 indicators, and it works well for themes such as *Governance* or *Data & Metrics*, for which indicators are very strongly tied to one theme only. It is not ideal for showing other indicators' relevance to multiple themes and could perhaps be better managed by an interactive ICT user interface.

Our matrix approach means that indicators are not 'siloed' within themes, so there is the potential for flexibility according to evolving policy goals, public concerns or communication needs. More themes or sub-themes could be added without disrupting the structure of the framework: for example, a Health & Safety[8] sub-theme within the *Sustainability* theme. In terms of **Table C** (**Appendix 4**), this would be a matter of adding additional theme columns. Ultimately, decisions about extra themes will be driven by priorities in energy security policy and communication goals. More general criteria for whether a category of indicators should be a theme include:

- Ideally, a theme should not need to refer to a more fundamental value captured by another theme (see discussion of flexibility in Section 5.3.1).
- Managing complexity: a greater or lesser number of themes may be needed to better manage overlaps and double-counting risk or to manage visual complexity in communication materials.
- As discussed in Section 3.3.1, aggregation results in a loss of useful information [49][32] and a dashboard of multiple themes and indicators is more useful and actionable than a single global score or index. If indicators within a theme are in conflict with many other indicators within that theme this could be a reason to create a separate theme or sub-theme. (See discussion of *Independence* theme, in Section 5.3.6).

[8] For example, the Fukushima disaster changed priorities in Japan and Germany towards public safety.

Table 3: The ‘4+4 Framework’ for monitoring energy security (illustration using two example indicators) †

Indicators are tagged as relevant to one or more of eight themes within energy security. *All* indicators are relevant to the *Data & Metrics* theme that assesses the availability and quality of data and metrics.

INDICATOR † (or groups of indicators)	**DATA SOURCES**	**Energy security THEMES** (relevant indicators marked with ‘**X**’)							
		Availability	**Accessibility**	**Affordability**	**Acceptability**	**Sustainability**	**Independence**	**Governance**	**Data & Metrics**
Loss of Load Expectation (LOLE) for gas and electricity	UK Energy in Brief (2023), Reliability, (p.17) UK Energy in Brief (2022), (p. 8) ‘Total Inland Primary Energy Consumption’ Statutory Security of Supply Report (2021) NESO - Winter Outlook Report UK Historic Energy Demand Data DESNZ Energy and emissions projections Meteorological data: Met Office	X							X
Energy Efficiency in housing	National Energy Efficiency Data Framework (NEED) Non-Domestic National Energy Efficiency Data Framework (ND-NEED) Household Energy Efficiency Statistics Green Homes Grant Voucher & Installation Statistics Green Homes Local Authority Statistics Energy Savings Opportunity Scheme (EOS) Energy efficiency of Housing, England and Wales, country and region Energy efficiency of Housing, England and Wales, cumulative financial years Energy efficiency of Housing, England and Wales, local authority districts Scottish Domestic Energy Performance Certificates Scottish Non-Domestic Energy Performance Certificates Energy Performance of Buildings Certificates in England & Wales	X		X		X	X		X

† The full table with all 72 indicators can be found in **Table C**, **Appendix 4.**

5.2.2 Approach to indicators

- We have attempted to assemble a comprehensive and holistic set of indicators for the whole of energy security – broader than most previous dashboards.
- Our choice of indicators was informed by the review of energy security indices and grey and academic literature on indicator-based approaches (**Table C**, in **Appendix 4** references some known precedents for each indicator where available). Selection of indicators was not constrained by the current availability or otherwise of data. We instead attempt to devise a holistic set of 'ideal'[9] indicators that is then used to:
    - Assemble relevant data sources;
    - Carry out an assessment of existing data availability, data quality and the fitness-for-purpose of metrics (see also 'Approach to data', below, and discussion of indicators in the *Data & Metrics* theme, in Section 5.1.3); and
    - Guide efforts to improve data and metrics where needed.
- In this draft framework there are 72 indicators, shown in full in **Table C**, **Appendix 4**. Known precedents and references are given there or in Section 5.3, below. The breadth and detail of indicators is to avoid significant risks being missed and to support making trade-offs in decision-making. Some of these numbered 72 indicators are themselves composites and contain sub-indicators which could, or should, be numbered individually. New indicators could be added, and some existing ones elaborated.
- Indicators can be tagged as being relevant to one theme or to multiple themes – as shown for two example indicators in **Table 3**, above, and in the larger table showing all indicators (**Table C**, **Appendix 4**).
- Some indicators are more given in detail (e.g. reliability standards within *Availability*), others much less so (e.g. specific indicators and metrics for cybersecurity). The framework is a work in progress and further development is needed including adding detail on indicators and specific metrics.

5.2.3 Approach to data

- Indicators are only as good as the data used to track them over time. We have tried to take a systematic and detailed approach to identifying data sources for indicators. Known data sources for each indicator are listed in **Table C**, **Appendix 4** – see example in **Table 3**, above. This is similar in approach to the SSFP Monitoring Framework [63] but much broader in scope, covering all aspects of energy security.
- Poor metrics or data are themselves risks for energy security and will determine the degree of confidence in any indicator assessment. For this reason, the framework also incorporates assessment of the availability and quality of data and metrics. This assessment is done using several indicators within the *Data & Metrics* theme - for details see Section 5.3.8 and Section 5.4.

[9] For which collection of supporting data should be at least potentially feasible.

- Some data sources are missing or lack detail (e.g. data for the *Governance* theme indicators). The framework is a work in progress and further development is needed including adding detail on data sources and data assessment.

5.3 Definitions of themes in the '4+4 framework'

For transparency, we explain below our definitions of the eight themes, with rationales for inclusion in our framework. The familiar four 'A's within our framework are relatively straightforward, while the additional '+4' themes (*Sustainability*, *Independence, Governance*, and *Data & Metrics*) require more discussion.

5.3.1. Availability

In some ways, 'availability' is not an ideal term, as everyday use of the word would suggest both 'Is there enough energy?' and also 'is it obtainable or *accessible?*' A more precise and preferable term might be 'sufficiency', but we have used 'availability' because it is now familiar through the various frameworks and literature using it (e.g. [15] [47][10]). As such it also requires less justification here for inclusion our framework.

Availability includes a broad range of aspects, and a large number of indicators, that include the following (with some precedents in brackets):

- Energy demand and intensity (e.g. [58])
- Reliability standards and security of supply [52]
- Energy diversity [10] [43]; electricity diversity [43]; and fuel diversity [47]
- Power system operability and restoration [52]

Another increasingly important and broad set of indicators tagged as relevant to *Availability* concern system flexibility, including: system balancing and Demand Side Response [47][43][63][10]. It is tempting to treat flexibility as a theme itself, because it is broad and is a stated priority in UK energy security strategy documents[11]. But ideally, a theme should not need to refer to a more fundamental value or goal captured by another theme: flexibility is important but is not desirable in itself - its importance and value is in terms of its impact on security of supply, energy costs, carbon emissions, independence, and acceptance – all covered by the existing themes. As such flexibility is a good illustration of the rationale for our choice of a matrix approach to themes rather than indicators being 'siloed' within one theme only.

For flexibility indicators, we follow the *Smart Systems & Flexibility Plan (SSFP) Monitoring Framework* [63], in differentiating between indicators for the deployment of assets and indicators for the actual performance of those assets. We also use their four indicator categories: Flexibility from consumers; Grid-level flexibility; Markets to reward flexibility; and Digitalising the system (we have added cybersecurity indicators under digitalisation but tagged it as relevant to multiple themes). The SSFP Monitoring Framework has stated that it will work with stakeholders to develop

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[10] Of over 30 frameworks summarised in **Table A**, **Appendix 2**, 16 include an 'Availability' dimension or sub-index.

[11] "*Energy security is […] is made up of three characteristics: flexibility, adequacy and resilience*" [21] (p.154); "*We are developing the technology options for delivering flexibility*" [12] (p.28); the *Scottish Energy Strategy and Just Transition Plan* [22] refers to "*improving the flexibility of the system*".

the flexibility monitoring framework by identifying further indicators and data sources and has identified a number of areas where further monitoring data would be valuable (for a discussion of these and further suggestions, see Section 4.2.1).

Indicators in **Table C** marked as relevant to *Availability* include critical minerals supply chains and resilience (used by Mitchell and Watson [58]). We also tag this against *Accessibility*, for the potential impact on infrastructure projects, and note the very real risk from supply chain constraints for equipment such as transformers [105]. Specific indicators and datasets for critical minerals are left to be detailed in further work, but several sources of existing assessment are given (e.g. UK Critical Minerals Intelligence Centre/BGS's *UK Criticality Assessment* [106]). Depletion of materials, critical minerals and rare earths could also be viewed as a sustainability issue [47][107], so it is also tagged as such.

5.3.2. Accessibility

Although almost 100% of UK households are connected to the electricity grid, and around 85% connected to the gas network, this does not mean that accessibility is not relevant or applicable for UK energy security. Accessibility is not only a mainstay within energy security frameworks [15], it is an explicitly-stated goal in the Scottish *Energy Strategy and Just Transition Plan*: "*Energy security can be defined as […] and having the means to get that energy to the point of use"* (p.189) [22].

Understanding the distribution of access to energy services, and any emerging bottlenecks, will be important for monitoring energy security and a Just Transition. For example, access is much lower and unequal for heat networks and EV-charging infrastructure (including off-street parking for lower-cost home-charging). Local distribution network constraints may not give equal access to heat pump connections: upgrades of the distribution grid and home fuses for heat pumps installations are not automatic, even at current low levels of penetration, and there are no standards of service [108]. These aspects of accessibility will be of growing importance and their distribution matters.

We have emphasised, or in some cases added new, indicators relevant to *Accessibility*, such as:

- Pipelines and timelines for developing transmission and distribution infrastructure for electricity ("*a network for wind by wire"* [109]).
- Supply chain constraints for equipment such as transformers.
- Investment indicators for transmission grid development [10] [110] [111] [112].
- Investment risk indicators [32] [55]. These indicators are relevant to all infrastructure including generation, transmission and storage. Specific indicators and metrics are to be determined but the Energy Charter Secretariat EIRA framework [55] uses three categories of indicators for assessing risk to energy investment: 'Unpredictable policy and regulatory change'[12]; 'Discrimination between domestic and foreign investors'; and 'Breach of state obligations'.

[12] An indicator for 'regulatory stability' is also highlighted by Axon, Darton and Winzer [32]. This may overlap with *Governance* indicators under 'Rules and Action Plans' (see *Governance,* Section 5.3.7).

- Risk to physical infrastructure from extreme weather, accidental damage (e.g. Baltic-connector in 2023) or sabotage (e.g. Nord Stream pipelines in 2022), which could also be risks for generation assets including offshore winds farms [113].
- Infrastructure reliability and resilience (incl. generation, transmission, distribution, and storage equipment failure as well as system-wide interoperability) [10] [43].
- International interconnectors (extends range of access to energy).

