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Credible and comprehensive? Comparing policy mixes for Local Energy systems in England, Scotland and Wales

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ABSTRACT

Integrated Local Energy Systems (LES) are being pursued internationally as a component of net zero, with additional benefits to regions and communities. This paper develops and tests a policy mixes approach to examine differential development of LES policies over 11 years in the three political jurisdictions (England, Scotland and Wales) which comprise Great Britain's (GB) single energy market. The analysis contributes to knowledge about the strengths and weaknesses of the policy mixes concept as an analytical tool for exploring divergence in devolved governments. It also considers the likely effectiveness of these policy mixes for stimulating LES developments in practice. Analysis of over 50 policy strategies and 105 policy instruments is used to evaluate the credibility of the policy mixes, ie. whether these are believable and reliable, and their comprehensiveness, ie. whether all market, system and institutional failures are addressed. The policy mix in England exhibits fluctuation and short-termism, making it the least credible. Strategies in Scotland and Wales demonstrate a more credible and ambitious policy mix for LES, including long term policies and new instruments added over time. However, limited political powers mean that the policy mixes in Scotland and Wales are less comprehensive than in England, making the realisation of LES uncertain. Further, none of the policies are designed to challenge systemic interdependencies of GB's liberalised and largely centralised energy system. This ultimately limits capacity to deliver LES and highlights the need for policy development, in GB and elsewhere, to encompass regulatory and institutional innovation to realise LES benefits.

1. Introduction: Local Energy Systems for decarbonisation

Locally integrated systems for heat, power, mobility, storage and flexibility services are being pursued internationally because of their potential to facilitate a whole system transition to net zero greenhouse gas emissions (see for example [1–3]). Integration at local or regional scale is expected to improve the whole system economics of clean energy by optimising use of distributed electricity generation and storage, combined with demand side flexibility, alternative heating technologies, and upgrades to thermal performance of buildings. In addition, locally integrated systems are expected to contribute co-benefits in the form of local prosperity through revenues from renewable generation and energy services, jobs, economic regeneration, and better health and welfare resulting from cleaner air, insulated buildings and more affordable energy bills.[1] Research commissioned by Innovate UK[2] has indicated that place-based approaches to climate change could be both lower cost and bring greater financial and social returns than blanket, national-level policy alone [4]. Specifically, Local Energy Systems (LES) could reduce consumer energy costs and save £1.7 billion of system costs per year through reduced need for electricity network investment [5].

Decentralised energy systems are already well-established in European countries such as Germany and Denmark, where local and regional governments have more autonomy, including tax-raising powers, and historical continuity in ownership of public utilities ([6,7]). Similarly, the federal system in the United States has enabled states such as California and New York to support decentralised energy, beyond commitments at Federal Government level [8]. How LES develop and their particular configurations are hence likely to be contingent on

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[1] For example, see: https://www.ukri.org/our-work/our-main-funds/industrial-strategy-challenge-fund/clean-growth/prospering-from-the-energy-revolution-challenge/ and https://neweconomics.org/2002/11/plugging-the-leaks.

[2] The UK's national innovation agency.

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constitutional divisions of central and sub-state powers and responsibilities.

Major questions remain about whether more localised energy systems can be realised in liberalised, centralised markets and how policies might vary in different regions. This paper contributes to answering these questions by examining LES policy developments and their likely significance in the unique case of the British liberalised single energy market. Within Great Britain (GB), devolved government in Scotland and Wales enables policy divergence, despite sovereignty of the UK Parliament with reserved powers over energy markets, taxation and regulation [9]. In addition, this paper tests the strengths and weaknesses of a policy mixes approach for comparative analysis within a single state. Analysis of the elements of policy strategy and instruments is combined with metrics to describe the characteristics and nature and qualities of LES policy mixes. This contributes further to development of relevant literature in this journal (see, for example, [10]) through testing and exploring the power of policy mix concepts for comparative analysis of a complex, emerging policy area, rather than specific technologies (e.g. electric vehicles) or sectors (e.g. energy efficiency).

In Britain, multiple definitions of LES, and questions about their role in decarbonisation, have emerged [11–14]. LES are broadly defined by the geography of generation and supply assets, and are expected to encompass interconnected technical and social domains, including governance, business structures, regulatory principles, finance and social justice. Lack of a working consensus beyond this broad characterisation indicates the continuing contested status and negotiability of developments, with political support and purposes varying over time and across different governments. Devolved government in GB provides a valuable natural experiment for research on 'the ebb and flow of government support for different modes of decentralised energy provision' ([11] p.985). The paper therefore asks:

In what ways do emerging policy mixes for Local Energy Systems differ across Great Britain? What are the implications of any variation for likely effectiveness of LES policy?

Answering these questions provides an essential step in evaluating how policies for LES differ over time and political jurisdiction, and subsequently evaluating the likelihood of realising LES for energy decarbonisation. The next section examines potential for energy policy divergence between GB's different political jurisdictions. Section 2 explains the policy mixes concept, and notions of credibility and comprehensiveness used to inform analysis. Section 3 details the method used to apply and test the policy mixes approach, including specific parameters used to compare policies across England, Scotland and Wales, before the results are presented in Section 4. The discussion in Section 5 explores divergence across England, Scotland and Wales and reflects on policy mix analysis as a tool for understanding this. The Conclusions highlight the implications for material progression of LES, suggestions for further developing the policy mixes concept, and recommendations for policy makers.

1.1. UK devolution of powers and the potential for policy divergence

Britain has a centralised energy system, including an extensive methane gas grid and large-scale fossil fuel electricity generation. Scotland, Wales and England participate in a single energy market, with common taxation and regulatory standards. Significant policy and regulatory innovation would be needed to catalyse investment in locally-integrated systems, and to realise local social, health, environmental and economic benefits.

UK devolution agreements in 1998 established parliaments, or assemblies, in Scotland, Wales and Northern Ireland, in addition to the Westminster Parliament. UK devolution is considered highly permissive of policy variation: first, different structural arrangements, legislative and executive powers were negotiated for each devolved government; second, block grant funding for devolved governments does not have stringent ties to UK Government objectives [15]. Powers not explicitly reserved to the UK Parliament are presumed to be devolved.[3]

Powers over regulation, licensing and tax of energy *supply* in England, Scotland and Wales are reserved to the UK Parliament, but *demand* side policy powers relating for example to energy efficiency, are more diffuse. There are also many fully devolved powers relevant to energy systems development, including economic development, land use planning and consents, environment and climate change law, local government and taxes, housing and building standards. In combination, this creates scope for policy innovation and divergence, for example in Scotland the energy efficiency of buildings has been defined as an infrastructure priority [16].

Welsh energy policy making was initially restricted by limited legislative powers [17]. The Wales Act 2017, however, enables the Senedd (Welsh Parliament) to make laws on all matters not explicitly reserved to the UK Parliament, thus aligning more with Scottish devolution. Welsh governments have also developed distinctive environmental policies, fundamental to greenhouse gas reduction, by using secondary and executive powers. Action on clean energy is exemplified in the Well-Being of Future Generations (Wales) Act 2015, and its use to influence energy-related strategies ([18], p.1187).

Thus, formally devolved powers create scope for sub-state policy innovation and variation for LES. In this paper we test policy mix concepts for the analysis of policies relevant to LES in England, Scotland and Wales, and consider the possible differential impacts of these on material development of LES.

2. Theory: policy mixes for Local Energy Systems

2.1. Analysing policy mixes

The term 'policy mix' has been variously defined, with descriptions including "that set of government policies which, by design or fortune, has direct or indirect impacts" on innovation ([19] cited in ([20], p.1621), and "complex arrangements of multiple goals and means which…develop incrementally over many years" ([21], p. 395). It has been suggested that such mixes can incorporate a combination of policy instruments developed within an overarching strategy [22], but might also emerge more organically with little strategic direction, or amidst a changing strategic context. The unsettled nature of the concept led Rogge & Reichardt ([20], p.1621) to take a "first step" towards an extended, interdisciplinary policy mix concept, while also recognising the challenge of "operationalising" it. This offers a valuable starting point for characterising the complex of policies relevant to the emerging LES field, and this paper therefore adopts and tests Rogge and Reichardt's [20] framework for complex LES policy mixes.

Rogge and Reichardt ([20], p. 1627) suggest that a policy mix comprises three building blocks (see Fig. 1): *elements*, *characteristics*, and *processes,* whilst *dimensions* captures the "space within which interactions" between building blocks occur (i.e. the parameters of any empirical investigation). *Elements* include policy strategy and instruments, *characteristics* describe the nature and performance of a policy mix, whilst *processes* seeks to capture political problem solving underpinning policy development. Our analysis focuses on *elements* and *characteristics* as a basis for a comparative framework to explore the empirical distinctions between policy mixes emerging across GB. The definition of elements and characteristics is elaborated in Sections 2.2 and 2.3, whilst Section 3 outlines how they are operationalised, including the *dimensions* for the study.

The *processes* component goes some way to addressing the messy and non-linear nature of policy development by capturing the political problem-solving entailed in development and delivery of strategies and instrument mixes [20]. However, this assumes that capturing such processes is always feasible. In reality, it is difficult to capture the

[3] Referred to as the reserved powers model.

