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Understanding the local energy transitions process: a systematic review

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ABSTRACT

The objective of this paper is to better understand the local energy transitions process, given the importance of local energy transitions. A systematic literature search was conducted and 18 core and 18 peripheral papers on local energy transitions were selected. The 18 core papers were assessed using the framework given by Turnheim et al. [1]. Findings show that local energy transitions have characteristics or features which are not adequately explained by the framework used. Sources of innovation and the innovation in niches in local energy transitions are explained by socio-technical theories such as Strategic Niche Management (SNM) and Multi-Level Perspective (MLP). The pathway dynamics and the normative goals are covered by quantitative modeling studies of local energy transitions. The specific features of local energy transitions which are not adequately analysed by the existing framework are ownerships of transitions, situative governance issues, spatial scale issues, differing priorities and differing institutional structures, along with the analysis of pathway dynamics. A suggestion for extending a framework to analyse local energy transitions is proposed.

Keywords:

Local energy transitions;
Socio-technical transitions;
Transitions research;
Dynamics;

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1. Rationale for studying local energy transitions

The field of energy transitions is considered very important in the current socio-politico-environmental context [2], with the earth entering the era of the Anthropocene [3]. Thus, energy transitions to sustainable and 'green' means of energy provision [4], along with but not limited to, increased energy efficiency and energy effectiveness are keys to limiting GHG emissions from fossil fuels. Energy transitions are deemed to be socio-technical transitions [5] and societal transitions [6]. Historically energy transitions have taken a rather long time, in most cases decades [7], and as such most studies of energy transitions have been *a posteriori* or "*after the fact*" studies [8].

Energy transitions are complex, involving different socio-political and cultural contexts with far-reaching impacts for the world. These different contexts impact upon many factors associated with the energy transitions processes, such as the time it takes for the transitions to happen, the choice of technological innovations underpinning the transitions processes, the pathways taken in the transitions etc. At the same time, energy transitions, at the local level, involve individual actors and policy structures leading to interactions and networks which are difficult to assess and predict. Furthermore, local energy transitions have an important place in current times, since local communities are well placed to identify local energy needs, and if given the agency are ideally situated to achieve common energy, environment and other wider societal goals [9]. Thus there are clear indications that the local level transitions are growing in importance [10].

There is no set definition of local energy transition. In general terms, *local energy transitions can be understood as energy transitions which happen at a sub-national scale, with some help partly coming from residents*. But,

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this definition is very simplistic. The authors agree with [11] that the term 'local' has multiple meanings and conceptualisations. At the same time, as Hoppe et al. [10] state, for the purposes of this paper the authors have defined local as "communities of place", *and to specifically mean a geographically bound sub-national "community of place"*. As Tomc and Vassallo [12] explain, a community is a loosely bound group of actors, and for purposes of this study, a group of actors who act to further an implementation of transitions process in a defined geographical place. This definition is important since it defines the crux of this study's research problem.

Some literatures also give tractable explanations of local energy transitions which encompass grassroots innovation [13], regional energy innovation [10], community energy [14], citizen power plants [15], local institutional and governance structures [16] among others. These are some of the empirically similar phenomena to local energy transitions which have been looked at in scientific literature.

The objective of this study is to understand the local energy transitions processes, through in-depth analysis of local energy transitions literature. As far as the authors know there have been no attempts to understand the local energy transitions processes by themselves. In most literature, energy transitions scholarship has been given a wider scope for investigation and explication, and given the rapid proliferation of local energy transitions and the effects they are having on the energy systems, as noted by [11, 14, 17, 18], the authors think that understanding local energy transitions should be a sustained activity on its own.

Ultimately, the paper intends to differentiate the study of local energy transitions from the broader transitions literature and propose an extended framework to study local energy transitions. The rest of the paper is structured as follows: Chapter 2 gives the methodological framework. Chapter 3 presents the analysis and findings of the core and peripheral papers. Chapter 4 discusses the main findings and contextualises the core papers amongst the findings from the peripheral papers. Section 5 concludes.

2. Methodological framework

This section explains the methodological steps underpinning this study. It explains the selection process of scientific literature analysed, the framework used for analysis in this study and subsequently the process of analysis which leads to its conclusions.

2.1. Selection of scientific literature

The selection of scientific literature is an important part of the research. The objectivity of the findings and their accuracy are invariably linked with the selection process. The method employed here closely follows the method proposed by Schulze et al. [19].