5.3.3. Affordability

Affordability is another common dimension in energy security frameworks (e.g. [15] [47]) and a clearly-stated priority for the UK Government. It includes fuel poverty, costs to consumers more broadly, and payments by Government to support consumer bills and technology adoption (e.g. Energy Price Guarantee, Energy Bill Support Scheme, Energy Bill Relief Scheme, Boiler Upgrade Scheme, and other subsidies and grants).

It should be noted that measuring 'affordability' is much more complex than simply tracking absolute energy prices, and may include assessment of disposable income, wage levels, inflation and cost of living (pers. comm. Emily Cox, 15.11.24). Metrics used for fuel poverty do include a relative affordability aspect but have several flaws, including a lack of sensitivity to fluctuation in retail energy prices (see Section 4.2.2). Greater energy efficiency could reduce consumer bills and exposure to price shocks but the availability and quality of data (notably EPC and SAP/RdSAP metrics and methods) also need improvement (see Section 5.3.8).

The short-term versus long-term is also highly relevant for *Affordability*: when we do reach the net zero 'destination' it is likely we can have a more secure and stable priced energy system but during the period of transition there will be affordability risks [109].

We include in our framework summary table (**Table C**, **Appendix 4**) some broader aspects of potential relevance for *Affordability*, including:

- The potential for demand response (DR) to reduce (or increase) bills.
- The cost of infrastructure damage due to extreme weather, accident or sabotage
- The cost to consumers of adopting key technologies, such as heat pumps [114], EVs and energy storage products. Indicators should include both installation and cost-of-ownership. Energy efficiency data for heat pump performance (i.e. Seasonal Performance Factor/SPF) should be of increasing value, as energy demand for heat is large and heat pump performance (SPF) can vary widely. Better data is needed on heat pump installation costs [115] and running costs [116].
- Network upgrade cost (included by Cox [47]). There is a potential risk of double-counting with the financial value of DSR in avoided network reinforcement.

5.3.4. Acceptability

Acceptability is the last of the four 'A's seen in several of the energy security frameworks reviewed in Chapter 3. The literature that stresses that energy security fundamentally involves the values we hold implies that *Acceptability* has the potential to be a very broad theme with many indicators.

Our framework has separate themes for *Affordability, Sustainability* and energy *Independence* – all of which might be concerns included within 'Acceptability'. Also, *Acceptability*, here, does not refer to the impacts that geopolitics or international relations may have on security of supply, which we cover under *Availability*.

Monitoring a Just Transition might also be placed within 'Acceptability'. Instead, our *Data & Metrics* theme includes assessing all data on whether it can support Just Transition analyses (see Section 5.3.8). The actual monitoring of a Just Transition progress could be done alongside an energy security framework or added as another theme or sub-theme[13]. As noted for Affordability [109], there is likely to be a difference between the fairness of the net zero 'destination' and periods during the journey to net zero when cost and benefits (financial and non-financial) are not fairly distributed.

Here, we intend *Acceptability* to refer to indicators of value judgements about the energy system and actors. *Acceptability* indicators cover two strands: public attitudes and ESG (Environmental, Social and Governance).

(i) **Indicators of attitudes, engagement and resistance in UK citizens and consumers** (households and industrial/commercial consumers).

Indicators include this first strand of our *Acceptance* theme include:

- Public support for, or opposition to, the UK mix of energy sources/fuels and technologies, on the basis of perceived environmental impacts, costs, health and safety, privacy, aesthetics (e.g. visual disamenity), jobs, or other concerns or co-benefits (included in Cox [47] [31] as 'Approval ratings of generation mix' and 'Disruptive opposition' under an 'Availability' dimension).
- Public attitudes to energy dependencies and import sources (actual energy independence and dependency is measured by indicators under the *Independence* theme).
- Public support for/opposition to infrastructure development – for example, 'NIMBY' (not in my backyard) or NAME (not at my expense) concerns about pylons, turbines, grid-level or community-level battery storage etc. Axon, Darton and Winzer [32] give the smart meter rollout and time-of-use tariffs as an example of resistance due to cost and privacy concerns.
- Beyond reported attitudes, we also include indicators of technology engagement such as data on adoption rates for low-carbon technologies or engagement with Demand Response services (Demand Response deployment and performance indicators are relevant to system flexibility and so are also tagged against our *Availability* theme). There is some indication that attitudes (*Acceptance*) are linked to engagement behaviours: "*Concerns and commitments relating to specific energy security and environmental issues were both strong predictors of willingness to adopt LCH technologies*" [117] (p.16).

To clarify, attitudes to environmental impacts and costs are included here, while actual physical carbon emissions (and other sustainability impacts) are captured by indicators in our *Sustainability* theme; similarly, actual costs are captured within *Affordability* theme. Carbon

[13] for example, the World Energy Trilemma includes 'energy equity' alongside 'energy security' and 'environmental sustainability' and highlights access, skills and phase out as challenges for a Just Transition [44].

emissions and costs may, of course, have secondary impacts on public attitudes monitored within *Acceptability*. Consumer perceptions of energy costs, the cost of policies, and other topics may depart from the evidence, with some data being complex and open to misrepresentation by stakeholders [118].

(ii) **Data and indicators for Environmental, Social and Governance (ESG) with respect to governments or companies involved in UK supply chains.**

ESG forms the second strand to *Acceptability*. We have not listed specific ESG metrics and data sources, but future work could select these based on well-established ESG indicators.

In some circumstances, the acceptability of supply chains will be formally acknowledged and enforced through sanctions and regulations that limit trade (e.g. the EU import ban on LNG from Russia).

As with other themes, acceptability to the UK Government, in the sense of moral, ethical or aesthetic value judgements, is assumed to be part of the process of making trade-offs in policy decision-making (and may be reflected in its reporting). So, beyond the ESG indicators for supply chains, our framework does not treat the UK Government's judgements on acceptability as a topic for which we need to assemble indicators and data. These trade-offs should, however, be made with transparency and we capture this via indicators for decision-making under our *Governance* theme.

5.3.5. Sustainability

Some sort of 'environment' or 'sustainability' theme is not uncommon in the energy security indexes reviewed here (e.g., Cox [47]; GEI's *U.S. Index of Energy Security Risk* [48] and *International Index of Energy Security Risk* [37]; *Energy Transition Index* [64]; *World Energy Trilemma Index* [119]). Environmental sustainability concerns might have been covered within our *Acceptability* theme, but UK Government strategy documents highlight 'clean energy' as a key goal [19] [3] [12] and, moreover, the UK has a legal obligation and targets for GHG emissions reductions (Climate Change Act 2008, 2019). The *25 Year Environment Plan* [120] is another clear policy commitment to sustainability. *Sustainability* is, then, the first of our additional themes beyond the four 'A's.

Indicators relevant to this theme are potentially broad: GHG emissions; depletion of natural resources [47]; water usage [5] [107]. Indicators and data for carbon emissions are relatively well-developed but there are gaps in other areas - e.g. for sustainability of biomass supply chains [121].

For this draft, we have included indicators for which there is precedent in previous energy security dashboards, and added other such as:

- Pollutants beyond GHGs. This includes air, noise, waterways, seas and coastline, radiation. Precedents include Stavytskyy et al [107], who have indicators for 'pollution due to mining activities'. Attributing pollutants to specific sources and gauging the impact of energy-related activities is unlikely to be straightforward.
- Biodiversity impacts (e.g. logging for biomass, other habitat/land use impacts oil spills, bird kills). Data sources such as UK Biodiversity Indicators 2024 [122] may be hard to link to

energy-related activities. Environmental Impact Assessments in the energy sector [123] may provide more useful assessments e.g. Offshore Energy Strategic Environmental Assessment (SEA) [124]. From 2025, biodiversity net gain requirements will begin to apply to Nationally Significant Infrastructure Projects (NSIPs) which includes the energy sector.

- Environmental pollution also has impacts on public health but measuring the energy-related health impacts pollution is challenging. Relevant data could include UK public health data on the burden of illness/disease (and potentially, the financial costs of this). Models conservatively estimate that wind powered electricity generation results in 1,230 times fewer deaths from pollution and accidents than coal-fire power, or 613 times less deaths than gas-fired [125]. Public safety concerns following the Fukushima disaster led to a decision to phase out nuclear power in both Japan and Germany (the German government also initiated a "*nuclear moratorium*" to re-evaluate the safety of German nuclear power plants). We suggest that future development of our draft framework could include a Health and Safety sub-theme within the *Sustainability* theme.

Further indicators and data for monitoring sustainability could draw on the *Outcome Indicator Framework for the 25 Year Environment Plan* [126], a comprehensive set of indicators that relates to the 10 goals within the *25 Year Environment Plan*; the framework contains 66 indicators, with data for 45 indicators. Work done within UKERC Theme 4 (Energy, Environment and Landscapes) could also help inform indicators and data for energy security sustainability and related decision-making.[14]

Many other energy indicators have potential to affect the carbon emissions and carbon intensity of the energy system (e.g. DSR and other flexibility indicators that impact the carbon intensity of grid power). These have, for now, not been tagged against this *Sustainability* theme.

5.3.6. Independence

The UK's dependence on energy imports appears to have some resonance with the UK public. Although now some time ago, UKERC work by Happer, Filo and Froggatt [127] reported, "*widespread discontent with the UK being dependent on imports of gas*" (p.3)[15]. More recently, a survey for BEIS [128] found that 53% of UK public reported being 'very concerned' about the UK becoming too dependent on energy from other countries. Energy independence also overlaps considerably with indicators within *Availability*.

Nevertheless, we chose to make energy *Independence* a theme separate from *Availability* and *Acceptance*. We do this because:

Firstly, UK Government strategy documents (see below) clearly state energy independence to be a key goal, so it should be measured objectively whatever public perceptions may be (within *Acceptability*):

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[14] For example, UKERC Theme 4 work on: marine net gain in off-shore wind farm planning [146]; tracking air quality and biodiversity co-benefits [104]; how to maximise biodiversity alongside solar farms [147]; and a modelling tool for optimising the location of energy infrastructure to minimise ecosystem damage [148].

[15] This work explored the influence of news media on public attitudes and behaviours related to energy security. It stresses the importance of the media environment and the potential impact of new information on beliefs. This suggests that clearer metrics and communication of energy security (key aims of our framework) has potential to increase engagement with Net Zero.

- "*[E]nergy independence*" [12]
- "*British energy*" [3] [12]
- "*[H]omegrown" energy* [11]
- "*We need a power supply that's made in Britain, for Britain"; "reducing our dependence on imported oil and gas*" [3]
- *"[B]ecome more self-sufficient*" [23]

Energy independence may be viewed as more politically controversial than the other themes and associated with negative aspects of energy nationalism. The associations and implications of energy independence are ambivalent and contested but include positive aspects. Ultimately, for now at least it is an explicit goal and should be a theme to support transparency in goals and in how trade-offs are made.