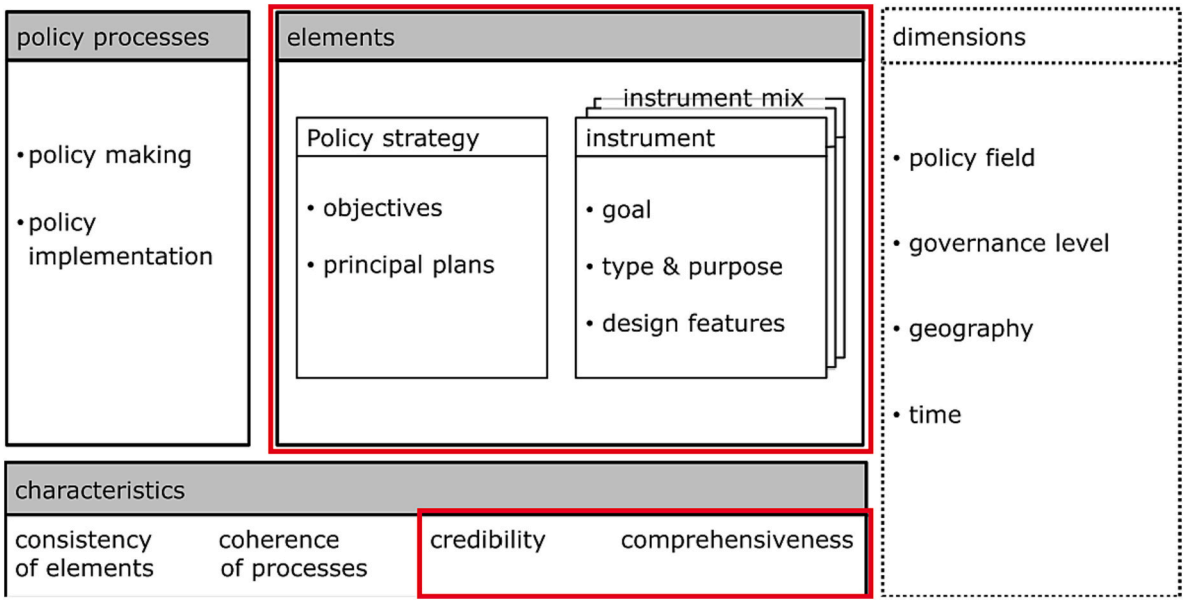

Fig. 1. Building blocks of the policy mix concept, indicating the aspects assessed in this study (adapted from [20]).

negotiations and tensions at play in the development of an incrementally emerging (and rarely pre-defined) instrument mix, especially for a policy field such as LES that represents a long-term systemic shift in an incumbent energy system. This paper therefore focusses on analysing the current state of LES policy processes in the form of strategy, instruments and their characteristics.

2.2. Elements: instrument mix and policy strategy

Policy instruments are the tools or techniques of governance [23] that translate objectives into action (such as regulations, financial incentives, pilot schemes). Developing LES, with their cross-sector incorporation of multiple technologies and aspects of society, is especially likely to require varied, but inter-related, policy instruments. As such, this analysis specifically focuses on the *instrument mix* as a key element of the LES policy mix. The importance of a varied mix of instruments has been highlighted by analyses of renewable energy technologies [24] and energy efficiency policies ([10,25]). These authors argue that although individual policy instruments, like a specific funding scheme, can be core to particular aims, achieving low-carbon transition objectives is reliant on embedding multiple instruments within a broader policy mix ([10], p.2).

A second key element is the *policy strategy*, which can be explored through identification of policy objectives (for example, long-term targets) and principal plans, or the paths that governments propose for achieving their objectives (this might include roadmaps and strategic action plans) [20]. *Policy strategy* is a particularly important consideration for comparative studies. Such studies have primarily considered different states with discrete political systems (e.g. [26,27]), however emerging policy mixes are "likely to depend on both the geographical scale at which policies are designed to impact and the level of government responsible" ([28], p.3). It is therefore particularly valuable to consider potential divergence or similarity in *policy strategy* among Britain's devolved governments. This is particularly significant for LES where the emphasis is on coordination across energy vectors for achieving integrated local energy system objectives.

2.3. Characteristics: credibility and comprehensiveness

Characteristics can be used to describe the nature and performance of a policy mix; this offers a useful device for describing and comparing the LES mixes emerging across different jurisdictions. Rogge and Reichardt ([20], p.1632) suggest that *characteristics* comprise: consistency of elements, coherence of process, credibility and comprehensiveness. They, however, note that "some of the components [of the policy mixes framework] lack well-established indicators, which may complicate their investigation in empirical studies" and they do not provide a specific method for evaluating policy mix characteristics. Our analysis therefore draws on additional research to develop a method for evaluating LES policy mix characteristics, focussing on the dimensions of *credibility* and *comprehensiveness* where an empirical approach to evaluation is proposed (as detailed in Section 3).

Credibility can be defined as the extent to which the policy mix is believable and reliable ([20], citing [29]). Credibility may play an important role in effectiveness of a policy mix [10], but the evaluation of credibility is also subject to judgement. Multiple ways to assess credibility have been suggested, for example, through exploring commitment from political leaders [24] and operationalization of targets [30].

The *comprehensiveness* of a policy mix can be determined by the degree to which it addresses all market, system and institutional failures ([31,32]). A comprehensive instrument mix would therefore address technology-push, demand-pull and systemic-concerns [20], for example, spanning policies that support the research, development and deployment (R,D&D) of innovative technologies, alongside those encouraging investment in them. For LES, this idea is helpful for considering whether cross-sector, social and technical factors are supported through emerging policy mixes.

Coherence of process is not analysed in the paper, as it relates to whether policy-making processes are synergistic. As described in 2.1, developing systematic analysis of the complex *processes* involved in ongoing policy areas is particularly challenging, and is therefore excluded. *Consistency* seeks to capture potential contradictions or synergies between policy instruments, with Rogge & Reichardt [20] suggesting that this could be assessed through interaction analysis. Process for practically assigning interactions to complex, nascent policy mixes where instruments span scales, sectors and political jurisdictions are, however, lacking. Additionally, analysing interactions between large numbers of policy instruments, such as the 105 included in this analysis, is particularly difficult. Consistency is therefore also excluded from our empirical assessment. We return to the challenges of operationalising policy mix characteristics in the discussion.

The policy mix parameters taken forward for analysis are

Table 1
Policy mix building blocks and the parameters considered in this analysis.

Policy mix building block	Parameter for analysis	Definition applied for this analysis
Elements	Policy strategy	Objectives, long-term targets, action plans
	Policy instruments	Tools of governance: specific policies, programmes and measures
Characteristics	Credibility	Reliability, established through stability and temporal consistency of policy mix
	Comprehensiveness	Ability of policy mix to address range of market, system and institutional aspects.

summarised in Table 1.

3. Method: data collection and analysis framework

3.1. Analytical scope and identification of policy instruments

Scholars have used a variety of methods to develop insights into policy mixes, and "no universally appropriate 'policy mapping' approach exists" ([22], p.2). A systematic identification of policy mix *elements* requires setting the *dimensions* (see Fig. 1) of the analysis, including: defining a timeframe; specifying the geographical focus; and identifying relevant governing entities [20]. Following this principle, analysis started from Scottish, Welsh and UK Governments' overarching energy strategies. Although LES could take shape through policy making at regional and local government levels, this focus on central government policies has been selected to provide an indication of the emerging country-wide policy landscape. An 11-year period (2010−2021) was selected to capture earlier policies supporting growth of distributed renewables (a core foundation of LES), alongside more recent policy developments. Given the potential cross-sector remit of LES, numerous sector-specific strategy documents could feed into development. Resource and feasibility limitations have however restricted this analysis to publicly available overarching energy strategies, alongside strategies specifically concerned with 'local', 'community' or 'area-based' energy. In addition, although transport could be an important aspect of LES, the sector has been excluded in order to create a manageable analytical strategy. LES dimensions analysed are distributed energy generation, energy efficiency and low carbon heat. This resulted in detailed analysis of over 50 policy documents (listed in Appendix A), and identification of 105 policy instruments across the three jurisdictions (see supplementary materials). Documentation has been retrieved primarily from Scottish, Welsh and UK Government websites.

Details about individual instruments were then collated using government sources (for example, evaluation reports), or websites of managing organisations. If financial information about an instrument was obscure, Freedom of Information (FOI) requests were submitted to establish additional detail,[4] but financial information for some instruments remained unclear. The authors each cross-checked the instrument database drawing on their expertise in Scottish, Welsh and UK Government energy policy. The instrument database was also verified through review by two external policy experts. One expert had experience across Scottish and UK Government energy policy, the other specialised in Welsh and UK Government energy policy. The external experts were asked to evaluate: the completeness of the overall database, the relevance of policies listed, and the accuracy of information listed for each instrument.

[4] For different instruments, FOI requests asked for information on: total funding promised at policy announcement and total funding actually allocated. FOI requests were submitted to: Welsh Government, Scottish Government, Ofgem (who noted that they did not hold financial information about the requested scheme); and UK Government Department for Levelling Up, Housing and Communities and Department of Business, Energy & Industrial Strategy (who had still not responded at the time of writing).

3.2. Establishing parameters for assessing credibility and comprehensiveness

Although credibility and comprehensiveness have been defined (see Section 2), specific techniques for evaluating them based on document analysis are less clear. Therefore, a technique providing both quantitative metrics and qualitative assessment of each characteristic has been developed by combining the parameters outlined below.