Literature dealing with local energy transitions between the years 2010 to 2017 are systematically selected. The reason for limiting our search to these years is that the authors posit that local energy transitions in peer-reviewed literature are sparse in years preceding 2010 and as such, the study is not losing out on any significant peer-reviewed literature. The authors carried out the same search for all the years, and did not find any significant papers that would have warranted changing the search filters.

In the quest to find papers studying local energy transitions, an electronic database search was done on the SCOPUS. The search strings are "local" AND "energy transitions" in the Title, Abstract, Keywords field.

It may be argued that there are empirical findings which can be found by using other similar search queries such as community energy or local energy projects. But the purpose of this paper is not to analyse similar empirical phenomena, but rather to focus on understanding the *process of local energy transitions*[1]. The presence of energy communities and local energy initiatives in the literatures by themselves does not imply that the literature deals with local energy transitions. The focus in this study is on understanding the process of local energy transitions and thus only the papers dealing with transitions at the local level are of interest. While community energy or grassroots energy initiatives and bottom-up energy initiatives are allied concepts, they do not necessarily imply transitions at their core. Thus, for the purposes of this study, which is to understand and shed light on the local energy transitions process, the search queries "local" and "energy transitions" suffice.

The search results were refined further by filtering for language and journal articles. The reasoning for using the logic operator 'AND' for the two search strings was to eliminate energy transitions papers which did not focus on local energy transitions.

[1] It could be argued that the search query should include the word "process". The authors ran the search query with the word "process" along with "local" and "energy transitions" and there were no differences to the relevant search results returned. This has lead the authors to infer that papers dealing with local energy transitions processes and energy transitions do not differentiate themselves under those two categories.

This search query returned 344 research articles, out of which 36 articles were selected by the authors by reviewing the abstract manually, one by one. Apart from the 36 papers selected, the rest of the papers were deemed not useful for this study. Most of the discarded papers fell under completely different fields of study such as phase transitions, waste water treatment methods etc. Table A1 in the Supplementary File gives the complete list of journal articles returned through the search query.

In addition to this, the authors used the referencing software Mendeley (see [20] for further details) and added the selected literatures to it. From then on, Mendeley sent curated emails with suggestions for related papers on a bi-weekly basis, which is continuing till the time of writing, and these suggestions were also monitored extensively to make sure that critical papers were not missed by the authors.

The 36 papers selected were further divided into two categories, chiefly based on their treatment of local energy transitions process. Of these 36, 18 peer-reviewed papers are directly studying local energy transitions, and from herein known as the core papers. These core papers will form the crux of the material which is analysed and studied in this study.

The rest of the selected papers are situated on the periphery of local energy transitions; that is, these papers do not focus on the local energy transitions processes, but, are important enough to be assessed to gauge challenges and opportunities within the local energy transitions field. These papers are defined as peripheral papers, in this study. These papers are used to tease out features which are present in them, but which may or may not be present in the core papers, and features which are not assessed by the frameworks in

Table 1: A brief description of the framework put forward by Turnheim et al. [1]

Characteristic	Sub-criteria explanation
Scale and temporality	Analytical scale — types of scale and sectoral divisions. E.g. national comparisons across the world or transitions processes in the world. Multi-scale linkages — how multiple scales have been linked. E.g. how the sector being analysed has been linked with the technology or innovation. Time horizon — time duration of the transitions process analysis, such as whether short term, medium term or long term. Time orientation — forward looking or backward looking, temporally Temporal articulation – time resolution. E.g. annual or bi-annual
Treatment of complexity	Methodological strategy — the methodology that has been used in the study of the transitions process, such as whether quantitative or qualitative. Explanatory focus — how the transitions process has been explained. E.g. has it been explained through case studies, or through model-building. Predictive inclination – Projections or forecasts into the future, or back-casting from an ideal future. Treatment of uncertainty — how the various uncertainties associated with the study of the transitions process are handled. E.g. handled through sensitivity analyses or through validation by experts.
Innovation and inertia	Sources of innovation — how sources of innovation are considered. E.g. multiple sources of innovation considered together, or in isolation. System inertia — how the barriers for the change through the transitions process have been handled in the study.
Normative goals	Normative positioning and conceptualisation -A normative goal has been considered and conceptualised. E.g. absolute reduction of energy use and if so whether the goal has been conceptualised in numbers for a specific year, with respect to base year. Approach to sustainability – The handling of sustainability, whether explicitly through some indicator, or implicit.
Governing transitions	Conceptualisation of policy — how policy has been considered in the study. E.g. policy can be conceptualised as a rigid rule under which all the aspects of the transition process should come under or it could also be conceptualised as a soft rule, which can be exempted. Representation of decision-makers — indicates how the different heterogenous agents of the transitions process have been taken into account in the study. View on intervention — how the study tackles the different intervention methods in the transitions process.

literature. Figure 1 gives a representation of the mapping of the scientific literature.