With respect to trade-offs, it is also worth noting that within these documents there is potential tension between the goal of energy independence and an accompanying goal of international cooperation:

- "[*S]ecurity through strong international partnerships*" (p.4) [12]
- "*[T]he goal of a fully interconnected North Sea grid" (p.125), and, "we must look to collaborate with others, particularly our neighbours around the North Sea, in creating mutual energy security […] and how best to create shared and mutually reinforcing systems and infrastructure*" (p.3) [22]

Secondly, energy independence can conflict with many indicators relevant to *Availability* – greater energy imports can increase energy *Availability* but decrease *Independence*. As discussed in Chapter 3, aggregation results in a loss of useful information [49]. This is part of our rationale for separating *Independence* from *Availability*. Similarly, we use the term 'independence' rather than 'self-sufficiency' (e.g. the *Global Energy Vulnerability Index* includes Self-Sufficiency with a 30% weighting [16]) because the latter combines independence with sufficiency, which is covered more directly in *Availability*. Increasing energy independence may reduce sufficiency. Likewise, we do not use 'energy sovereignty', which implies aspects of governance as well as energy independence and self-sufficiency (e.g. the European Council on Foreign Relations' *Energy Sovereignty Index* [129] has indicator-categories for 'cleanliness', 'efficiency', 'independence' and 'narrative').

Our indicators for *Independence* are also all indicators for *Availability* (e.g. energy diversity, domestic production, and import diversity, stability and dependency) but, as noted, changes in these indicators that increase *Availability* may often decrease *Independence* and vice-versa.

5.3.7. Governance

Good governance should help a nation to better manage multiple goals related to energy security. As with poor frameworks or poor data, bad decision-making processes will hamper effective responses. We have argued in Chapter 3 and 4 that we not only need a dashboard of indicators for stresses and shocks but also need indicators how a framework is used.

[16] The Index is behind a paywall but see [149].

There are precedents for a governance dimension in energy security literature and monitoring frameworks (see Section 3.4.1). It is one of seven major energy security dimensions identified by Ang et al. [8]. Governance indicators are also included in WEF's *Energy Transition Index* [64] and in academic work by Zhang, Bai, Xiao, and Ren [65], Song et al. [66], Axon, Darton and Winzer [32] Mitchell and Watson [58] and Benamirouche et al's ESIA framework [26].

Our approach was influenced by the *Energy Investment Risk Assessment (EIRA)* framework [55] and the indicators for 'institutional preparedness' in DiXi Group's *Energy Security Scoreboard* [38]. Our indicators for Governance fall into four categories, outlined below, though specific metrics and data sources are less well developed than for other themes and require future collaborative work.

Table 4: *Governance* indicators in the '4+4 Framework'	
i.	Rules, action plans and reporting
ii.	Inclusive stakeholder participation
iii.	Intra-governmental coordination and inter-ministerial cooperation
iv.	Transparency and anti-corruption measures

(i) Rules, action plans and reporting

This group of indicators will track the clarity of strategic goals and delivery plans, and is similar to the 'Security rules and action plans' category of indicators in DiXi Group's *Energy Security Scoreboard* [38].

In terms of past work highlighting these indicators, Mitchell and Watson [58] argue that energy security requires a long-term strategic framework. The *Energy Investment Risk Assessment* (EIRA) framework [55] tracks risks to investment via indicators that include 'Unpredictable policy and regulatory change'. An indicator for 'regulatory stability' was also highlighted by Axon, Darton and Winzer [32]. DiXi Group [38] found that reporting appeared to be the 'weakest link' in all countries' energy security institutional systems. Specific metrics and data sources are left for future work but would likely include legislation, regulation, UK Government strategy documents and reports, Climate Change Committee progress reports, and Government responses to them (e.g. [130]).

(ii) Inclusive stakeholder participation

Our final three categories of *Governance* indicators concern *decision-making processes* and draw on the 'Management of decision-making processes' indicators in the *Energy Investment Risk Assessment (EIRA*) framework [55]. These indicators also reflect key aspects of Open Government [131], such as transparency and inclusive decision-making processes, and are intended to cover policymaking and implementation (e.g. procurement).

Mitchell and Watson [58] suggest that "*government decision-making processes – and the basis for decisions that are made – need to be clear*" (p.256) but conclude that "*governance arrangements for integrated energy policy decision-making are still under-developed in the UK*" (p.250). Since then, there has been increased interest in monitoring and evaluation and it is worth drawing attention to DESNZ' *Smart Systems and Flexibility Plan Monitoring Framework* [63] and *Department for Energy Security and Net Zero: Monitoring and Evaluation Framework* [72].

Cox [47] [31] includes indicators for 'Participation in decisions' (within an 'Availability' dimension) and has elsewhere highlighted that "*there is a real need to attempt to take into account multiple competing and context-specific views on energy security*" (p.1) [5].

A crucial aspect of decision-making concerns how trade-offs are made. Mitchell and Watson [58] cite the example of shale gas tax breaks, for which, "*there has not been a clear enough articulation by government of how the trade-off between environmental, economic and security goals has been made with respect to this decision*" (p.251). They argue that instead of the current ad-hoc processes,

> "*[T]here needs to be a clear process of decision-making which, whilst based on evidence, also recognises that balancing energy policy objectives is at least partly a political process […] that requires policies to be based on holistic, interdisciplinary analysis. […] Appropriate institutions for legitimate decision-making are essential to deal with this complexity*" p.251.

This work, under the 'Energy in a Multi-Polar World' programme, proposed formalising inclusion of diverse 'experts' in Government analysis of energy security risks and publication of metrics and risk assessments. Mitchell and Watson recommend "*a cross-governmental inter-departmental forum on energy which meets regularly; it would include senior civil servants and external experts […] which publishes its deliberations*" (Ibid, p.252). Its key functions would be to consistently provide oversight of energy policy decision-making, ensure transparency, and explain how trade-offs are made.

(iii) Intra-governmental coordination and inter-ministerial cooperation

These indicators aim to assess the processes and activities to ensure that government agencies and ministries work together to achieve common goals. We also include here cooperation and collaboration between the UK, Scottish and Welsh Governments (though, strictly, this would be *inter*-governmental).

There have been calls for more 'joined-up thinking' than is seen in the British Energy Security Strategy[17]. Lovett et al [132] also identify the current lack of interaction between energy and environment and a tendency for 'silo working'.

The *EIRA* framework [55] includes an 'Institutional governance' sub-index for management of decision-making processes. This measures how well governments coordinate the decision-making processes for policy design and implementation. The importance of a central body with responsibility for reconciling diverging perspectives and intra-governmental coordination is stressed.

Indicators for this category within our draft framework are to be developed, but might draw on those from the Worldwide Governance Indicators [133] (such as 'Government Effectiveness')[18].

[17] "*It is this type of innovative and joined-up thinking that we urgently need from government, but unfortunately this focus appears to be lacking from the energy security strategy*." Prof. Karen Turner quoted in [114].

[18] The Worldwide Governance Indicators website also makes available data for the UK.

(iv) Transparency and anti-corruption measures

Another sub-indicator within 'Management of decision-making processes' in the ERIA framework is 'Transparency and anti-corruption measures'.

Other precedents for including transparency indicators in energy security frameworks include DiXi Group [38]. Mitchell and Watson [58] recommend greater transparency and suggest a cross-government inter-department forum that provides oversight [134][19].

The importance of anti-corruption measures for energy security has been highlighted in the academic literature [35] [67] [135] [42] [59] and beyond, e.g. Transparency International [136], Energy Charter Secretariat [55], and *The United Kingdom's Critical Minerals Strategy* [137] and the *World Energy Trilemma Index* [44].

The choice of specific metrics and data sources is again for future work, but can draw on the following: 'Control of Corruption Indicator' within the World Bank's Worldwide Governance Indicators [133]; *UK Anti-Corruption Strategy* [138] (metrics to be developed by the Joint Anti-Corruption Unit); OECD Anti-Bribery Convention [139]; Open Government Partnership (OGP) Anti-Corruption Working Group, whose recommendations include toolkit 'open contracting' [134].

One issue that arises for decision-making and trade-offs is how far down the causal chain we look when assessing impacts. Chapter 3 noted secondary effects and multiple impacts. An example can be seen in Western nations buying up LNG to replace Russian gas; the global south could not compete on the global market and so increased coal consumption [140]. This raises the question of how far down the causal chain of knock-on effects do indicators and decision-making processes need to go in order to monitor and manage unintended economic, geopolitical, social or environment impacts. The potential for UK purchasing to have secondary economic and environmental impacts that could affect trade-offs is underlined by work that stresses market competition:

- "*The UK now faces a period of more intense competition for LNG*" [1] (p.vi); and
- "*This low-carbon transition is also a source of competition. Access to critical materials for making electric vehicles and other green technologies, and control of these supply chains, is becoming a key issue, with a form of 'green protectionism' emerging in some countries. For many emerging economies, access to energy of any kind is the most pressing challenge. […] the transformation of energy systems is unlikely to be just, orderly or equitable*" [141]

5.3.8. Data and metrics

As discussed in Chapter 4, poor metrics and data jeopardise energy security by limiting awareness of risks, confidence in risk assessments, and the ability to respond and manage them effectively. Mitchell and Watson [58] also highlight the need for "*evidence-based decision-making*", which also requires good data. Some energy security indexes have chosen or filtered dashboard indicators based on data availability (e.g. the GEI's *Index of U.S. Energy Security Risk* – see Section 3.3.4 and

[19] Zhang et al [65] give an example of Why-Why Analysis (after Toyoda) for energy security; this might also be useful for transparency by making clear the rationale for policy decisions.

4.3). We view this as putting the cart before the horse, or indicative of the 'streetlight effect' (see Section 3.3.4), and as detrimental to much-needed rigor and improvement in monitoring energy security[20]. Instead, we view limitations in data and metrics as sources of risk to energy security and so incorporate into our framework the assessment of the availability and quality of metrics and data.

These assessments have two functions: to help to inform energy security *risk* assessments (confidence in assessments being weaker if data and metrics are poor); and to guide activity to improve metrics and data where needed. Assessments are to be summarised in a *Data Dashboard* that is separate from an energy security *Risk Dashboard* (see Section 5.4.1 and 5.4.2, below).

All metrics and data (across all themes) are assessed against the *Data & Metrics* indicators/criteria. Accordingly, in **Table C** (**Appendix 4**) a*ll* indicators and data are tagged as relevant to the *Data & Metrics* theme and, in that sense, this theme is unique. The data sources for these *Data & Metrics* assessments are, therefore, all the data sources listed for all other indicators. **Note**: the fitness-for-purpose of these *Data & Metrics* indicators can itself be assessed - for example, limitations in how data accuracy is assessed within the Government Data Quality Framework were noted in Chapter 4. However, using the *Data & Metrics* indicators to assess the *Data & Metrics* indicators risks becoming somewhat reflexive, or circular, and will require more work.

We use three categories of indicators within the *Data & Metrics* theme, summarised below (also listed in **Table C**, **Appendix 4** with some reference to precedents).

Table 5: *Data & Metrics* indicators in the '4+4 Framework'
i. Metrics (fitness for purpose, validity, accuracy, reliability and transparency)
ii. Data availability and access
iii. Data quality (DQA)

(i) Assessment of metrics (fitness for purpose, validity, accuracy, reliability and transparency)

This category of indicators would assess limitations and lack of transparency in the metrics and associated methodologies. How assessments would be done requires future clarification but would involve qualitative judgements by experts and stakeholders.