Credibility can be evaluated by studying stability and temporal consistency of the policy mix, alongside commitment from political leadership [20]. Here, stability and temporal consistency is measured through evaluating *duration* of policy instruments, which includes looking at both the number of policy instruments over time, and how long they are retained for. Since LES represents a systemic shift covering multiple sectors, it is likely that longer-duration policies will help to provide certainty to communities, investors and developers. The significance of the number of instruments is subject to interpretation (e.g. is a large number good, or does it indicate proliferation of policy without overarching strategy?), and so the results couple this with qualitative review of policy strategy narratives and specific policies. Commitment from political leadership is difficult to evaluate; this analysis uses *policy strategy*; *delivery mechanisms* and *budget* as proxies. Analysis therefore includes consideration of: the setting of long-term targets (*policy strategy)* and the identification of funding source and managing organisation (see Appendix C for definitions, and [33] for use of managing organisation to evaluate credibility) (*delivery mechanisms*). There is ambiguity here: the delegation of competencies to independent managing organisations could infer both stable, long-term policy support, but also the transfer of risk and responsibility without equivalent resources. However, for LES, where a diverse range of actors and technologies are involved, it is likely that a more diverse range of delivery organisations adds to credibility. Whilst budget information was sought for all policy instruments, for many schemes this data was ultimately incomplete, or the final budget allocated was not available.

For analysing comprehensiveness, or the degree to which the instrument mix addresses market, system and institutional aspects, this paper combines *balance* with *technology-specificity*. Schmidt & Sewerin ([26], p.3) define *balance* as 'the dispersion of policy instruments across different instrument types', and develop a technique to quantify this by looking at the mix of *instrument types* over time. Balance is calculated using the 1-Simpson Index (also called the Gini-Simpson Index):

$$\sum_{\text{instrument type}_{m=1}}^{M} p_i^2 = 1 - \frac{\sum_{\text{instrument type}_{m=1}}^{M} (\text{instruments}_m * (\text{instruments}_m - 1))}{\sum \text{instruments} * ((\sum \text{instruments}) - 1)}$$

Equation 1: The 1-Simpson Index used for calculation of balance across instrument types.

Here, $Instruments_m$ represents the number of policy instruments of $type_m$. The index ranges from 0 to 1, with an index of 1 indicating 100 % likelihood that all instruments will be different types. A lower index means it would be more likely that instruments would be the same types. Thus, to calculate balance for each year, two analytical parameters are required: *policy instrument type* and *total number of instruments*. The categorisation of instrument types has been adapted from Schmidt & Sewerin [26], who draw on definitions from the International Energy Agency [34]. The adaptations used here seek to avoid overlap in some

IEA categories, and incorporate common policy mechanisms that may support LES (for example, Research, Development & Deployment (R, D&D)). The definitions used for each instrument type are provided in Appendix B. The balance calculations for Scotland and Wales incorporated all instruments active within those countries. For example, the Welsh calculation includes both UK Government schemes that are active in England and Wales, and schemes introduced by Welsh Government. The calculations for England only included schemes introduced by UK Government, since those from Welsh and Scottish Governments are not applicable in England.

Comprehensiveness is additionally assessed by studying *technology-specificity*, ie. whether policy instruments focus on a specific technology, a broader sector, or are economy-wide. This aspect of the analytical framework is drawn from Schmidt & Sewerin [26] and allows for consideration of whether different technologies and tiers of support are incorporated; for example, high technology-specificity may encourage the emergence of new technologies, whilst sector- and economy-level tier support may advance more mature technologies. Schmidt & Sewerin [26] suggest that a comprehensive mix would include a balanced range of policy instrument types across a variety of tiers; the significance of addressing varied tiers is unclear for LES, which spans a range of technologies and sectors, but can also be developed using already established technologies (such as district heating infrastructures). A description of each of these parameters, along with the specific categories used for analysis, is detailed in Table 2.

4. Results: how Local Energy Systems policy mixes vary across England, Scotland and Wales

This section presents an assessment of the credibility and comprehensiveness of LES policy mixes in England, Scotland and Wales.

4.1. England

4.1.1. Credibility

England shows the most **fluctuation** in instruments over time (see Figs. 2a and 4). Following the publication of a series of strategies supporting community-scale renewables: the *Microgeneration Strategy* (2011); *Future of Heat* (2011); *Community Energy Strategy* (2014) and *Future of Heat Strategy* (2014), instruments relevant to LES increased between 2010 and 2015, peaking at twenty-seven. However, a number of these instruments were subsequently closed, reflecting a broader trend towards policy instruments with short-term **duration**. This is evident in the number of policy instruments active for three years or less (18 across the analysis period), with only three instruments active throughout the full period.

Fewer policy instruments relevant to LES were introduced after 2015. For example, aside from a feasibility study of local flexibility trading, *Upgrading our Energy System* (2017) does not detail any policy instruments that might support LES. Instead, it commits to 'assess[ing] the case for more proactive communications on smart energy, combined with strong engagement via local and community organisations' ([35], p.27). There is an increase in total instruments relevant to LES towards the late 2010's, with 31 instruments in place by 2021. For example, a core mechanism to deliver the *Industrial Strategy* was the Industrial Strategy Challenge Fund. Particularly relevant to LES, Innovate UK secured Challenge Funding for the Prospering from the Energy Revolution (PFER) programme (2018–2022), which seeks to develop world-leading local smart energy systems [36]. However, in 2021, the Industrial Strategy was closed, whilst the *Clean Growth Strategy* was superseded by the *Net Zero Strategy: Build Back Greener* and *Build Back Better: Our Plan for Growth*. These focus on infrastructure investment (for example City and Growth Deals oriented to road building, housing and regional regeneration) and large-scale energy infrastructure (offshore wind, nuclear, and hydrogen) rather than integrated local or community energy systems.

In 2021 the **managing organisation** for the majority, 79 %, of policy instruments in England was a central government department. Some longer-term instruments, such as Salix Finance, have been overseen by non-departmental public bodies. However, central government funding was withdrawn from managing organisations like Energy Saving Trust England and Carbon Trust in 2012. Additionally, the Catapult Network was initially run by Energy Systems Catapult as a non-departmental public body; however, with reduced central government support this is now a not-for-profit company which raises funding from government grants, research & development bodies and commercial contracts. Complex management models have emerged for recent schemes. For example, there are five Net Zero Hubs in England covering multiple Local Enterprise Partnership regions. They were governed by public and private sector representatives, along with the BEIS Local Energy Team.[5] England also has the only instance of a policy with a private sector managing organisation: the Heat Networks Investment Project (HNIP; 2019–2022) provides loans and third party financing via Triple Point, an asset management company.

There is evidence of a deliberate shift towards programmes which combine public and private **funding sources**, based on the argument that this will enable quicker innovation and crowd in private investment [37]. The 2017 *Clean Growth* and *Industrial Strategies* highlight the need for private-sector investment in LES and significant initiatives such as the UK Infrastructure Bank and the Prospering from the Energy Revolution programme combine UK Government funding with private sector funding.

4.1.2. Comprehensiveness

The average **balance** of instruments in England varies from 0.84 to 0.89, which demonstrates the inclusion of a variety of instrument types throughout the analysis period. The use of Grants and Subsidies peaks between 2014 and 2018, but declines with the closure of a number of grant programmes directed towards community energy generation towards the 2020's. The use of Regulatory Instruments has also declined over time, with the Community Energy Saving Programme (2009–2012) and Feed-in-Tariffs (2010−2020), which both supported community-scale electricity generation, now closed. Instead, there is an increase in the use of other instrument types, including Framework Policies (e.g. Heat Network (Metering and Billing) Regulations 2014; Cities and Local Government Devolution Act 2016), Public Investments and RD&D.

Since 2020 there has been an increase in Public Investments, specifically, the allocation of funds to Local Authorities for action on heat decarbonisation. This includes the Green Homes Grant: Local Authority Delivery Scheme (2020−2022), the Public Sector Decarbonisation Scheme (2020–2025) and the Social Housing Decarbonisation Fund (2020−2023). The remit of these schemes is set by central government; local authorities support delivery, with the emphasis on energy efficiency and boiler upgrades. Meanwhile, R,D&D instruments relevant to LES include Prospering from the Energy Revolution (2018–2022), the Whole House Retrofit Innovation Competition (2019–2020) and Building a Market for Energy Efficiency: Demonstration Project (2018–2021). Although these can provide insight for developing LES, R,D&D funding is often short-lived and does not necessarily result in subsequent action.

Instruments relevant to LES in England also incorporate a range of technology specificities (Fig. 3a). Technology-field tier instruments dominate the 2013–2016 period; this reflects policy instruments supporting community-scale renewable technologies (announced in community energy strategies 2011–2014), and includes: the Urban Community Energy Fund (2014–2016), Rural Community Energy Fund

[5] Central government funding was withdrawn from Local Enterprise Partnerships in August 2023 and it is unclear whether the new Department for Energy Security and Net Zero (DESNZ) has any role. See: https://www.gov.uk/government/publications/transfer-of-local-enterprise-partnership-lep-core-functions-to-combined-and-local-authorities.

Table 2
Design features for top-down analysis of policy documents and the characteristic that each design feature helps to evaluate. Developed based on [20,26].

	Design feature	Description/ analytical categories	Characteristic design features contribute to
Analytical scope	Timeframe for analysis	2010–2021	N/A
	Policy Strategy	Considers: narrative framing of the strategy, target-setting and rationale for opposition and support. Includes: overarching energy strategies and strategies concerned specifically with 'local', 'community' and 'area-based' energy.	Credibility
Analytical framework	Managing Organisation	Central government department; Non-departmental public body; Charity; Not-for-profit company; Private sector; Public Sector Partnership; Public-Private Partnership	
	Funding source	Public; private; combination of public & private	
	Budget[a]	Funding promised at policy announcement and total funding allocated by government to date/end of scheme.	
	Duration	Classified as 0–2 years, 3–5 years, 6–10 years, >10 years, Ongoing.	
	Technology specificity	Economy-tier – (potentially) affects all sectors and their technologies; e.g. information campaigns; broad taxes. Sector-tier – targets climate-relevant technologies associated with a particular sector of the economy; e.g. focusing on power generation, transmission, but not energy efficiency/buildings Technology-field-tier – targeting or applying to particular categories of technologies within a sector e.g. specifically targeting renewable power generation Technology-tier – policies that focus on a single technology; e.g. Feed-in-Tariffs for specific technologies	Comprehensiveness
	Policy instrument type	Education and outreach Fiscal Framework policy Grants & Subsidies Loans & third party finance Public investment Regulatory instruments Research, Development & Distribution	Balance - contributing to assessment of both credibility and comprehensiveness over time

[a] Although efforts were made to collect information about budget for each policy instrument, this information remained incomplete. As such, budget is not included as a parameter in the Results section.