For the purposes of this paper, the authors have clearly focused on papers dealing only with the local energy transitions process. Hence, inherently, the study may miss out on learnings from other aligned fields, such as other ecological transitions etc. While the authors do not see this as an obvious flaw in the methodology, it may be argued that there might be valuable learnings to be obtained from other fields. The authors acknowledge this argument, but, at the same time due to the focus of the paper being on local energy transitions and time constraints, refrain from increasing the scope of the paper.

2.2. General overview of the framework used to assess the core papers

There are a few literatures which elucidate frameworks to assess broader energy transitions or similar empirical phenomena, chiefs among them being [5, 21], [1, 22]. The authors of this study found the framework put forward by [1] to be the most comprehensive. In the seminal work by [1], the paper identified five challenges in the study of sustainability transitions.

In this study, the authors reframe the challenges presented by Turnheim et al. [1] as a framework consisting of five essential characteristics and sub-criteria that needs to be assessed. As per [23], a framework helps to identify the elements and the relationship among these elements that one needs to consider for analysis. The authors of this study posit that analytically, the comprehensive challenges and their descriptions Turnheim et al. [1] postulate is a framework. Thus, Figure 2 presents the five characteristics and their sub-criteria as stylised by the authors of this study.

Turnheim et al. [1] framed the five challenges to highlight the analytical aspects of sustainability

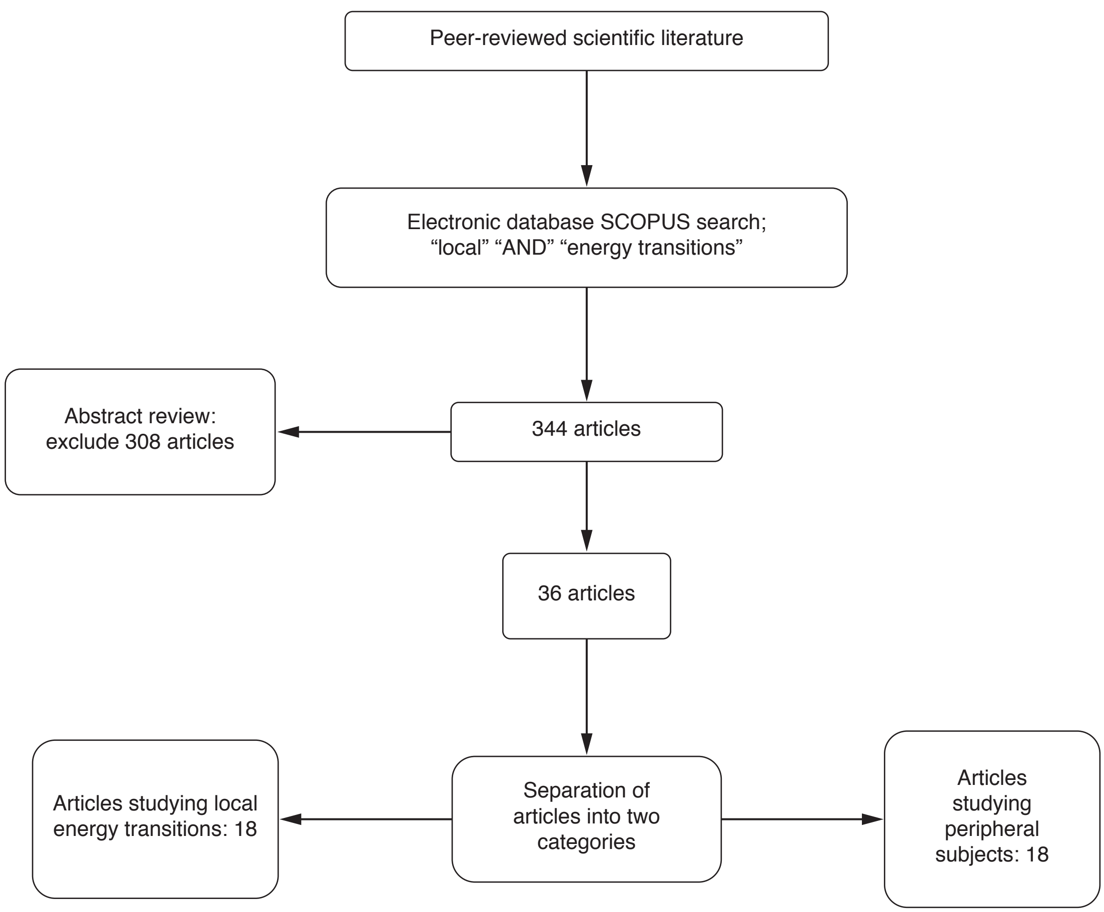

Figure 1: A representation of the method of paper selection for review in this study, adopted from [19]