The need to include the assessment of current metrics is illustrated by some examples of current limitations:

- Energy reliability standards: the need to change or at least broaden the metrics used is discussed in a DESNZ research paper [69].
- Energy Efficiency: the accuracy of SAP and RdSAP methodologies for estimating energy efficiency, and generating EPC certificates for residential buildings, has been roundly critiqued (see [116]). Weaknesses include the following: the EPC main rating is not a good

[20] For selection of indicators, we suggest that *feasibility* of collecting data, rather than current data availability, should be used as a criterion.

indicator of energy efficiency as it is a cost-based metric; and EPC ratings have poor accuracy and inter-rater reliability [142] [143]. The Climate Change Committee (CCC), Environmental Audit Committee (EAC), Scottish Government and others have strongly criticised EPC methodology and advocated replacing the current reliance on estimation and modelling with much greater measurement and use of real-world outcomes (e.g. use of smart meter enabled thermal efficiency ratings/SMETERs [144]).

- UK fuel poverty metrics: Different fuel poverty metrics are used in England, Scotland and N. Ireland; they are insensitive to fluctuations in retail energy prices (see Section 4.2.2) and are affected by limitations in metrics and data for energy efficiency (SAP and RdSAP methods).
- Biomass sustainability: the National Audit Office [121] has said the Government cannot demonstrate that biomass companies are complying with sustainability standards without a better evaluation of assurance schemes.
- Flexibility indicators: for an outline of limitations and suggested additional indicators and data see Section 4.2.1.
- On the more technical side of analytic methods for interpreting data, Axon, Darton and Winzer [32] highlight that algorithms for measuring diversity and concentration, such as the Shannon Weiner (SW) diversity index, provide only an incomplete picture and that, "*using SW […] to calculate diversity in energy supply fails to take into account correlations between disruptions from different energy sources*" (p.213) so will not be fit for all purposes.

(ii) Assessment of data availability and access

The indicators highlight data gaps and data access issues. Data 'availability' and 'accessibility' are two of the 'Transparency Criteria' used to assess energy security data within DiXi Group's *Energy Security Scoreboard* [38]. The process for assessing data availability and access would also likely be a collaborative and qualitative exercise by experts and stakeholders and would begin with a more thorough (and open-ended) cataloguing of data sources for each indicator.

Current data access issues for oil and gas data were noted by workshop participants in Chapter 4. The need for improved availability of weather data was also raised. Another example of a data gap is that data for the in-situ performance of heat pumps is no longer being collected (between 2018 and 2022 all new all heat pumps applications to the Domestic Renewable Heat Incentive scheme required the heat pump electricity consumption to be metered and submitted to Ofgem, with some installations being paid to submit more data through a Metering and Monitoring Service Package). Data for heat pump performance (i.e. COP or SPF) could be an increasingly valuable indicator, as energy demand for heat makes up a very large proportion of domestic energy demand and heat pump performance (SPF) can vary widely.

(iii) Data Quality Assessment (DQA)

We suggest assessing data quality using the DAMA data quality dimensions recommended by the Government Data Quality Framework [94]: Accuracy, Completeness, Uniqueness, Consistency, Timeliness, Validity, plus User Needs.

One example of current limitations in data quality is that EPC datasets are incomplete and out-of-date: 31% of residential dwellings in England (34% in Wales) have never had an EPC [145].

These assessments of metrics (under 'Fitness for Purpose') and data (under 'User Needs', within DQA) should include evaluating if they support monitoring of a Just Transition – i.e. whether data and metrics support analyses of costs and benefits (financial and otherwise) to understand their distribution geospatially, socio-economically and with respect to other characteristics (such as type of tenancy, building type, and vulnerabilities). For example, the transition to electric vehicles should deliver reduced air pollution but these impacts may not be distributed evenly, and geospatial data is missing from datasets on EV ownership. (See also Section 4.3.5 'Data for a Just Transition').

Finally, as for all indicators, in **Table C** (**Appendix 4**) indicators for Cybersecurity are, of course, tagged as relevant to the *Data & Metrics* theme. However, insofar as cybersecurity is a risk to data storage, it poses a potentially serious threat here that could affect data availability and data quality for all indicators in all themes.

5.4 Using the '4+4 monitoring framework' and example Risk and Data Dashboards

As emphasised in Chapter 3, energy security frameworks should be clear about what their purpose is and should be designed to be fit for that purpose [32] [47]. The intended purpose of this draft monitoring framework is to support better assessment, tracking and communication of UK energy security over the net zero transition. More specifically, it is intended to be used to better support:

- Identifying, measuring and tracking energy security risks;
- Assessing and improving metrics and data;
- Managing energy security including policy decision-making and trade-offs;
- Communicating energy security to the UK public and other stakeholders.

The steps below outline how the framework could be used to support the above aims.

5.4.1 Step 1: Assess data and metrics

The first step is to assess current metrics and data for each indicator (the full list of 72 indicators is in **Table C, Appendix 4**) using the *Data & Metrics* indicators, which cover three criteria (for detail, see Section 5.3.8):

- Metrics (fitness for purpose, validity, accuracy, reliability and transparency)
- Data availability and access
- Data Quality (DQA)

This cataloguing and assessment exercise should produce a rating for the quality of data and metrics for each indicator across all themes. This should reflect both current and future data needs. These assessments of metrics (under 'Fitness for Purpose') and data (under 'User Needs', within DQA) should also include evaluating if they support decision-making for a Just Transition (see Section 4.3.5), i.e. whether data and metrics support analyses of the distribution of costs and benefits geospatially, socio-economically and with respect to other characteristics.

The assessments of data and metrics may be presented as a ***Data Dashboard*** - at either the level of individual indicators or at the level of themes. **Table 6**, below, is an illustrative example of a dashboard at the level of the eight themes.

These assessments and Data Dashboards can serve two purposes:

(i) To inform activity to improve metrics and data for all indicators;

(ii) To inform energy security risk assessments for all indicators (see Step 2, below).

5.4.2 Step 2: Assess energy security risks

The second step is to assess energy security *risks* using existing indicators and available data. This should reflect both short and long-term perspectives and take note of potential double-counting where indicators are relevant to more than one theme (shown in **Table C**, **Appendix 4**). Risk assessments should also reflect the strength of the data and metrics for that indicator (assessed in Step 1). For example, an indicator may have excellent metrics and high-quality data available that indicate with high confidence, a low level of risk; in terms of a traffic light rating for a dashboard, the indicator could be rated green for risk. If, instead, that indicator appeared to be a low risk but had very poor metrics or data, the overall risk assessment should have a low confidence that should be reflected by an amber risk rating at best.

This assessment should produce a rating for the level of risk for each indicator across all themes and may be presented as a **Risk Dashboard** - at either the level of individual indicators or aggregated to the level of themes (as illustrated in **Table 6**, for both Data and Risk). Aggregating ratings to the theme level does lose important and useful detail. While the use of weightings to aggregate indicators may be unproblematic for a sub-category of indicators (e.g. security of supply indicators), we do not recommend quantitative weighting to aggregate assessments (of data or risk) across whole themes (see discussion in Section 3.3.2). Instead, we concur with previous work [58] [5] that suggests using stakeholder involvement and panels of experts to combine multiple indicators into overall assessments (such as red/amber/green ratings on a dashboard). As the UK moves through the transition, the relative importance of different risks will shift and should be reflected through either formal, quantitative weightings or expert, collaborative judgements. Otherwise, specific methods for producing and aggregating ratings are left for future work.

These energy security risk assessments and Risk Dashboards can serve three purposes:

(i) To inform decision-making in policymaking and implementation;

(ii) To support communicating energy security issues, policy and progress to UK public and other stakeholders;

(iii) To further inform activities to improve metrics and data (as priority should be given to areas where metrics or data are poor and where risk level also appears significant).

In practice, monitoring practises are more active and developed for some areas of energy security than others. Some will require much more intensive assessment and more regular monitoring (e.g. gas security monitoring on a monthly basis), others at a lower level of detail and frequency. These differing monitoring practices can be nested within the larger energy security monitoring framework; equally, the framework could be implemented and developed by different teams focussing on different areas.

Notes to Table 6:

- The table below gives an example of what a combined Data Dashboard and Risk Dashboard at the level of themes could look like. The traffic light ratings and grey text in **Table 6** are purely illustrative – a proper assessment of data, metrics and risks is for future work. In practice, each individual indicator would first be assessed in a much more detailed dashboard.

- The 'Data and Metrics Rating' indicates the strength of existing metrics and data for measuring risks in each theme; they do not indicate energy security risk levels (see Step 1, above).
- The 'Risk Rating' indicates the level of energy security for each theme, as we can assess them currently (see Step 2, above).

TABLE II: Data and Risk Dashboard for the '4+4 Framework' for monitoring energy security ** Mock example **			
Energy Security THEME	**DATA & METRICS RATING** using *Data & Metrics* indicators	**RISK RATING** using available data (and the *Data & Metrics* assessments)	**REASONS for current Data and Risk ratings**
Availability			DATA & METRICS: A wider set of reliability metrics will be needed as system flexibility develops. More data also needed for DSR (both deployment and performance indicators and including the potential for heat pump loads to provide reliable flexibility). RISK: Good security of supply in short-term but changes in both generation and demand may disrupt this in longer-term.
Accessibility			DATA & METRICS: Need better metrics and data for distribution network capacity in context of new heat pump and EV-charging loads and their degree of flexibility. Need for better visibility of pipeline/timelines for grid development projects. RISK: Transmission network needs investment for wind and grid-level storage. Risks for distribution network capacity and connections for heat pumps and EV-charging.
Affordability			DATA & METRICS: Clear data for Government support for bills. Limitations in fuel poverty metrics and costs relative to incomes and cost-of-living. Energy efficiency (EE) data limited and savings from DSR not included. RISK: Support for consumer bills has been very costly for UK Government. Building EE is poor and the cost-of-living context challenging. Higher cost of electricity compared to gas is a risk to other energy security goals (themes).
Acceptability			DATA & METRICS: Generally good data on public attitudes but should be expanded to wider issues. Better data needed on consumer engagement with key technologies and services, including DSR. RISK: Generally good public support for a move to a high-renewables system and more energy independence. Stronger consumer engagement with key technologies and services needed, including DSR, and data lacking.
Sustainability			DATA & METRICS: Good data on carbon. Some specific gaps in other indicators and data (e.g. sustainability of biomass). RISK: Good past progress in cutting the carbon intensity of grid electricity. Keys challenges include reducing gas consumption for heat in buildings.
Independence			DATA & METRICS: Indicators and data sources generally good with several overlaps with *Availability*. RISK: Substantial energy dependencies including power interconnectors and imports of biomass and LNG. Synergies with *Acceptability*; synergies and trade-offs with *Availability.*
Governance			DATA & METRICS: Work is needed to further develop clear metrics and high-quality data for the four categories of *Governance* indicators. RISK: Clear broad goals exist for an energy security strategy but lacking detail for delivery and use of clear, measurable and transparent indicators and processes to support tracking, decision-making and reporting for energy security.
Data & Metrics			DATA & METRICS:† Criteria exist for DQA (e.g. DAMA) but lack clarity for data accuracy, gaps and access, the quality and use of metrics. RISK: A full assessment of data and metrics has not been done but some known limitations. Cybersecurity is a potential threat to *all* data.