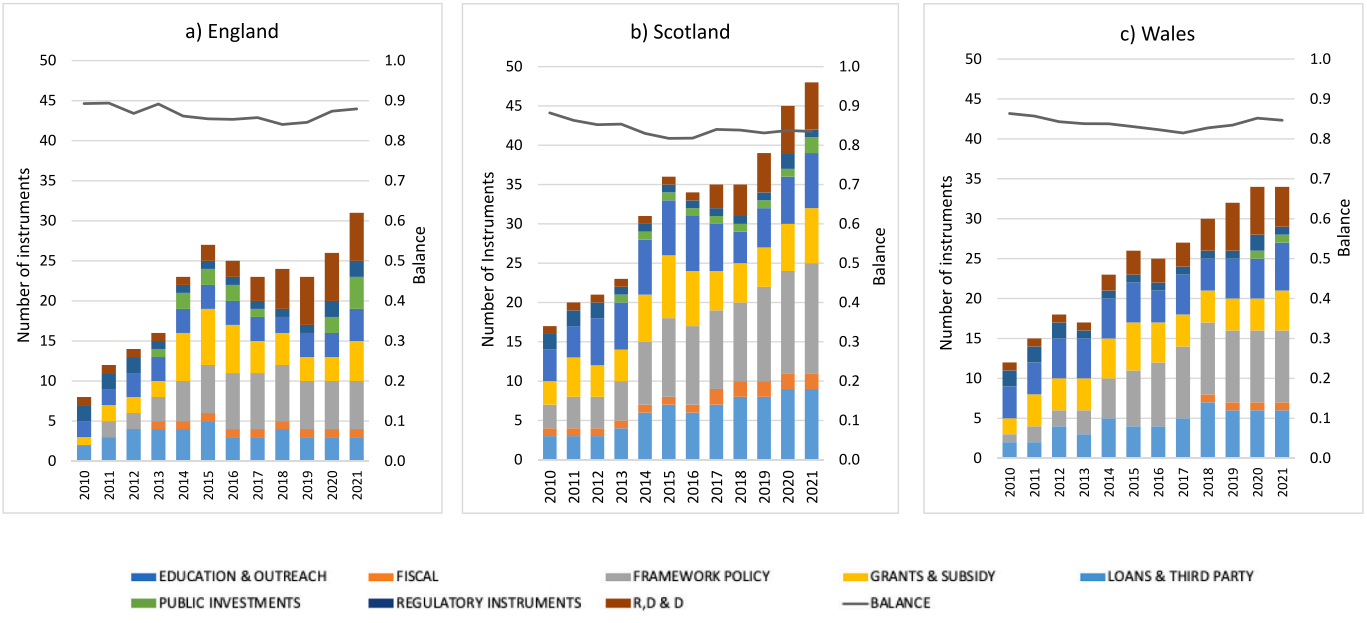

Fig. 2. LES instrument mix and balance, 2010–2021, for a) England, b) Scotland and c) Wales. The total number of instruments is indicated on the left-hand axis. The overall balance (the dispersion of policy instruments across different instrument types) of different instrument types is indicated by the value on the right-hand axis.

(2014 – Ongoing), Community Energy Saving Competition (2014–2015), Community Energy Contact Group (2012–2015), Community Energy Peer Mentoring Fund (2013–2015), Community Energy Unit (2014–2015). Use of technology-field instruments declined with closure of most of these in 2015/16. Use of technology-tier instruments has subsequently increased. These support individual technologies, including heat networks, through the Heat Networks Investment Project (2019–2022) and Green Heat Network Fund (2021 – launched 2022), and renewable energy generation through Contracts for Difference (onshore wind and solar; 2021 – Ongoing) and the Smart Export Guarantee (2020 – Ongoing).

4.2. Scotland

4.2.1. Credibility

Overall, Scotland has the highest number of policy instruments supporting LES, reaching 48 by 2021 (see Fig. 2b). In addition, and despite being affected by closure of schemes at UK Government level,

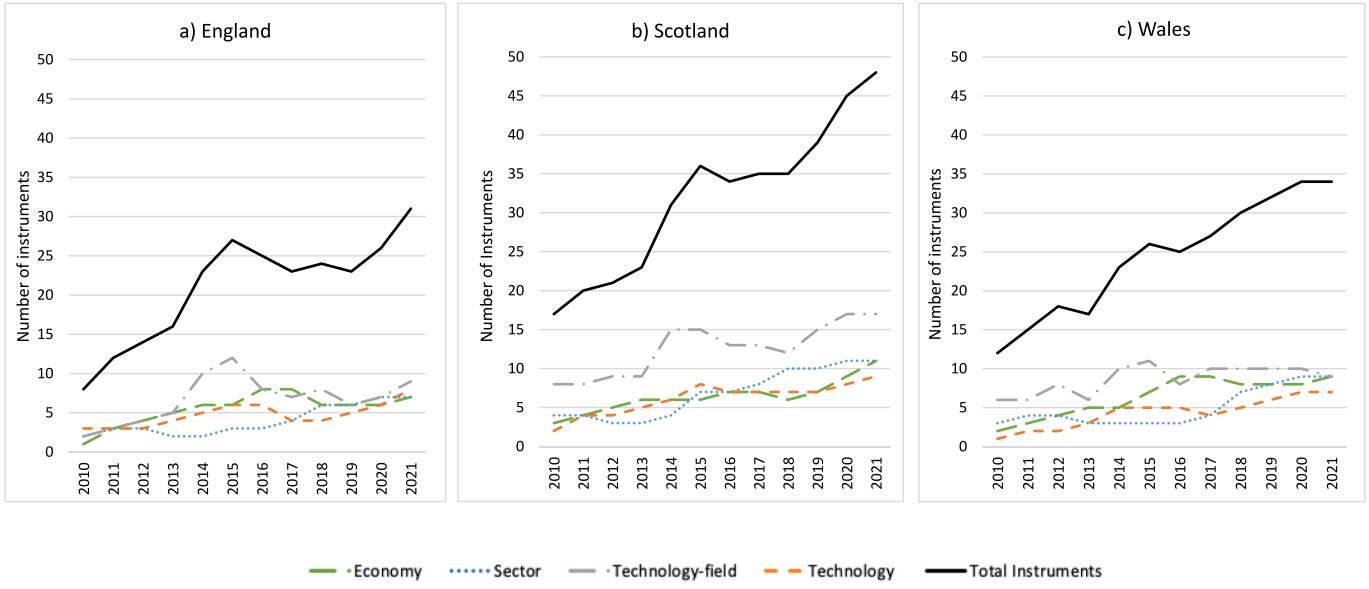

Fig. 3. Technology specificity of LES instrument mix, 2010–2021, for a) England, b) Scotland and c) Wales. Technology specificity is whether policy instruments focus on a specific technology, a broader sector, or are economy-wide. The total number of instruments is indicated by the solid line.