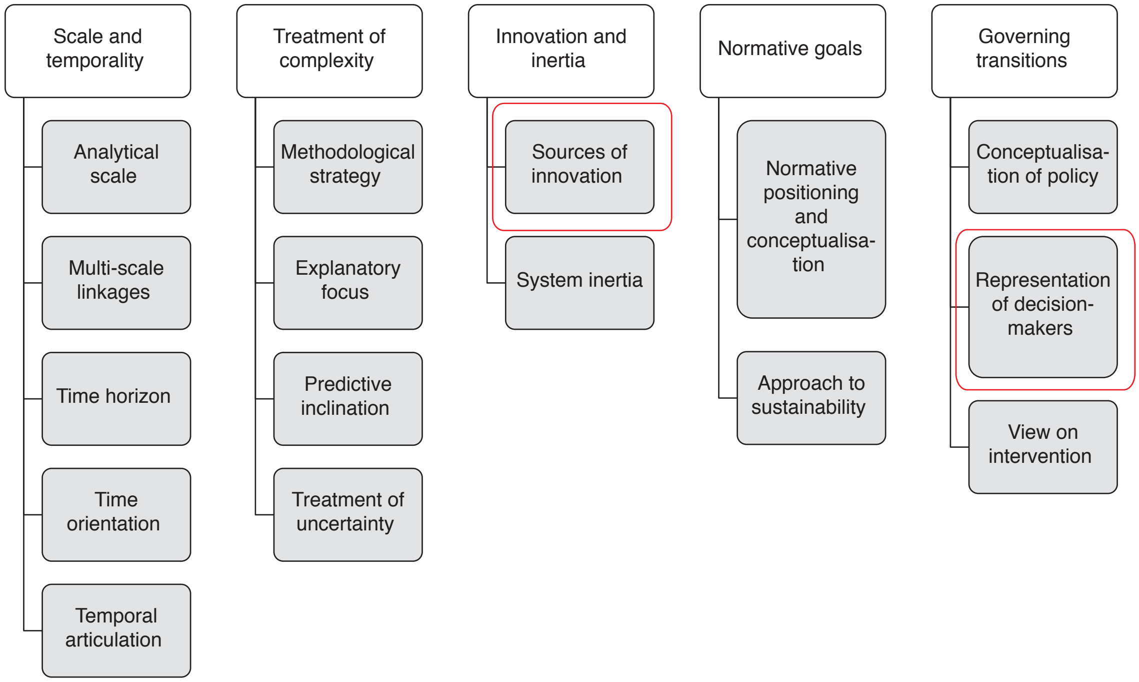

Figure 2: The framework which lists key characteristics and sub-criteria to assess the local energy transition studies, as given by Turnheim et al. [1], stylised by authors

transitions that need to be considered when studying transitions.

The five challenges (now reframed as characteristics in this current study) that Turnheim et al. [1] mention is:

- *Scale and temporality — the different scales, for example macro, meso and micro scales noted in socio-technical analysis, and the inter-scale and inter-temporal treatment of transitions.*
- *Treatment of complexity — how uncertainty is treated in the transitions study, along with what the explanatory focus in on.*
- *Innovation and inertia — where and who the sources of innovation are and how the emergence of innovation is explained, along with how system inertia is treated.*
- *Normative goals — how the normative positioning is treated in the transition along with the presence of sustainability and other secondary goals.*
- *Governing transitions — how the plurality of actors, and their interplay and how they are governed are all dealt with.*

These five characteristics are essential to understanding how the transitions process has been studied. Each of these characteristics have sub-criteria which feed into the characteristics. The brief explanations for the sub-criteria given in Figure 2 are presented in Table 1.

The authors of this study use this framework to assess the core papers and see how they have studied local energy transitions and have helped to understand the local energy transition processes. Hence this framework, with its sets of characteristics and sub-criteria are essential to this paper.