† *Data & Metrics* indicators/criteria could themselves be assessed though this may be somewhat circular/reflexive and requires more work.

5.4.3 Complexity

The 4+4 Framework work is relatively complex. We have attempted to assemble a comprehensive and holistic set of indicators and themes for the whole of energy security. It has a total of 72 indicators, plus data sources, tagged against eight themes, and produces separate dashboards for the quality of data and the level of risk. This inevitably means it has a greater degree of complexity than most dashboards but should also help to avoid significant risks being missed and better support decision-making that accounts for trade-offs and synergies.

According to Kruyt et al [16], only a limited number of indicators are used in policymaking. A key point here is that until policymaking processes are made clearer and more transparent, we will not know when the number of indicators becomes unmanageable. The aims of the framework include enabling continued improvement in data and governance: if an energy security monitoring framework fits *too* easily into existing policymaking processes, then perhaps it is not having enough impact in stimulating improvement. Lastly, the complexity might be made more manageable if this framework was implemented in an interactive ICT interface that better supported use cases and user needs.

5.4.4 Future work

As with several previous frameworks (e.g. [10] [63]), this draft framework is a work in progress and would require further work. We have attempted to identify indicators but some are more developed than others and in some cases data sources have not yet been identified (e.g. data for indicators of cybersecurity and *Governance*). We have not carried out the assessment of metrics or data and have not assessed energy security risks (the Data Dashboard and Risk Dashboards in **Table 6** are illustrative only). All these activities would be open-ended activities requiring regular updates.

We hope this draft framework can be the basis for review, and iteration and further development if it proves promising and feasible to potential end-users. We suggest that the first steps would be a more thorough review of indicators, assessing existing metrics and data using the criteria in the *Data & Metrics* theme (as per Step 1, above), and establishing agreed methods for aggregating assessments of data and risk. The sooner limitations in metrics and data are addressed the sooner tracking change over time will be supported. The sooner limitations in metrics and data are addressed the sooner tracking change over time will be supported.

Further developing and implementing the framework would best be achieved through inclusive collaboration among stakeholders and experts. This would better manage the challenges we discuss in Section 3.3 and incorporate diverse perspectives, highlighted by previous work as important for risk assessments.

5.5 Key points

- This chapter has presented our '4+4 Framework' for monitoring energy security. It has outlined our approach to themes, indicators and data that is intended to better support more data-led and transparent policy decision-making, policy evaluation and communication on energy security.
- We use eight themes: '4+4' refers to the four 'A's commonly seen in energy security literature and frameworks (*Availability, Accessibility, Affordability and Acceptability*), plus four more*: Sustainability, Independence, Governance* and *Data & Metrics.* Our somewhat novel approach to themes recognises the inherent issue of fuzzy boundaries by allowing for and highlighting where indicators are relevant to multiple themes, therefore helping to manage risks of double-counting. We have not attempted to devise a set of dimensions that neatly cover all aspects of energy security without any overlaps, and for this reason, we favour the term 'theme' over 'dimension'. Our matrix approach means that indicators are not 'siloed' within themes, which allows flexibility for policy or communication goals: more themes could be added without disrupting the structure of the framework. We have explained our definitions of the eight themes and rationales for inclusion in the framework.
- We have attempted to assemble a comprehensive and holistic set of indicators for the whole of energy security – broader than most previous dashboards. This is to avoid significant risks being missed and to support making trade-offs in decision-making for policy and implementation. Choice of indicators was not influenced by the current availability or otherwise of data. *Governance* indicators have been included, as poor implementation and use of a framework poses risks to energy security.
- We take a systematic and detailed approach to identifying data sources for indicators, as with the SSFP Monitoring Framework [63], and, as for that work, identifying data sources will be an ongoing and collaborative task.
- The framework also incorporates assessment of the availability and quality of data and metrics, as these determine the confidence in any risk assessment and poor metrics or data are themselves risk factors for energy security.
- This chapter has also presented brief guidance for using the framework.
  - **Step 1** is to assess the metrics and data for all indicators, using the criteria in the *Data & Metrics* theme indicators. Accordingly, in **Table C** (**Appendix 4**) all indicators are tagged as relevant to the *Data & Metrics* theme and, in that sense, this theme is unique. Assessments may be used to produce a **Data Dashboard***.*
  - **Step 2** is to then assess all energy security risks using the available data, combined with the assessment of data and metrics to inform confidence. Assessments may be shown in a **Risk Dashboard**. Examples of both dashboards are given with illustrative content.
- The 4+4 Framework is relatively complex compared to most dashboards, but this should also help to avoid significant energy security risks being missed, better inform decisions about

trade-offs, and support improvement in data and policymaking processes. Complexity might be better managed by an interactive ICT user interface.

- We hope this framework can be the basis for review and, if useful to potential end-users, iteration and further development, beginning with a more thorough cataloguing and assessment of indicators, metrics and data. Implementing and further developing the framework would best be achieved through open-ended and inclusive collaboration among stakeholders and experts.

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Appendices

Appendix 1 - Summary of method for review of energy security literature, indices and frameworks

Databases/sources

Databases used were Scopus, Google and Google Scholar. Specific government and industry websites also searched.

Summary of search terms

Keyword categories		
Energy Security	**Measurement**	**Policy evaluation**
energy security security of supply availability accessibility affordability acceptability resilience sovereignty flexibility	metrics measuring/measurement tracking indicators data/datasets …	Assessment/assessing Evaluation/evaluating …

Inclusion/exclusion criteria

i. English language publications.
ii. Both academic peer-reviewed publications (Scopus/Google Scholar) and grey literature (Google).
iii. Year of publication from 2014-present.
iv. Evidence will also include relevant datasets.

Returned results were filtered for relevance based on their title and abstract.

These systematic searches were supplemented by:

- Additional searches on specific websites hosting relevant material.
- Following citation trails.
- The authors' pre-existing library of documents from previous work on energy security and related topics.

Appendix 2 - Table A: Summary of energy security indices and frameworks with dimensions and number of indicators

	Source	**Themes/Dimensions** (may be called sub-indexes or indicator-categories) and **Notes**	No. of Indicators
1.	International Energy Security Risk Index (IESRI) Global Energy Institute/US Chamber of Commerce	Comprises four 'sub-indexes': Geopolitical Risk; Economic Risk; Environmental Impact; Energy Reliability. There are eight categories of metrics (dimensions): Global Fuel; Fuel Imports; Energy Expenditure; Price and Market Volatility; Energy Use Intensity; Electric Power Sector; Transportation; and Environment. Each category is made up of between two and six metrics.	29 metrics: nine are "*universal*" metrics that apply equally to every country and 20 are "*country-specific*"
2.	US Energy Security Risk Index Global Energy Institute/US Chamber of Commerce	Four Sub-Indexes: geopolitical, economic, reliability, and environmental. Nine categories of metrics. Each of 37 metrics is mapped to one or more of these four Sub-Indexes.	37
3.	Energy Transition Index World Economic Forum	Nine dimensions split between two categories. 1. '*System Performance Imperatives'*: Security & Access; Environmental Sustainability; Economic Development & Growth; *2. 'Transition Readiness: Enabling Dimensions':* Capital & investment; Regulation & political commitment; Institutions & governance; Infrastructure & innovation business environment; Human capital & consumer participation; and Energy system structure.	39
4.	World Energy Trilemma Index World Energy Council	Energy security; Energy equity; Environmental sustainability	35
5.	Dynamic Resilience Framework World Energy Council	Five 'sets of capabilities': 1. Baseline reserve: instruments, policies, collaborative networks; 2. Capabilities in situational awareness; 3. Agility and speed of response; 4. Adaptive capacity and flexibility; 5. Regenerative and preventive capacity;	
6.	Energy and Climate Security Risk Index (ECSRI) Centre for the Study of Democracy	Geopolitics; Affordability; Reliability; Sustainability. Geopolitical component centres on metrics such as the security of reserve production. Affordability component focuses on amount ($) spent on importing fuels, as well as associated CO_2 costs.	42

		Reliability component focuses on transportation and infrastructure, as well as per capita usage. Sustainability component focuses on energy intensity, associated emissions and land use.	
7.	IEA (2007), *Energy Security and Climate Policy - Assessing Interactions* International Energy Agency/OECD	Two components: physical Availability of energy; Energy Prices. The report presents two new 'indicators' to illustrate the energy security implications of resource concentration: these make a distinction between the price and physical availability components of energy security.	
8.	ECFR Energy Sovereignty Index European Council of Foreign Relations	Four 'categories' of indicators: Cleanliness, Efficiency, Independence, and Narrative. 'Independence' appears to be limited to 'dependence on energy imports'.	15
9.	Global Energy Vulnerability Index Euromonitor International	Main focus is on Energy Availability. Full index report is behind a paywall but there are six groups or indicator themes, which are as follow: energy self-sufficiency (30% of total score); alternatives to fossil fuels (35%); energy reserves potential (10%); energy accessibility (5%); energy efficiency (10%); economic resilience (10%).	Unknown
10.	Global Energy Architecture Performance Index World Economic Forum	Three dimensions/sub-indices: Environmental impact; Energy access and security; Economic growth and development. Each of these contains six indicators.	18
11.	Energy Security Scoreboard (2023) DiXi Group	This scoreboard has five categories of indicators for '*Institutional preparedness*' (not energy security): Risk assessment and forecasting; Security rules and action plans; Reliability and security reports; Infrastructure and resource adequacy; Energy security statistics. Data for these indicators are assessed using six '*Transparency criteria*': Availability; Accessibility; Relevance; Frequency; Usability; Completeness.	5 Categories of institutional preparedness; 6 transparency criteria
12.	Europe Energy Transition Readiness Index Roland Berger; Siemens Energy	11 Priorities (set by researchers): 1. Accelerate Renewables 2. Implement Energy Storage Solutions 3. Decarbonise Industry (Scope 1,2 and 3) 4. Drive Exit Strategies for Coal 5. Sector Coupling to Decarbonise End-User Sectors 6. Reinvent Energy Business Models 7. Power-to-X Solutions	11