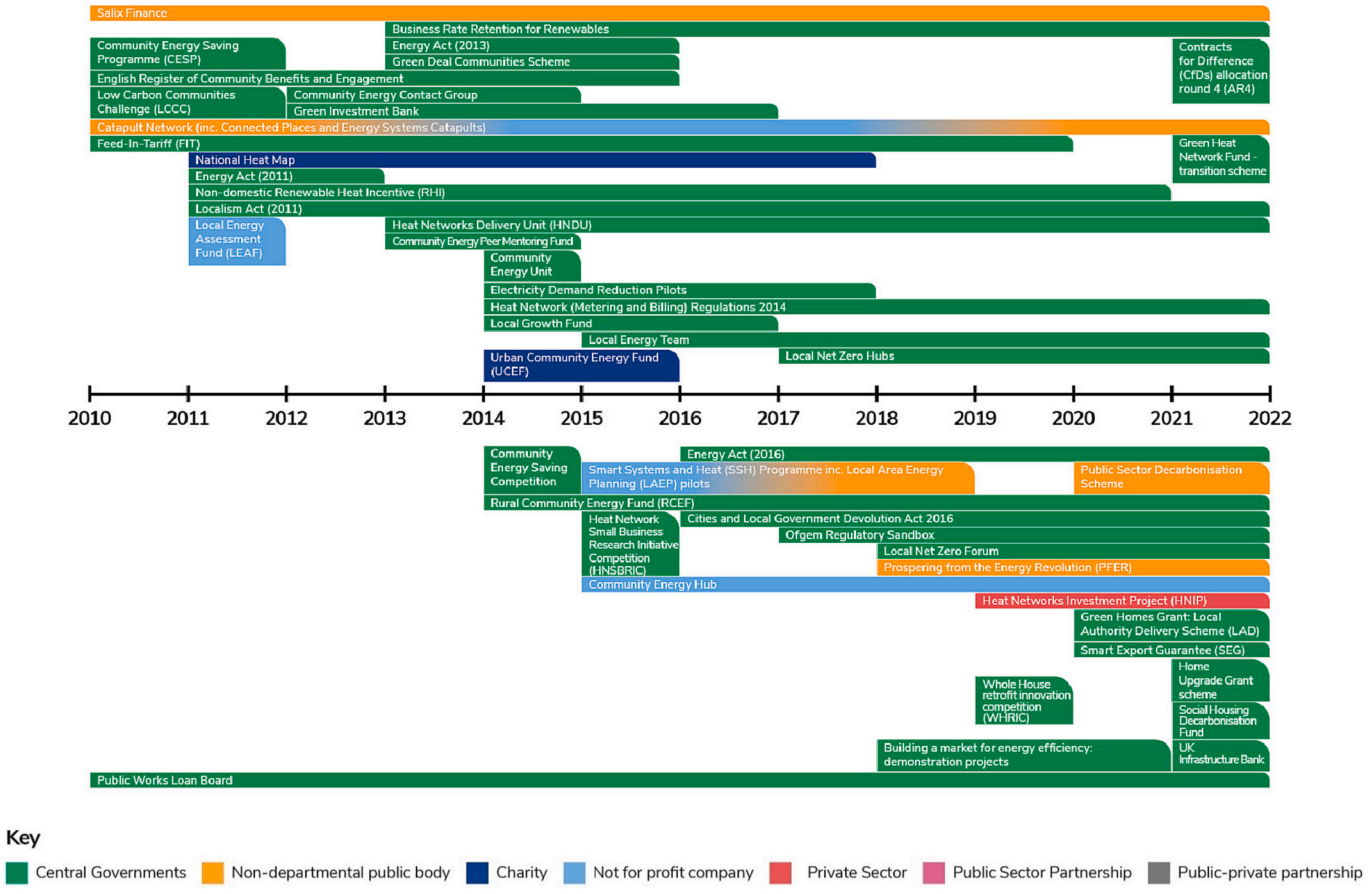

Fig. 4. England policy instrument timeline and managing organisation. Policy instruments with more than one colour indicate management by more than one organisation, or an organisation that falls into two categories.

there has been **consistent growth** in the number of instruments over time. This suggests that Scottish Government were introducing LES policy instruments at a rate which countered decline at UK Government level. It also reflects a degree of stability in Scottish Government's policy instruments for LES. Scotland has the highest proportion of instruments with a **duration** of 10 years or more, with 29 % of instruments in 2021 in place for 10 years or more (see Fig. 5). In contrast this number is 26 % in Wales and 19 % in England.

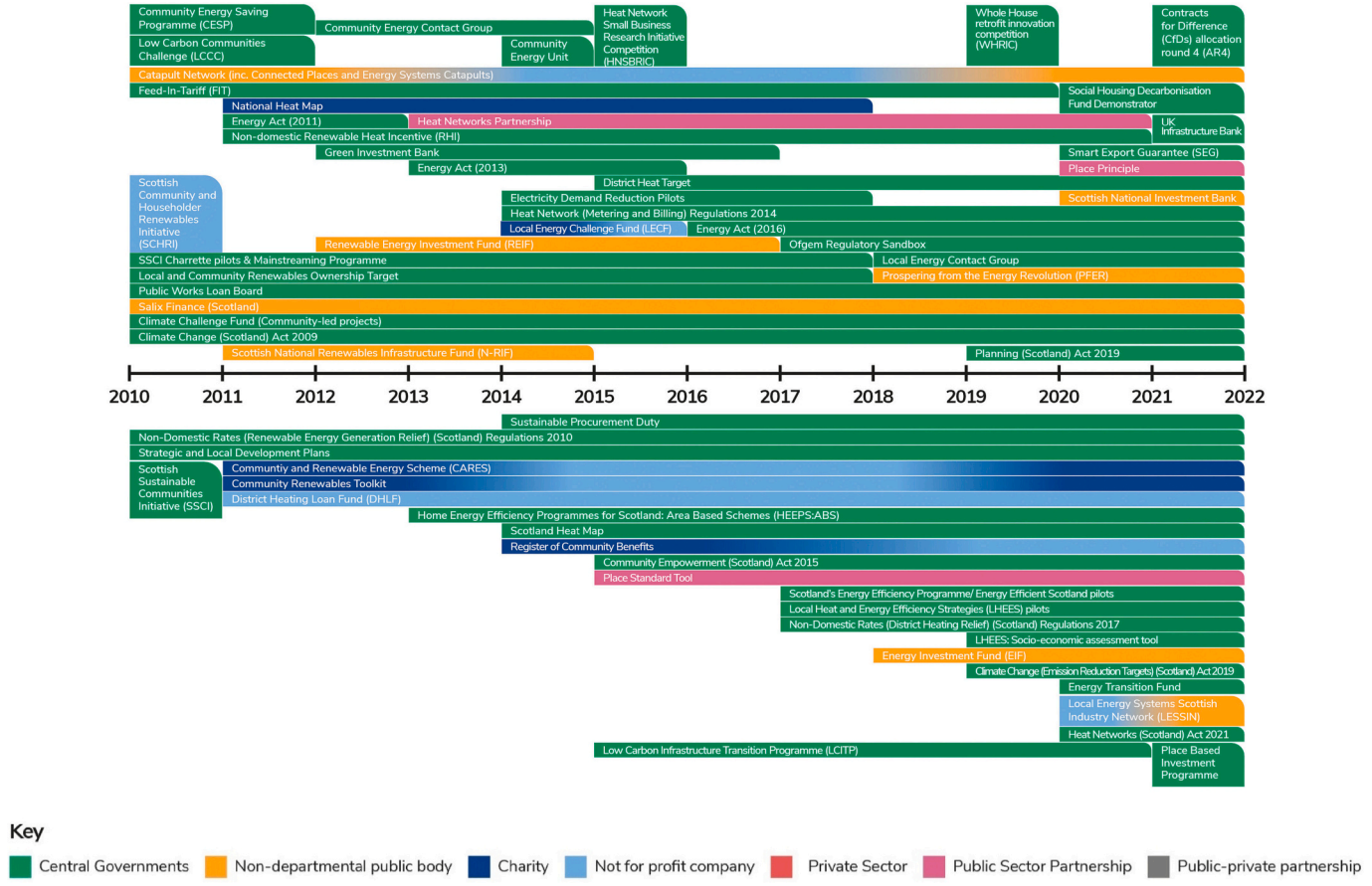

Fig. 5. Scotland policy instrument timeline and managing organisation. Policy instruments with more than one colour indicate management by more than one organisation, or an organisation that falls into two categories.

There was a particular increase in policy instruments following publication of Scotland's first Energy Strategy in 2017, and strategy documents show a developing narrative around community and local energy. For example, 2014's *Community Energy Policy Statement* focused on 'locally-owned energy' and policy instruments in the early 2010's support small-scale generation owned by community groups and small local businesses. This narrative quickly shifted towards local systems integration, with the 2015 *Infrastructure Investment Plan* identifying areas of 'value' including: 'linking local energy demand with local renewable energy generation' and 'delivering renewable heat and electricity to local consumers' ([38], p.78). The Scottish Government emphasised their commitment to local systems integration and explicitly recognised the different physical characteristics, ambitions and priorities of local areas in 2021's *Local Energy Policy Statement,* which defined LES as:

> [Energy systems] which link the supply and demand of energy services within an area across electricity, heat and transport, deliver real value to everyone in local areas, and support the growth of vibrant, net zero economies. ([39], p.2)

Like England, the majority of relevant policy instruments in Scotland designate central government as the **managing organisation**. However, there is more variety in types of organisation designated. For example, Scotland is the only GB country where public sector partnerships are being used to develop mechanisms relevant to LES, including the Place Principle (Framework Policy) and Place Standard Tool (Education and Outreach). Not-for-profit companies and charities are also managing organisations for more instruments than in England. For example, since 2011 Local Energy Scotland (a consortium of charities) has administered the Scottish Government Community and Renewable Energy Scheme (CARES) (Grants and Subsidy; Loans and Third Part Finance) and the Community Renewables Toolkit (Education and Outreach).

Similar to England there is evidence of increasing emphasis on blending public and private sector **funding sources** to deliver LES. The 2017 *Energy Strategy* is explicit about the desire to commercialise local energy systems for private investment and the *Local Energy Policy Statement* (2021) re-iterates that Scottish Government is seeking to create commercially-viable solutions, and attract private investment [39]. This is supported by five policy instruments which draw on private, as well as public, investment: the Scottish National Investment Bank, the former Renewable Energy Investment Fund,[6] the District Heat Loan Fund, the Heat Network Partnership and the Energy Investment Fund.[7]

4.2.2. *Comprehensiveness*

The **balance** for Scotland follows a slight downward trend, from 0.88 to 0.84, over the analysis period. This is slightly lower than the UK balance, despite the full range of policy instrument types being utilised over time. The lower balance is largely attributable to a higher proportion of Education and Outreach and Framework Policy instruments in Scotland. In 2021 there are 9 and 14 instruments in these categories respectively, compared to 3 and 6 in England. There is a notable increase

[6] This later became the Energy Investment Fund and now seems to have been subsumed into the Scottish National Investment Bank

[7] A new £300 million Heat Network Fund was also announced in 2022; the fund aims 'to stimulate commercial interest, investment and maximise Scotland's vast potential in the low carbon sector' - https://www.gov.scot/publications/heat-network-fund-application-guidance/.