		8. Digitize the Energy Grid 9. Design Emissions Markets 10. Just Energy Transition 11. Drive Carbon Capture & Storage	
13.	Le Coq and Paltseva (2009)	Energy Availability, Energy Infrastructure; Energy Prices	
14.	Sovacool (2011)	Energy Availability; Energy Prices; Energy Affordability; Environmental Impact; Energy Efficiency	200
15.	Sovacool and Mukherjee (2011)	Five dimensions: availability, affordability, technology development, sustainability, and regulation.	52 complex indicators; 320 simple indicators
16.	Vivoda (2010)	11 dimensions: Energy supply, Demand management, Efficiency, Economic, Environmental, Domestic socio-cultural and political factors, Human security, Military–security, Technology, International, Policy,	44
17.	Zhang, Ji and Fan (2013)	Energy Availability; Energy Prices	8
18.	Zhang, Bai, Xiao and Ren (2021)	7 dimensions: Availability and diversity; Affordability; Sociality and equality; Energy infrastructure; Technology and efficiency; Environmental sustainability; Governance.	28
19.	Song, Zhang and Sun (2019)	Energy Availability; Energy Prices; Energy Infrastructure; Environmental Impact; Energy Efficiency; Governance	18
20.	Iyke, Tran and Narayan (2021)	Energy Availability; Energy Affordability; Energy Acceptability; Energy Developability	10
21.	Azzuni and Breyer (2020)	Provides a numerical method to formulate an energy security index that is globally comprehensive, but also nationally applicable to all countries. Proposes 15 dimensions, 50 parameters and 76 indicators.	76
22.	Yu, Li and Yang (2022)	Yu, Li and Yang (2022) reviews the indexes used in academic studies and official reports to quantify energy security levels and observe that: energy security indexes have clearly become more complex, and the focus broader, from simple energy market issues to environmental, technological, and social issues.	NA

23.	Stavytskyy et al (2021)	Six 'groups of indicators': (1) consumption of natural resources; (2) resource depletion; (3) efficient use of resources; (4) attracting new energy sources; (5) pollution due to mining activities; (6) access to resources. Focus is on inter-country comparison. Indicators follow World Bank	29
24.	Benamirouche et al (2022)	Author develops a composite energy security index 'ESIA', on the basis of five indicators: Availability, Affordability, Applicability, Acceptability & Governance.	
25.	Gasser, P. (2020)	Review of energy security indices to compare performances of specific countries. Reviewed 63 energy security indices with respect to their scope, geographical coverage, number of countries analysed, time frame covered, the number of indicators considered, data treatment approach.	NA
26.	Mitchell and Watson (2013) (Ch.11)		13 (comprised of 4 from the DECC, 2012, Energy Security Strategy, plus 9 further indicators)
27.	Fitzgerald (2013) (Annex - *ESMW Dashboard Indicators*)		16
28.	Cox (2016)		22
29.	Cox (2018)	Availability; Affordability; Environmental sustainability; Reliability	17
30.	Watson et al (2018)	Availability and Reliability	7 indicators or 12 indicators when split for fuel type (gas, electricity and biomass).
31.	Burns (2019)	Sustainability, Independence, Efficiency, Affordability and Accessibility	
32.	Ang, Choong and Ng (2015)	Review identified seven major energy security dimensions: energy availability, infrastructure, energy prices, societal effects, environment, governance, and energy efficiency.	NA

33.	Yao and Chang (2014)	Proposed an approach known as the '4 As framework': 1. Availability of indigenous and sustainable supply of natural, extractable, or renewable energy resources 2. Applicability of technologies and infrastructure to economically extract and harness the available energy resources 3. Acceptability of the energy sources' environmental and social impacts and 4. Affordability of the energy sources for the end-user Five indicators per theme giving a total of 20 indicators.	20 (five indicators under each of four 'A's)
34.	DECC (2012) Energy Security Strategy	Four key characteristics or indicators of security for each of the consumer fuels (electricity, gas and oil): Capacity, Diversity, Reliability, and Demand side responsiveness.	4 per fuel type

Appendix 3 - Table B: Indicators and data sources in the *Smart Systems and Flexibility Plan Monitoring Framework*

(Adapted from BEIS [63])

Type of indicator (Chapter of the *Smart Systems & Flexibility Plan*)	**Indicators**	**Rationale for indicator**	**Data Sources**
Facilitating flexibility from consumers	**Indicators in SSFP *Monitoring Framework:*** 1. Proportion of domestic consumers with smart meters (% of total meters) 2. Ultra-low emission vehicles (number of registrations) 3. Heat pump deployment (number of domestic installations) 4. Industrial and commercial demand side response (GW available)	The rollout of smart meters, and the deployment of domestic low carbon technologies are expected to be leading indicators of consumer flexibility. As a higher proportion of consumers own electric vehicles or heat pumps, the opportunity for demand side flexibility increases. Future work could aim to gather information on: - the smart functionality of these technologies - enablers such as smart EV charge points and half-hourly settlement, - consumer behaviour such as take up of smart tariffs.	**GB electricity generation mix and deployment of low carbon flexibility** Energy Trends, BEIS, https://www.gov.uk/government/statistics/electricity-section-5-energy-trends (Table 5.1) Future Energy Scenarios, National Grid ESO, https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents **Facilitating flexibility from consumers** Smart Meter Statistics, BEIS, https://www.gov.uk/government/collections/smart-metersstatistics Vehicle Licensing Statistics, Department for Transport, https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01 (VEH0171) Renewable Heat Incentive Statistics, BEIS, https://www.gov.uk/government/collections/renewable-heat-incentive-statistics
Removing barriers to flexibility on the grid	**Indicators in SSFP Monitoring Framework:** 1. Storage deployment (GW) 2. Interconnection capacity (GW) 3. Storage pipeline (projects at different stages of development and time in pipeline) 4. Size of storage projects (proportion of projects in different MW size bands)	The deployment of storage, as well as the size and duration of projects, provides an indicator of the amount of flexibility available on the system. The pipeline of projects is a leading indicator, showing the potential future deployment of assets, but also the number of projects that are not progressing to operation. We mainly focus on battery projects, as this is the technology with most activity, but there are also pumped hydro storage projects in the pipeline and the potential for novel technologies. Future work should look	Renewable Energy Planning Database, BEIS, https://www.gov.uk/government/collections/renewable-energy-planning-data

	5. Duration of storage projects (proportion of projects in different duration bands – e.g. greater than 1-hour duration	to capture new technologies as they enter the market, including novel energy storage technologies.	
Reforming markets to reward flexibility	**Indicators in SSFP Monitoring Framework:** 1 **Capacity market** (GW of flexible technologies winning contracts and £/MW price achieved) 2 **Balancing mechanism** (MWh of bids and offers from flexible technologies, number of virtual lead parties) 3 **Frequency response** (MW of flexible technologies winning contracts and £/MW/h price achieved) 4 **Distribution-level (DNO) flexibility markets** (MW of tendered contracts, % of technologies winning contracts).	This range of indicators is chosen to cover the main markets in which we expect flexible technologies to be competing. The indicators will track the volume of different flexible technologies participating in each market, as well as information on the prices of key services. By looking across different markets we expect to be able to identify the different business models that technologies are following. There is a lot of change in this area. For example, new ancillary services markets are being developed. Future iterations of the monitoring report will need to capture the changes in markets and could include an assessment of carbon intensity across each market when this information is available.	**Capacity market** Capacity Market Registers, National Grid ESO, https://www.emrdeliverybody.com/CM/Registers.aspx **Balancing mechanism** Elexon via EnAppSys, https://www.netareports.com/ Registered Balancing mechanism units, Elexon, https://www.elexonportal.co.uk/REGISTEREDBMUNITS **Frequency response** Firm Frequency Response (FFR) Post Tender Reports, National Grid ESO, https://data.nationalgrideso.com/ancillary-services/firm-frequency-response-post-tender-reports Dynamic Containment Data, National Grid ESO, https://data.nationalgrideso.com/ancillary-services/dynamic-containment-data **Distribution-level flexibility** DNO Flexibility Tenders, Energy Networks Association, https://www.energynetworks.org/assets/images/ENA%20Consolodated%20Flex%20Figures%202020-PUBLISHED.xlsx
Digitalising the system	No specific indicators or data for digitalisation have been selected for the first iteration of the SSFP monitoring framework. Data and digitalisation actions are expected be to enablers of many of the intended outcomes in the other areas of the plan. Future iterations of the framework could look to identify specific indicators for digitalisation, where outcomes are different to the other actions in the Plan. For example, indicators that could track the number of datasets that have been made available by different organisations and how often these datasets were requested by users. Further indicators could monitor the proportion of distributed assets (e.g. electric vehicles, heat pumps) that are registered in databases, or gather stakeholder feedback on their use of new instruments through the use of surveys.		

List of datasets referenced in the Smart Systems and Flexibility Plan Monitoring Framework

i. GB electricity generation mix and deployment of low carbon flexibility Energy Trends, BEIS, https://www.gov.uk/government/statistics/electricity-section-5-energy-trends (Table 5.1)
ii. Future Energy Scenarios, National Grid ESO, https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents
iii. Facilitating flexibility from consumers Smart Meter Statistics, BEIS, https://www.gov.uk/government/collections/smart-meters-statistics
iv. Vehicle Licensing Statistics, Department for Transport, https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01 (VEH0171)
v. Renewable Heat Incentive Statistics, BEIS, https://www.gov.uk/government/collections/renewable-heat-incentive-statistics
vi. Removing barriers to flexibility on the grid Renewable Energy Planning Database, BEIS, https://www.gov.uk/government/collections/renewable-energy-planning-data
vii. Capacity market Capacity Market Registers, National Grid ESO, https://www.emrdeliverybody.com/CM/Registers.aspx
viii. Balancing mechanism Elexon via EnAppSys, https://www.netareports.com/
ix. Registered Balancing mechanism units, Elexon, https://www.elexonportal.co.uk/REGISTEREDBMUNITS
x. Frequency response Firm Frequency Response (FFR) Post Tender Reports, National Grid ESO, https://data.nationalgrideso.com/ancillary-services/firm-frequency-response-post-tender-reports
xi. Dynamic Containment Data, National Grid ESO, https://data.nationalgrideso.com/ancillary-services/dynamic-containment-data
xii. Distribution-level flexibility DNO Flexibility Tenders, Energy Networks Association, https://www.energynetworks.org/assets/images/ENA%20Consolodated%20Flex%20Figures%202020-PUBLISHED.xlsx

Appendix 4 - Table C: The 4+4 Energy Security Monitoring Framework - indicators, data sources and themes

Table C, below we present the '4+4 Framework' showing 8 themes, 72 indicators and all identified data sources.

Indicators are listed along with their relevant known data sources; relevance of each indicators (and its data) is tagged for relevance to one or more of the eight themes, as shown by an 'X' in the coloured columns on right.

We have also grouped and colour-coded indicators to one theme as much as possible to help the reader navigate the long table. Colour-coding works well for themes such as *Governance* or *Data & Metrics*, for which indicators are tied to one theme only; it is not ideal for indicators that are relevant to multiple themes (this could perhaps be better managed by an interactive ICT user interface).

Table C: The '4+4' Energy Security Monitoring Framework - matrix showing indicators with data sources and relevance to 8 themes *All* indicators are relevant to the *Data & Metrics* theme that assesses the availability and quality of data and metrics									
INDICATOR (with precedents for inclusion)	**DATA Sources**	**Energy security THEMES** (relevant indicators marked with '**X**')							
		Availability	**Accessibility**	**Affordability**	**Acceptability**	**Sustainability**	**Independence**	**Governance**	**Data & metrics**
1. **Energy demand and energy intensity**	UK Energy in Brief UK Energy Consumption Energy Trends UK Historic Energy Demand Data Energy intensity: Annual Business Survey 2019 and Annual Purchases Survey 2018 Energy use: renewable and waste sources Energy use: generation of heat from renewable sources Energy use: total Energy use: by industry, source and fuel Energy Crops Scheme Agreements Energy Use Percentage from Renewable and Waste Sources (Total) Energy Use: Fossil Fuels by Fuel Type Energy Use: Fossil Fuels by Fuel Type and Industry Energy Use: by Industry, Source and Fuel Type Sub-National Total Final Energy Consumption Sub-national electricity consumption data Sub-national Consumption of Residual Fuel	X							X

	Scotland - Scottish Energy Consumption Wales - Domestic Energy Consumption NI - Energy in Northern Ireland See also data sources for Diversity, below.								
2. **Diversity** in energy [10]; in electricity [43] and in fuel [47]	UK Energy in Brief United Kingdom - Energy Profile United Kingdom - Key Statistics Energy Trends (Table 5.1) Digest of UK Energy Statistics (DUKES), Chapter 1, Table 1.1 'Aggregate Energy Balance' UK Energy Flow Chart UK Renewable Power Plants Renewables Obligation: Certificates & Generation Energy from Renewable and Waste Sources (Mtoe) Energy from Non-fossil Fuel Sources (Mtoe) Scotland: Embedded Register (NG ESO, Scotland)/NESO Renewable Energy Sites Scotland Scottish Renewable Energy Development Scottish Energy Resources (Sectoral Marine Plan) Heat Network Locations Scotland (Existing & Planned) Wind Turbine Spatial Framework Renewable Electricity (Scotland) Wales: Hydropower Permits Low Carbon Energy Generation by Technology (Wales) Low Carbon Energy Generation by Local Authority (Wales) Low carbon Energy Generation by Local Authority & Technology (Wales) Northern Ireland: Northern Ireland Renewable Electricity Data Tables Energy in Northern Ireland Offshore Renewable Energy Strategic Action Plan (ORESAP)	X					X		X

3. **Pipeline and timelines for new generation projects** Affected by supply chains for equipment such as transformers.	Data sources TBD	X					X		X
4. **Domestic fossil fuel and biomass production** [43]	See data sources for Diversity.	X					X		X
5. **Import diversity** [47]: energy; electricity; biomass; fossil fuels;	United Kingdom - Key Statistics (Energy Imports/Exports) ACER (2021) Gas Market Monitoring Report DESNZ (2023) Diversity and security of gas supply in Europe, 2022	X					X		X
6. **Import stability** [47] Includes political stability and international relations. E.g. Le Coq and Paltseva's [49] 'Risky External Energy Supply' index uses import shares weighted by political risk.	Relevant to political stability, the World Bank's Worldwide Governance Indicators include a range of indicators (Voice and Accountability; Political Stability and Absence of Violence/Terrorism; Government Effectiveness; Regulatory Quality; Rule of Law; and Control of Corruption)	X					X		X
7. **Import dependency** [47]: energy; electricity; biomass; fossil fuels. Note: Reducing dependency on foreign gas is an explicit priority for the UK Government [3]	UK Energy in Brief (2023) 'Import Dependency', (p. 11)	X					X		X
Reliability standards 8. **1-in-20 and 1-in-50 Security Standard** (gas) [43]	UK Energy in Brief (2023), Reliability, (p.17) UK Energy in Brief (2022), (p. 8) 'Total Inland Primary Energy Consumption' Statutory Security of Supply Report (2021) NESO - Winter Outlook Report UK Historic Energy Demand Data DESNZ Energy and emissions projections Meteorological data: Met Office	X							X
9. **Loss of Load Expectation (LOLE)** for gas and electricity [43] [47]		X							X
10. **System Average Interruption Frequency Index (SAIFI)**		X							X
11. **Loss of Load Probability (LOLP)** (electricity) [69]		X							X
12. **Expected Energy Unserved (EEU)** (electricity) [69]		X							X
13. **Duration of loss of load**. Indicators include: LOLD [69] SAIDI, CAIDI, and CTAIDI.		X							X
14. **De-rated capacity margins/DRCM** (i.e. excess supply above peak demand) [47]	Embedded Capacity Register – WPD Embedded Capacity Register (UKPN) Generation Capacity Register (WPD) Monthly Operational Metered Wind Output	X							X
15. **Oversupply** [47]	Monthly Operational Metered Wind Output	X							X
16. **Response and reserve/STOR** [47]	Data sources TBC	X							X

17. **Frequency Response** [47]		Data sources TBC	X							X
18. **Power system operability and restoration** [52]		Data sources TBC	X							X
19. **Infrastructure reliability and resilience** (incl. generation, transmission, distribution, and storage equipment failure as well as system-wide interoperability) [43] [10]		Data sources TBC	X	X						X
20. **Critical minerals supply chains and resilience** [58] ***Depletion*** of materials, critical minerals and rare earths could also be viewed as an environmental sustainability issue [47] [107] so we have also marked this indicator as also relevant for our *Sustainability* theme.		CMIC (2024) UK 2024 Criticality Assessment HM Gov (2022) *The United Kingdom's Critical Minerals Strategy* Task & Finish Group Report (2023) *An analysis of sector risks and recommendations for the UK's supply chain resilience* (wind, solar, nuclear, hydrogen) IEA's *Global Critical Minerals Outlook 2024* *UK Criticality Assessment*, UK Critical Minerals Intelligence Centre/BGS	X	X			X	X		X
Flexibility - Consumers [63]	***Deployment*** indicators [63] for resources/assets and their smart functionality. Several of these deployment indicators are also indicators of public engagement so are also indicators for *Acceptability*. 21. **Deployment of smart meters** (proportion of domestic consumers; location, functionality)	Smart Meter Statistics, DESNZ	X			X				X
	22. **Deployment of electric vehicles** (number, location, charging functionality/characteristics)	Vehicle Licensing Statistics, (VEH0171; VEH0132; VEH0133; VEH0171; VEH0172), Department for Transport	X			X				X
	23. **Deployment of heat pumps** (number, smart functionality, location)	Heat Pump Deployment statistics MCS data Low Carbon Technologies Connected to UK Power Networks/UKPN	X			X				X
	24. **Deployment of home energy management systems** (HEMs) (Number, smart functionality, location)	Data sources TBC	X			X				X
	25. **Uptake of smart time-of-use tariffs and other flexibility services** (e.g. Demand Flexibility Service/DFS).	Data sources TBC	X			X				X

	26. **EV charge-points**: number; if public/ home/business; functionality (e.g. bi-directional); distribution/location; and use.	National Chargepoint Registry (NCR) Electric vehicle public charging infrastructure statistics	X	X						X
	Performance of DSR resources [63]: 27. **Aggregated response** from residential consumers and small businesses (GW available and as % of demand). DSR has an important time-varying aspect that may require season-specific and time-specific figures. E.g. in winter, overall demand will rise for heating but the % of demand that is flexible may drop.	Aggregated impact of the Demand Flexibility Service (DFS)	X		X	X				X
	28. **Aggregated response from industrial and commercial DSR** (GW available and as % of demand)	Data sources TBC	X		X	X				X
Flexibility - Grid-level [63]	29. **Electricity interconnector capacity** (GW) [47] [43] [63]	Spatial Datasets (UK Electricity Supply Areas)	X	X						X
	30. **Grid-level storage deployment** (GW): electricity [47]; fuel reserves (e.g. gas); other (e.g. thermal)	Data sources TBD	X							X
	31. **Storage projects pipeline** Affected by supply chains for equipment such as transformers.	Renewable Energy Planning Database (REPD), DESNZ	X							X
	32. **Size of storage projects** (proportion of projects in different MW size bands)	Spatial Datasets (UK Electricity Supply Areas) Green Recovery Power Map	X							X
	33. **Duration of storage projects**	Data sources TBD	X							X
Flexibility - Markets to reward flexibility [63]	34. **Capacity market** (GW of flexible technologies winning contracts and £/MW price achieved) *Ofgem's Flexibility Platforms in electricity markets* may suggest some further indicators for conditions that would assist innovation and the development of competitive markets for flexibility	Capacity Market Registers, NESO	X							X
	35. **Balancing mechanism** (MWh of bids and offers from flexible technologies, number of virtual lead parties)	Elexon via EnAppSys Registered Balancing mechanism units, Elexon	X							X
	36. **Frequency response** (MW of flexible technologies winning contracts and £/MW/h price achieved)	Firm Frequency Response (FFR) Post Tender Reports, NESO Dynamic Containment Data, NESO	X							X

	37. **Distribution-level (DNO) flexibility markets** (MW of tendered contracts, % of technologies winning contracts)	DNO Flexibility Tenders, Energy Networks Association	X							X
Flexibility – Digitalisation [63]	38. **Digitalisation** No specific indicators or datasets for digitalisation have been selected for the first iteration of the SSFP Monitoring Framework.	Data sources TBD See outputs from the Energy Digitalisation Taskforce (EDiT) and IcebreakerOne. See also: BEIS' *Digitalising our energy system for net zero: Strategy and Action Plan 2021* and Ofgem's *Digitalisation Strategy and Action Plan, Supporting Information*	X							X
	39. **Cybersecurity** risk indicators. Possible indicators: number of security incidents; mean time to detect (MTTD); mean time to respond (MTTR); cybersecurity regulations. ¥ As for all indicators, Cybersecurity is tagged as relevant to the *Data & Metrics* theme. However, insofar as cybersecurity is a risk to data storage, it poses a potentially serious threat here that *could affect data for all indicators across all themes.*	Data sources TBD	X	X						X¥
40.	**Workforce skills gaps**. May act as bottlenecks (e.g. shortage/anticipated shortages of adequate numbers of skilled workforce for heat pump installers, large generation and transmission infrastructure and grid-level storage projects).	Data needs to be improved but green jobs data includes the ONS LCREE and EGSS. Data on skills demand (e.g. NESTA's Open Jobs Observatory/OJO) and current or anticipated skills gaps is less good.	X	X				X		X
41.	**Infrastructure reliability and resilience** (including generation, transmission, distribution, and storage equipment failure as well as system-wide interoperability) [43]. See [32] for discussion. Impacts on infrastructure (e.g. from extreme weather damage) could have secondary impacts on public acceptance (*Acceptability*).	Data sources TBC. Weather data Met Office. Better data needed on emerging increased risk posed to energy infrastructure from extreme weather events (e.g. storm/flooding) [58] - also needed for security of supply estimates (in *Availability*).		X						X
42.	**Risk to physical infrastructure from accidental damage and sabotage** E.g. of accidental damage: Balticconnector in 2023. E.g. of sabotage: Nord Stream pipelines in 2022. Accidents and sabotage could potentially also affect generation assets.	Data sources TBC.	X	X						