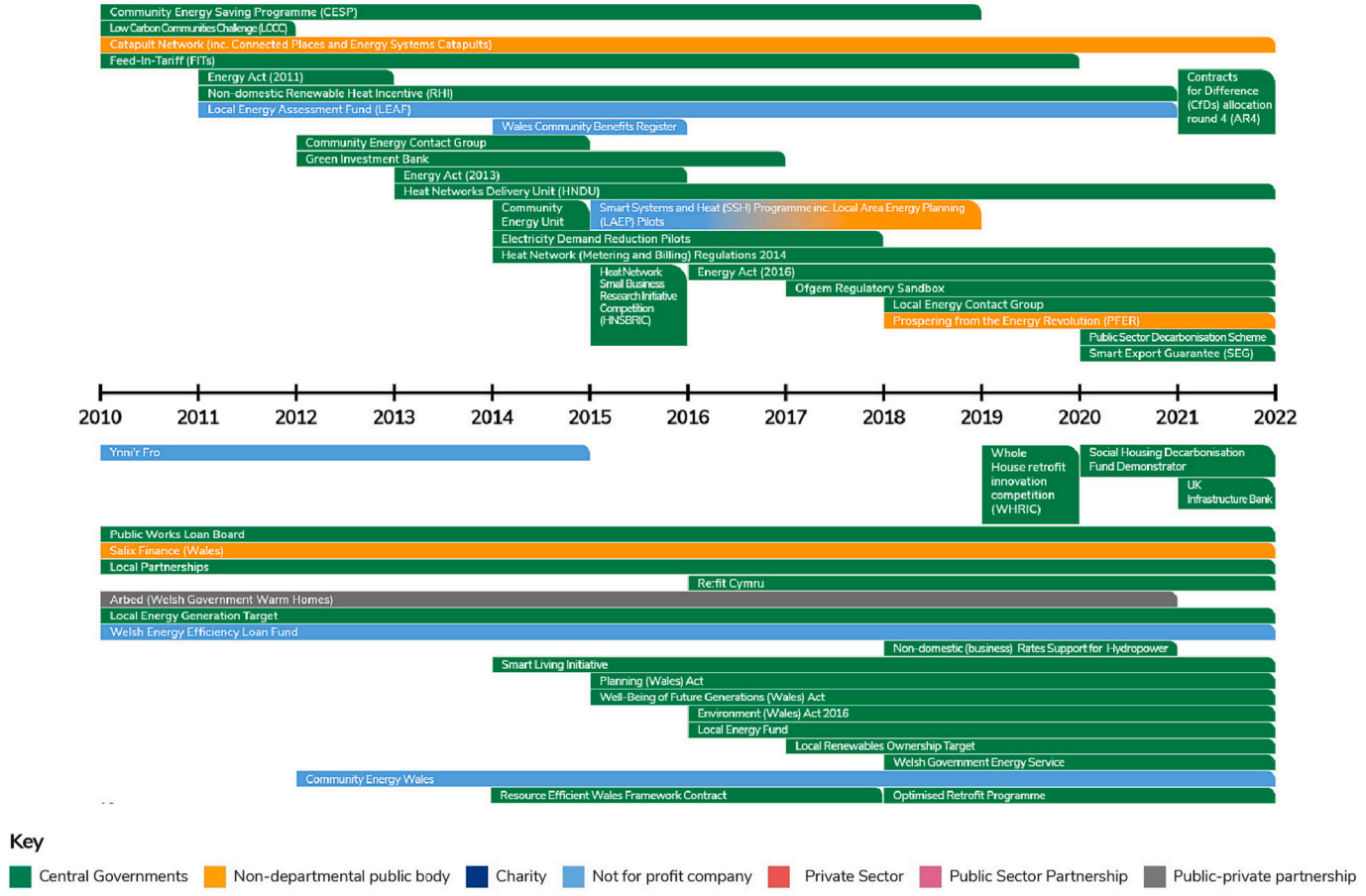

Fig. 6. Wales policy instrument timeline and managing organisation. Policy instruments with more than one colour indicate management by more than one organisation, or an organisation that falls into two categories.

in the use of Framework Policy instruments over time with a jump from three in 2010 to fourteen in 2021. Additional Scotland-specific Framework Policies from this time include: Community Empowerment (Scotland) Act 2015; District Heat Target (2015); Place Principle (2020) and; Heat Networks (Scotland) Act 2021. Such instruments provide direction to support decision making. For example, the Place Principle provides 'a collective focus to support inclusive and sustainable economic growth, while creating places which are both successful and sustainable' ([40], p.15), although this is an advisory Framework Policy, rather than a legal obligation. However, it has been used to underpin decisions made in *A National Mission with Local Impact: Infrastructure Investment Plan for Scotland 2021–22 to 2025–26*. There is also an increase in R,D&D instruments from one to six between 2010 and 2021. This represents a combination of Scottish Government instruments like the Energy Efficient Scotland and Local Heat and Energy Efficiency Strategy (LHEES)[8] pilots (both 2017 – Ongoing) and UK Government R,D&D programmes that apply in Scotland.

Instruments covering a range of **technology specificities** are also employed in Scotland, although technology-field tier instruments dominate throughout the period (see Fig. 3b). Analysis shows use of a range of instrument types providing complementary support. For example, technology-field tier instruments to support community renewables include: Local and Community Renewables Ownership Target (Framework Policy; 2011); Community Energy Contact Group (Education & Outreach; 2012–2015); CARES (Grants and Subsidy, Loans; 2011 – Ongoing). A similar approach has been used to support district heating. A portfolio of technology-tier instruments include: the Heat Networks (Scotland) Act 2021 (Framework Policy; 2021), Heat Networks Partnership (Education & Outreach; 2013–2021) and the District Heating Loan Fund (Loans and Third Party Financing; 2011 – Ongoing). There are fewer economy-tier instruments in Scotland, which is largely reliant on UK Government for such instruments due to limited devolved powers over energy. Notable exceptions include the Climate Change (Scotland) Acts 2009 and 2019 and the Place Principle (2020). Instead, Scottish Government have pursued their own sector-tier instruments; these surpass the number in England and include the Community Empowerment (Scotland) Act 2015; Place Standard Tool (2015 – Ongoing) and Low Carbon Infrastructure Transition Programme[9] (LCITP; 2015–2021).

4.3. Wales

4.3.1. Credibility

Wales has similar total instrument numbers to England, with a peak of 34 in 2020 and 2021. The **duration** of instruments tends to be longer than in England (see Fig. 6). In contrast to England's fluctuating instrument mix, Wales maintains a fairly **consistent upward trajectory** in the total number of instruments. As in Scotland, Welsh Government have introduced policy instruments at a rate which counters periods of

[8] LHEES are comprehensive, area-based plans for systematically improving energy efficiency and decarbonising heat across all building sectors, developed by local authorities (see: [59]).

[9] LCITP is funded through Scottish Government and the European Regional Development Fund (ERDF). The current round of LCITP funding is due to end in 2021; it is unclear whether further funding will be allocated after this, or whether ERDF funding will be continued or replaced following the UK's departure from the European Union.

decline from UK Government. For example, whilst the total number of instruments in England declined in 2016–2017, Welsh Government community-related activity provided continuity in number of instruments relevant to LES. New instruments introduced around the publication of *Green Growth Wales: Local Energy* (2015) include: Community Energy Wales (2012 – Ongoing), Resource Efficient Wales Framework Contract (2014–2018) and Wales' Community Benefits Register (2014 – now closed). Welsh Government's narrative begins to shift towards a place-based approach in later policy documents as apparent in 2018's *Infrastructure Plan* and 2019's *Prosperity for All: A Low Carbon Wales*. The latter identifies 'a place-based approach to deliver better results at the local level' as one of three national priorities for managing natural resources ([41], p.26).

The primary **managing organisation** in Wales is either UK or Welsh Government, depending on the instrument origins. No charities, public sector partnerships or private sector organisations have been tasked with managing policy instruments relevant to LES. Instead, instruments introduced by Welsh Government tend to be centrally managed, or management is allocated to not-for-profit companies. Examples include: Ynni'r Fro (Energy Saving trust, NGO), Welsh Energy Efficiency Loan Fund (Carbon Trust, Not for profit company), Community Energy Wales (Community Energy Wales, Not for profit company), Welsh Community Benefits Register (Renewable UK; Not for profit company). In addition, narrative analysis suggests an increasing role for local authorities with 2020's *Local Ownership of Energy Generation in Wales* highlighting a role for local authority development plans, which should identify:

> Opportunities for district heating, local renewable and low carbon energy generation schemes, and the co-location of new proposals and land allocations with existing developments, heat suppliers and heat users ([42], p.8).

In 2019, *Prosperity for All: A Low Carbon Wales* highlights the appointment of Chief Regional Officers (covering North Wales, South West and Mid Wales and South East Wales) tasked with understanding the challenges and opportunities of decarbonisation on a regional basis, although this is not associated with a specific policy instrument. Like England and Scotland, Welsh strategy documents also suggest an increasing role for private sector **funding sources**. *Energy Wales: A Low Carbon Transition* (2012) and its accompanying *Delivery Plan* include references to investment in community energy from private businesses, and express a desire to ensure that private investment benefits both the business and Welsh communities, including through 'jobs and economic benefits in every viable sense' ([43], p.18).

4.3.2. Comprehensiveness

The **balance** of instrument types in Wales stays relatively stable, moving from 0.86 to 0.85 over the analysis period; the average is the same as Scotland, but Wales draws on fewer instrument types. For example, there are no active Fiscal instruments in Wales until 2018's Non-domestic (business) Rates Support for Hydropower, and no active Public Investments until the UK Government's Public Sector Decarbonisation Scheme (2020–2025). There is also an increase in R,D&D and Grants and Subsidy during the period. These primarily reflect UK Government schemes, but include Welsh Government's Optimised Retrofit Programme (R,D&D; 2019 – Ongoing), Arbed (Grants and Subsidy; 2009–2021), and Ynni'r Fro (Grants and Subsidy; 2010–2015). However, Framework Policies increase from one in 2010 to nine in 2021; these are buoyed from 2015 with the Planning (Wales) Act (2015), Well-Being of Future Generations (Wales) Act (2015), Environment (Wales) Act (2016) and, Local Renewables Ownership Target (2017). Growing use of Framework Policies may reflect increased devolved powers in the Wales Acts of 2014 and 2017.