43.	**Pipeline and timelines for transmission/distribution infrastructure development**. Affected by supply chains for equipment such as transformers.	Renewable Energy Planning Database, DESNZ GIS Boundaries for Grid Supply Points Heat Networks Planning Database (HNPD) Scotland Heat Map Spatial Datasets (UK Electricity Supply Areas) Green Recovery Power Map		X						X
44.	**Investment indicators for transmission grid development** [110] [112]	Data sources TBC UK Energy In Brief Digest of UK Energy Statistics		X						X
45.	**Investment *risk* indicators** [32] [58] Applies to all infrastructure including generation, transmission, storage. The *Energy Investment Risk Assessment* [55] has three risks to investment: Unpredictable policy and regulatory change; Discrimination between domestic and foreign investors; and Breach of State obligations. An indicator for 'regulatory stability' is also highlighted by Axon, Darton and Winzer [32].	Data sources TBC.	X	X						X
46.	**Coverage/access to district heating networks**.	Heat networks pipelines Heat Networks registered under the Heat Network (Metering and Billing) Regulations (ONS) Opportunity areas for district heating networks in the UK: second National Comprehensive Assessment Heat Network Locations (Existing and Planned) - Scotland		X						X
47.	**Local grid capacity for heat pump installations**. Upgrades of the distribution grid and home fuses for heat pumps installations are not automatic, even at current low levels of penetration, and there are no standards of service [108].	TBC but likely from DNOs.		X						X
48.	**Energy Efficiency** in housing Note: Existing EE metrics (EPC ratings) and methods (SAP and RdSAP) are flawed. Greater measurement and use of real-world outcomes is recommended to improve metrics and data quality.	National Energy Efficiency Data Framework (NEED) Non-Domestic National Energy Efficiency Data Framework (ND-NEED) Household Energy Efficiency Statistics Green Homes Grant Voucher & Installation Statistics Green Homes Local Authority Statistics Energy Savings Opportunity Scheme (EOS)	X		X		X	X		X

Energy efficiency data for *heat pump performance* (i.e. COP or SPF) should be of increasing value, as energy demand for heat is large and heat pump performance (SPF) can vary considerably.	Energy efficiency of Housing, England and Wales, country and region Energy efficiency of Housing, England and Wales, cumulative financial years Energy efficiency of Housing, England and Wales, local authority districts Scottish Domestic Energy Performance Certificates Scottish Non-Domestic Energy Performance Certificates Energy Performance of Buildings Certificates in England & Wales								
49. **Energy costs to consumers** Indicators may include: - fuel cost factors - annual electricity bills [47] - Mobility/transport costs: public transport and vehicle TCO (risk of double-counting with fuel cost factors, e.g. for EVs vs ICE vehicles)	Energy Prices Weekly Road Fuel Prices UK Energy Trends & Prices Renewable Heat Incentive (RHI) & Renewable Heat Premium Payments Number of energy consumers and average income and energy expenditure for individuals in rented households, UK, financial year ending 2018 Green Homes Grants Local Authority Northern Ireland Household Energy Expenditure: Income Differences and Non-Discretionary Impacts Northern Ireland household domestic energy expenditure 2013-15 to 2018-20 Northern Ireland business energy purchases provisional estimates 2016 to 2018			X					X
50. **Fuel poverty** [47] [58] Existing metrics: *Fuel Poverty Energy Efficiency Rating* (FPEER); *Low Income and Low Energy Efficiency* (LILEE); *Fuel Poverty Gap*. Depth (severity) of fuel poverty is also measured using the FPEER and criteria for 'severe'/'persistent' and 'extreme' fuel poverty. UK nations use different metrics. Improvements needed in the energy efficiency metrics also used for fuel poverty. Additional possible indicators include number of households in arrears with fuel bills [86] and low internal temperature/thermal comfort [87] [88] [89].	Fuel Poverty Statistics (England) - DESNZ English Housing Survey – DLUHC/MHCLG Sub-Regional Fuel Poverty Statistics GLA Fuel Poverty Dataset Scotland - Scottish House Condition Survey Wales - Fuel Poverty Estimates for Wales NI - Housing Condition Survey (N. Ireland)			X					X

	51. **Cost/affordability of technology adoption for consumers**, e.g. heat pumps [114], EVs and energy storage devices (both installation and cost-of-ownership)	Solar PV Cost Data Need better data on heat pump installation costs [115] and running costs [116].			X					X
	52. **Costs of UK Government support for energy bills and technology adoption** (EPG, EBSS, EBRS, ECO, BUS, other subsidies and grants)	OBR's Forecast evaluation reports (for bills support) Green Homes Grants Local Authority			X					X
	53. **Energy wholesale costs**	Gas Price Volatility Index (Ofgem)			X					X
	54. **Levelised cost of generation** (LCOE) [47]	Data sources TBD			X					X
	55. **Network upgrade cost** [47] (Risk of double-counting with financial value of DSR to avoid network reinforcement)	Data sources TBD (source from DNOs)		X	X					X
Public attitudes, engagement and resistance	56. Public support for/opposition to the ***UK mix of energy sources/fuels and technologies***, on the basis of environmental impacts, costs, health and safety, privacy, visual disamenity (e.g. NIMBY), jobs, or other co-benefits or concerns ('Approval ratings of generation mix' included [47] under 'Availability' dimension)	DESNZ Public Attitudes Tracker DESNZ Energy Efficiency and Net Zero Tracker (under development) Where needed suggest adding to DESNZ tracker surveys.				X				X
	57. Public support for/opposition to ***dependence on energy imports***.	Data sources TBD – suggest adding to DESNZ tracker surveys				X				X
	58. Public support for/opposition to ***source of imports*** of energy and materials (incl. geopolitical concerns and secondary impacts on global markets).	Data sources TBD – suggest adding to DESNZ tracker surveys				X				X
	59. Public support for/opposition to ***infrastructure development***, e.g. pylons.	Data sources TBD				X				X
	60. **Indicators for Environmental, Social and Governance (ESG)** with respect to governments/companies involved in UK supply chains.	Data sources TBD but metrics exist for ESG				X				X

61. **Carbon intensity and GHG emissions** [47] NB. Risk of double-counting emissions.	Historic Generation Mix & Carbon Intensity Final UK Greenhouse Gas Emissions Statistics Energy and Emissions Projections					X			X
62. **Water usage** [47]	Data sources TBD See datasets in the *Outcome Indicator Framework for the 25 Year Environment Plan* [126]					X			X
63. **Biodiversity impacts**, e.g. from logging, other land use/habitat impacts, bird kills, oil spills, …). From 2025, biodiversity net gain requirements will begin to apply to Nationally Significant Infrastructure Projects (NSIPs) which includes the energy sector.	Data sources such as UK Biodiversity Indicators 2024 may be hard to link to energy-related activities. Environmental Impact Assessments may provide more useful assessments e.g. Offshore Energy Strategic Environmental Assessment (SEA). For other indicators and datasets see datasets in the *Outcome Indicator Framework for the 25 Year Environment Plan* [126] and work in UKERC Theme 4, e.g. [104] [146].					X			X
64. **Pollution** (air; waterways, coastline and seas; radiation emissions; noise; …). Precedents include Stavytskyy et al [107], who have indicators for 'pollution due to mining activities'. Attributing pollutants to specific sources and gauging the impact of energy-related activities is unlikely to be straightforward. Looking at the health impacts of energy-related pollution would also be complex but could include UK public health data on the burden of illness/disease, and the financial costs of this. We suggest that future development of this draft framework could include a 'Health and Safety' sub-theme within the *Sustainability* theme to reflect actual impacts and keep pace with evolving concerns.	Air pollution: UK AIR; National Atmospheric Emissions Inventory; PHOF; London Datastore Water pollution: DEFRA water quality data archive; and SEPA data. Noise: Noise exposure data; Scotland's Noise Environmental Noise Mapping; Noise maps; London Datastore For other indicators and datasets see datasets in the *Outcome Indicator Framework for the 25 Year Environment Plan* [126] and work in UKERC Theme 4, e.g. [104] [146]. Tracking the health impacts of environmental pollution would entail a broad set of data.					X			X
65. **Natural resource *depletion*** [47] Example: deforestation. Notes: - Depletion in critical minerals is covered by its own indicator (*Critical minerals supply chains & resilience*). - Risk of double-counting resource depletion with security of supply chains.	Data sources TBD. For other indicators and datasets see datasets in the *Outcome Indicator Framework for the 25 Year Environment Plan* [126].	X				X			X

66. ***Rules, action plans and reporting.*** Precedents: [38] [58] [121]	Metrics and data sources TBC. Action plans evidenced by Government publications, legislation and regulation.							X	X
67. ***Inclusive stakeholder participation*** *in decision-making.* Precedents: [58] [55]; included by Cox [47] as 'Participation in decisions' under an 'Availability' dimension.	Data sources TBD. Mitchell and Watson [58] recommend a cross-governmental inter-departmental forum on energy which meets regularly.				X			X	X
68. ***Intra-governmental coordination and inter-ministerial cooperation*** in decision-making. Precedents: [55]	Indicators TBC but may include those from: Worldwide Governance Indicators (WGI) such as 'Government Effectiveness'; and the Regional Authority Index (RAI).							X	X
69. ***Transparency*** [38] [58] ***and anti-corruption measures*** *for decision-making.* Precedents: [35] [58] [67] [136] [135] [42] and the *UK Critical Minerals Strategy* [137]. The *Energy Investment Risk Assessment* (EIRA) framework [55] covers anti-corruption issues and transparency in public procurement processes.	Some existing indicators such as: - the World Bank's Control of Corruption Indicator (CCI); - UK Anti-Corruption Strategy (metrics to be developed by the Joint Anti-Corruption Unit); - OECD Anti-Bribery Convention; - Open Government Partnership (OGP) Anti-Corruption Working Group, such as open contracting							X	X
70. ***Assessment of Metrics (fitness for purpose, validity, accuracy, reliability and transparency)*** These indicators provide criteria for assessing limitations in metrics used (e.g. fuel poverty metrics not reflecting volatility in energy retail prices). Precedents: Broadly, these indicators are similar to 'Energy security statistics' within the Energy Security Scoreboard [38]. GEI's *Index of U.S. Energy Security Risk* includes transparency *"in data derivations and manipulations".*	These *Data & Metrics* indicators are used to assess the availability and quality of metrics and data for *all* indicators. These assessments are summarised in our Energy Security *Data Dashboard*. The data sources for assessing metrics are *all the metrics and associated methods listed for all indicators and all themes.* NB. the fitness-for-purpose of these *Data & Metrics* indicators could itself be assessed, but the criteria used for assessing them risks becoming somewhat circular/reflexive and will require more work.	X	X	X	X	X	X	X	X
71. ***Assessment of Data Availability and Access.*** Precedents include data 'availability' and 'access' in DiXi Group's Energy Security Scoreboard [38]. This should highlight data *gaps* (which are not included in the Data Quality Assessment, below)	The data sources are *all the data sources listed for all other indicators.*	X	X	X	X	X	X	X	X
72. ***Data Quality Assessment (DQA)*** Assessed using the DAMA data quality dimensions [95], as recommended by the UK Government Data Quality Hub and National Data Strategy's Data Quality Framework: *Accuracy, Completeness, Uniqueness, Consistency, Timeliness, Validity*,	The data sources are *all the data sources listed for all other indicators.*	X	X	X	X	X	X	X	X

and *User Needs*). 'User needs' should include assessment of whether the metrics and data are fit for tracking a Just Transition (i.e. if includes information on *distribution* - geospatially, socio-economically and by other relevant characteristics).									
	Number of indicators relevant to theme	48	17	13	16	10	12	7	72