The **technology-specificity** of instruments in Wales also reflects greater reliance on UK Government for economy- and sector- wide programmes, with the number of economy-, sector- and technology-tier instruments broadly mirroring those at UK Level (see Fig. 2a and c). Like Scotland, there is more consistent use of technology-field instruments that cover multiple technologies, and the number of technology-field instruments periodically surpasses those in England. There is a peak in technology-field-tier instruments in 2012, with Arbed (2009 – Ongoing), Y'nnir Fro (2010–2015) and Community Energy Wales (2012 – Ongoing) all active. There is a second peak in the 2017–2021 period with Re:fit Cymru (Education & Outreach; 2016 – Ongoing) and the Local Renewables Ownership Target (Framework Policy, 2017) both initiated by Welsh Government in this period.

5. Discussion

5.1. Differentiating Great Britain's policy mixes for Local Energy Systems

The number of policy instruments relevant to LES across England, Scotland and Wales has significantly increased since 2010, and all three jurisdictions show high diversity of instrument mix (balance). However analysis of the characteristics of these policy mixes reveals variability in credibility and comprehensiveness. This demonstrates that distinct approaches to LES are feasible in sub-state, or devolved, policy systems, although this research does not assess the impact of these divergent policy mixes on material developments.

In England, the lower number of instruments, increased fluctuation, and shorter duration indicate a policy mix with lower **credibility** than Scotland and Wales. Credibility impacts on investor confidence [24], so this could be particularly damaging to current UK Government ambitions for leveraging private sector investment. The policy mix in England is nevertheless relatively **comprehensive** with a range of instrument types incorporated. However, it is important to explore the underlying reality. For example, the recent increased focus on locally delivered (but centrally controlled) heat decarbonisation and energy efficiency schemes is taking place in the context of major reductions in energy efficiency funding since 2012 [44] and a real-terms reduction of grant funding from central government to English local authorities of 37 % between 2010 and 2020 [45]. In addition, despite strategy document emphasis on private sector investment and leadership, local support mechanisms for this are unclear, with the exception of specific short-term R,D&D programmes, such as PFER. There is no clear evidence that such short lived R,D&D programmes result in systemic change.

Scotland and Wales both demonstrate clear ambition for LES; explicit definitions are developed in Scotland's *Local Energy Policy Statement* and a more systemic view is adopted in Wales' *Local Ownership of Energy*. With more continuity, less fluctuation, and specific instruments of longer duration, both Scotland and Wales showed greater **credibility**. The distinctive LES agenda in Scotland and Wales indicates that devolution is working to support energy policy differentiated at the sub-state level. In Scotland, analysis indicated development of a diverse group of LES actors including Non-Departmental Public Bodies, consortia of not-for-profit companies and charities, and public sector partnerships managing and delivering a range of instruments. As in England there has been increasingly explicit emphasis on inclusion of private sector actors and funding, for example, in the new Scottish National Investment Bank. This is likely a response to austerity policies which have reduced public funding across the UK since 2010, although funding reductions in England have been more pronounced than Scotland and Wales ([46,47]).

The balance of instruments in Scotland and Wales was slightly lower, indicating a less **comprehensive** policy mix than in England. For example, specific policy instruments to support Wales' systemic approach are lacking, and Scotland's ambitions are heavily reliant on LHEES as a lynchpin around which several strategies hinge. Both countries depend more heavily on technology-, and technology-field-, tier instruments. This reflects restricted powers over regulatory and systemic (economy-wide; connecting generation and distribution) policy, as well as interdependencies of GB energy markets. Where additional powers are made available, they are utilised. For example, both Scotland and Wales have increased use of Framework Policies in line

with increased devolution of energy-related powers. However, devolved governments still have limited capacity to act, raising questions about the realisation of LES ambitions. The current analysis is an ex-ante assessment of potential effects of emerging LES policy mixes; the impact of recently-introduced policies is inherently uncertain. Future research could incorporate a longitudinal analysis of these policy instruments and their impact on LES development. This is particularly important given that the process for developing these policy mixes is complex, as discussed in the following section.

5.2. Layering policy instruments for Local Energy Systems

Policy instruments relevant to LES have emerged incrementally over time. Specific narratives about systemic benefits of locally *integrated* energy systems became an explicit focus only after 2017 (with this being more pronounced in Scotland and Wales).

Across GB, earlier policy instruments focussed on, for example, community ownership of distributed renewables (like CARES and Community Energy Wales). Such instruments could be a key component of LES, but narrative analysis of strategies suggests that these instruments were not established to support LES per se. District Heat Networks (DHNs) have received explicit support across Britain, with the introduction of a suite of instruments spanning Framework Policy, Grants and Subsidy, Loans and Third Party Finance, and Education and Outreach. DHNs are a system infrastructure, which creates new interdependencies between actors across sectors and scales. However, it is only in Scotland that DHNs have been positioned in a LES perspective, through the statutory LHEES requirement to consider heat network zoning. The closest equivalent in England is Local Area Energy Plans (LAEP)[10] which could connect network planning and local authority net zero commitments but are not currently statutory. England is however making provision for heat zoning for DHNs, but without a wider requirement for whole system local energy planning ([48,49]). In Wales the government has committed to ensuring 'all areas of Wales have a detailed local energy plan by the end of 2023–24' bolstered by technical support and additional local authority funding to appoint LAEP co-ordinators ([50], p.64).

Moreover, the complexity of LES means that policy across a wide range of topics is potentially relevant, sometimes with local aspects relatively peripheral to policy objectives. For example, the development of national infrastructure banks and industrial strategies both include elements relevant to LES, but lending to local areas has been slow [51] and Local Industrial Strategies have been downgraded by Government in favour of more centralised approaches [52].

Thus, despite their potential relevance, these policy instruments have not all been introduced with the explicit intention of supporting LES. Given that this study is an ex-ante assessment of a developing policy area, it is difficult to determine whether shifts in policy mixes are the result of 'conscious design choices by policy-makers' or processes of 'layering' new policies and instruments on the existing mix ([26], p.4). Layering is intended to capture the process of new instruments being added to an existing regime without closing previous ones [53]. There is more evidence of layering in the Scottish LES policy mix with the retention of several policy instruments over the 11-year assessment period and the steady accumulation of instruments. Such layering can function as an intentional process of policy '*patching*' where whereby new policies are added to existing frameworks in order to "*correct flaws or allow them to adapt to changing circumstances*" ([*54*], p.177). In Scotland new policy instruments tended to focus on supporting local capacity through pilots (LHEES and Energy Efficiency Scotland) and funding (EIF, Place-based investment programme). Further analysis of political rationales is needed to explore how and why processes of policy packaging and layering are taking place [54].

Layering can also add to incoherence with policies "hampered due to internal inconsistencies [and…] legacies from earlier rounds of decision making" ([53], p.138). In the context of a largely centralised GB energy system, with an extant methane gas grid and a liberalised energy market, developing LES is likely to require more radical change in policy making than incremental layering. Whilst numerous instruments are in place to support aspects of LES there is limited evidence of these policy mixes being designed as a comprehensive package, addressing technology innovation and restructuring of regulatory frameworks governing liberalised markets. Cross vector integration and balancing supply and demand at the local/regional scale are at the heart of LES, but policy to reform regulation of electricity and gas networks, and new regulation to support heat and flexibility markets, is slow. To address these systemic interdependencies an 'integration' approach to policy mix development is needed. The creation of a more ordered, coherent policy domain can begin from a statement of key principles constituting the 'architecture' [54]. Scotland has already undertaken this step with the *Local Energy Policy Statement*; but GB interdependencies mean that cross-government collaboration is needed.

5.3. Developing policy mixes as an analytical tool

The application of policy mix concepts presented here is distinctive in its analysis of a complex, emerging policy field, instead of the more common emphasis on delineated technologies or sectors. Difficulties in operationalising policy mix analysis are well documented ([10,20,26]). We therefore built on Rogge & Reichardt's [20] conceptual framework by identifying an empirical approach to assessing policy strategy, instruments and the characteristics of credibility and comprehensiveness. This has provided insight into the differential development of complex policy mixes across devolved jurisdictions, but it has also revealed limitations of policy mix assessment methods.

Firstly, policy mix analysis does not attempt to identify the 'best policy' to deliver a specific aim, but focusses on understanding how to balance 'the strengths of different instrument types across a complex mix' ([26], p.3). The challenge with application of metrics in a policy area as complex as LES is that there is no single correct answer. For example, in this analysis, the results of the balance calculation were similar across all jurisdictions, despite differential powers governing the types of policy that could be developed. Balance is calculated as a ratio of the spread of categories against the total number of categories in use; it does not provide insight into the density of instruments, or reflect any change in the number of categories in use. In this way, balance has little sensitivity to difference and, used alone, offers limited insight into the comprehensiveness of a policy mix. Further, Schmidt & Sewerin's [26] balance calculation does not provide a mechanism to account for the relative power of different policy instruments. For example, in the case of LES a single policy, such as allocating more planning powers to local authorities, could provide a key to unlocking LES in a way that technology grant funding would not. Thus, the assessment of policy mix characteristics needs to recognise that the success of different policy instruments is dependent on context, objectives and resource allocated. Castrejon-Campos, Aye & Hui [55] develop a more integrated approach, incorporating qualitative and quantitative strategies to evaluate the robustness of policy mixes, which could strengthen future assessment.

Additionally, policy mix analysis may provide indicators of good practice, but this would have to be evaluated against political objectives and context behind the policy instruments. As standalone metrics, some measures for evaluating policy mixes are therefore limited. For example, a long duration could be indicative of consistency, which can support mobilisation of actors. However, it could also indicate complacency,

[10] Local Area Energy Planning (LAEP) is defined as 'a data driven and whole energy system, evidence-based approach that sets out to identify the most effective route for the local area to contribute towards meeting the national net zero target, as well as meeting its local net zero target' [60]. They have been developed by Energy Systems Catapult and trialled in a small number of English and Welsh authority areas.

whereby instruments are retained, but not updated to reflect changing priorities and circumstances. Similarly, it is unclear whether allocation of responsibility to a private, public or third sector managing organisation is beneficial. Retention of central government responsibility could be indicative of close oversight, or designation to an external organisation could mean greater resource for a specific instrument. It is therefore important for future policy mix analysis to incorporate assessment of complementarities, or desirable interactions and relationships, across instruments [56].

Evaluation of credibility and comprehensiveness is inherently subject to judgement; hence future appraisal of policy mixes would benefit from triangulation with other sources of evidence, for example, using a Delphi approach to incorporate analysis of stakeholder perspectives and political dynamics shaping developments (see [57]). This is especially important in the GB case, where different UK jurisdictions are currently governed by different political parties, and policy divergence may be part of strategy to justify extension of powers. For example, since 2007 in Scotland, successive Scottish National Party-led governments have deployed the mix of devolved and reserved powers to pursue distinctive energy and climate policies [16]. Understanding how such political processes shape and modify policies is critical to evaluating the success of any particular mix [54]. Future analysis could therefore incorporate discussion of political process with policy makers and key stakeholders (see for example [58]).

6. Conclusion

This paper has examined emerging policy mixes for Local Energy Systems across Great Britain's distinct political jurisdictions. This has demonstrated the value of the policy mixes framework as a device for comparative analysis of the composition of policy. The approach provides a more granular picture of the different policies potentially contributing to LES within England, Scotland and Wales. Differential levels of credibility and comprehensiveness have been identified in GB. The policy mix in England suggests the lowest overall credibility, with fluctuation in the number of relevant instruments and more short-term instruments. Cancellation of schemes and short-term funding create gaps in support, and a lack of clarity for the numerous actors needed to coalesce around LES. Analysis of Scotland and Wales indicates more policy credibility, including policy layering, with clearer ambition for LES, and continual growth in the number of relevant instruments. However, limitations in devolved political powers result in less comprehensiveness with, for example, less use of economy- and sector-tier instruments. There is therefore a question about whether Scottish and Welsh ambitions will be realised. Thus, this study has shown that the policy mixes approach can sensitise researchers to the underlying political economy and party political dynamics likely to be factors in policy changes. Such awareness can then be further tested through empirical research, for example expert interviews and Delphi techniques.

Analysis also provided insight into the practicalities of applying policy mix analysis to complex, emerging policy areas. We developed Rogge & Reichardt's [20] framework of policy mix building blocks to offer an approach to analysing policy strategy, instruments and the resulting credibility and comprehensiveness of the policy mix. This reveals that robust analysis of policy mix characteristics requires a combination of assessment techniques and that the intertwined nature of both policy instruments and characteristics make assessment complex and subject to a degree of judgement.

Towards the end of the analysis period evidence of more holistic policies relevant to LES started to emerge in all three jurisdictions, alongside aims to attract private investment. These tend to be innovation 'experiments', or emerging models for local energy planning, not yet translated into widely deployed instruments. However, the policy mixes approach does not inherently answer questions about the impacts and effectiveness of such policies. Applying the policy mixes framework to a complex 'systems' field (as opposed to a single technology) reveals its limitations for 'whole systems' analysis, where policies have to span different sectors, regulations and scales, and where the underlying value of proposed changes is contested. For example, in relation to LES in GB, knowledge about policies that 'work' to effect systemic change is relatively untested, there may be 'mixed motives' at work in different political circumstances and different degrees of willingness to advance ambitious policies.

The policy mixes approach therefore prompts new research questions around, for example, the possibilities of creating more integrated policy mixes with a clear 'architecture' across all aspects of generation and demand. The fluid and intertwined nature of policy instruments and characteristics make assessment complex and subject to judgement stimulating the future use of mixed methods and development of criteria for assessing the effectiveness and potential material outcomes of such mixes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data has been included in the 'attach file' stage

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Appendix A. Policy documents included in analysis

Year	UK Government	Scottish Government	Welsh Government
2010	National Infrastructure Plan	A Low Carbon Economic Strategy for Scotland: Scotland - A Low Carbon Society	A Low Carbon Revolution - Energy Policy Statement
	Local Growth: Realising Every Place's Potential		
2011	National Infrastructure Plan	2020 Routemap for Renewable Energy in Scotland	
	Growing Places Fund: Prospectus	Achieving a sustainable future: regeneration strategy	
	Unlocking Growth in Cities	Low Carbon Scotland - meeting the emissions reduction targets 2010–2022	
	Enterprise Zones Prospectus		
	The Carbon Plan: Delivering our low carbon future		
	Microgeneration Strategy		

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(*continued*)

Year	UK Government	Scottish Government	Welsh Government
2012	The Future of Heating: A Strategic Framework for Low Carbon Heat in the UK Low Carbon Communities Challenge		Wales Infrastructure Investment Plan for Growth and Jobs Energy Wales: A Low Carbon Transition
2013	Future of Heating National Infrastructure Plan	Low Carbon Scotland - Meeting Our Emissions Reduction Targets 2013–2027 Low Carbon Scotland: Behaviours Framework Creating Places Policy Statement	
2014	Community Energy Strategy National Infrastructure Plan		Community Benefits Energy Wales: A Low Carbon Transition Delivery Plan
2015	Growing Places Fund: Investing in Infrastructure Community Energy Strategy Update Delivering UK Energy Investment: Networks	2020 Routemap for Renewable Energy in Scotland - Update 2015 Heat Policy Statement Infrastructure Investment Plan Scotland's Economic Strategy Community Energy Policy Statement	Green Growth Wales: Local Energy
2016	National Infrastructure Delivery Plan (2016–2021)		Energy Efficiency in Wales
2017	Clean Growth Strategy Industrial Strategy: Building a Britain Fit for the Future Upgrading our Energy System: Smart Systems and Flexibility Plan	Scottish Energy Strategy	Prosperity for All: The National Strategy
2018	Strengthened Local Enterprise Partnerships	Climate Change Plan - Third Report on Proposals and Policies 2017–2032	Energy Generation in Wales Wales Infrastructure Investment Plan: Mid-point Review
2019			Prosperity for All: A Climate Conscious Wales Prosperity for All: A Low Carbon Wales
2020	National Infrastructure Strategy Energy White Paper – Powering Our Net Zero Future The Ten Point Plan for a Green Industrial Revolution	Update to Climate Change Plan	Local Ownership of Energy Generation in Wales
2021	Build Back Better: Our Plan for Growth Transitioning to a net zero energy system: Smart Systems and Flexibility Plan Net Zero Strategy: Build Back Greener	A National Mission with Local Impact: Infrastructure Investment Plan for Scotland 2021–2022 to 2025–2026 Local Energy Policy Statement	

Appendix B. Definition used for each policy instrument type

Adapted from Schmidt & Sewerin (2019) [citing Schaffrin, Sewerin & Seubert (2014), who reference EEA, http://www.eea.europa.eu/themes/climate/pam.

Policy type	Description
Education and outreach	Policies designed to increase knowledge, awareness, and training among relevant stakeholders or users, including information campaigns, training programs, labelling schemes.
Fiscal	Policies to encourage or stimulate certain activities via taxation. These include tax incentives, such as tax exemptions, reductions or credits on the purchase or installation of goods and services.
Grants & subsidies	Policies to stimulate certain activities, behaviours or investments. These include grants and rebates for the purchase of energy-efficient appliances.
Loans & third party finance	Policies to stimulate certain activities, behaviours or investments This includes preferential loans and third-party financing, for local authorities and community organisations, for example.
Framework policy	Elements of policy and regulation that create a landscape conducive to the development of Local Energy Systems. This generally covers strategic planning documents and Acts that guide policy development. It can also include the creation of specific bodies to further policy aims or develop specific programs.
Public investment	Policies guiding investment by public bodies, specifically, funds used by local government for capital works stipulated by central government – for example, to deliver area-based energy retrofitting. Also includes direct investment by central government in infrastructure.
Research, Development & Distribution	Policies and measures for the government to invest directly in or facilitate investment in technology research, development, demonstration and deployment activities.
Regulatory instruments	Covers a wide range of instruments by which a government will oblige actors to undertake specific measures and/or report on specific information to directly support LES. Examples relevant to LES include obligations on companies to support community/ local energy generation and feed-in-tariffs

Appendix C. Definition of managing organisation types

Managing organisation	Description
Central government department	UK government or the devolved governments of Wales and Scotland, including non-ministerial departments.
Non-departmental public body	A body which has a role in the processes of national government, but is not a government department or part of one, and which operates to a greater or lesser extent at arm's length from ministers. (definition from: https://www.gov.uk/guidance/public-bodies-reform)
Charity	An organisation with specific purposes defined in law to be charitable, and exclusively for public benefit (definition from: https://www.ncvo.org.uk/images/documents/about_us/media-centre/What-does-it-mean-to-be-a-charity-now.pdf)
Private sector	For profit companies, including Limited Liability Partnerships and Companies Limited by Guarantee
Not for profit company	Including not for profit membership organisations
Public Private Partnership	Contractual arrangements between a government agency (or agencies) and a private-sector company
Public Sector Partnership	Partnership arrangement between public sector organisations. For example, partnership between central and local government, or across multiple public sector organisations

Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2024.103413.

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