Turnheim et al. [1] also typify three different approaches normally in use to study sustainability transitions, and they are 1) quantitative systems modelling, 2) socio-technical analysis, and 3) initiative-based learning. Quantitative systems modelling is the approach of projecting various scenarios of future which are brought on by different transitions processes, which depart from a status-quo current state. This approach generally places emphasis on cost-optimizing transition pathways, while leaving out the dynamics of how the actual transitions are to be achieved. The socio-technical analysis is the approach of considering the transitions process as involving multiple processes resulting in social, technical and institutional reconfiguration and alignment, and often times with the possibility of multiple future outcomes. The initiative-based learning approach is a group of heterogenous approaches where the emphasis is placed on actors in novel socio-technical configurations, where most transitions takes place as a result of 'learning by doing'. In effect, the quantitative systems modelling approach can answer questions such as how much transitions are going to cost, and how much the benefits are going to be, whereas the socio-technical analysis approach can answer questions related to how the transitions processes are going to change the society. Likewise, the initiative-based learning approach can answer questions as to how different actors can enhance different transitions processes.

Turnheim et al. [1] provide an explanation on how these three approaches deal with the challenges (which has been reframed as 'characteristics', by the authors of this study) and conclude that the three approaches tackle the challenges differently and the sustainability transitions field may benefit from using the three approaches complementarily. While the definitions of quantitative systems modelling and socio-technical analysis, as defined by Turnheim et al. [1] are comprehensive (for more details see [1]), the authors of this study would like to discuss the definition given for initiative-based learning. Turnheim et al. [1] typify initiative-based learning as "*going from A to B to be achieved if the relevant actors are involved in defining and legitimising new technologies… Understanding the motives and strategies of actors on the ground is critical to making transitions socially-robust and sustainable*". Given this definition it would be reasonable to presume that understanding local energy transitions processes would be done mostly through initiative-based learning. This assumption underpins the current authors' analysis of the core papers.

As mentioned before, the framework put forward by Turnheim et al. [1] gives the most comprehensive set of key characteristics of transitions, with sub-criteria for each characteristic as well (see Figure 2). The red boxes encircling two sub-criteria have been inserted to point that these two are the sub-criteria which the authors surmise represent certain local energy transitions process characteristics. For example, Rygg [16] clearly shows how local-level biogas and heating transitions are impacted by the different decision-makers such as municipal officials, biogas producers, local households etc. and their interactions with each other. At the same time, Rygg [16] also articulates how the different decision-makers (or stakeholders) act as different sources of innovations, such as municipal governments etc.

After the selection of the core papers and the peripheral papers, the core papers are analysed through the framework given by Turnheim et al. [1]. After the analysis is done, the findings kept in mind, while the peripheral papers are inductively analysed.

The inductive analysis is carried out to find other features which have been highlighted and studied with regards to understanding the local energy transitions; features which are not the same as the characteristics identified by Turnheim et al. [1].

Once these features have been identified, how these features will help improve the understanding of the local energy transitions processes in the core-papers are discussed as well.

2.3. Summary of the methodology

The methodology undertaken in this study can be summarised thus: the core and peripheral papers are selected from existing literatures, and the framework is used to analyse the core papers, on the characteristics of scale and temporality, treatment of complexity, innovation and inertia, normative goals and governing transitions. Subsequently, with these characteristics in mind, the peripheral papers are inductively analysed for further features which are present in the understanding of local energy transitions processes and these features are identified. Following this, a discussion is presented such that the core papers are situated within these features identified in the peripheral papers.

The methodology chosen for this study is entirely based on secondary sources of information, specifically peer-reviewed scientific literatures. While this methodology serves the purpose in understanding what has been done in the field of study of local energy transitions, there has been no attempt to validate the findings or the conclusions with either experts or practitioners in the field.

3. Analysis and findings

Section 3 presents the analysis of the core papers with the framework presented in Section 2.2 and the inductive analysis of the peripheral papers. Prior to the analysis of the core papers using Turnheim et al.'s [1] framework, this sub-section presents the descriptions of the core papers. Table 2 gives the domain of interest of the selected papers, along with their methodological choice and the theoretical concepts that have been used in the papers' analysis.

In the papers selected there is a wide variety in terms of both demand [13, 24–26] and supply side interest.

Table 2: A general description of the local energy transitions literature

No.	Title	Domain of interest	Methodology	
			Theoretical concept	Choice of analysis
1	A grassroots sustainable energy niche? Reflections on community energy in the UK [13]	Supply side and demand side	Strategic Niche Management (SNM)	Qualitative: analyses of 12 case studies in various communities in the UK, along with 15 interviews with key stakeholders
2	Challenging obduracy: How local communities transform the energy system [17]	Supply side	Actor-Network Theory (ANT), Social Movement Theory (SMT)	Qualitative methods: structured interviews
3	Decentralisation dynamics in energy systems: A generic simulation of network effects [30]	Supply side	Network theory coupled with system dynamics simulation, systems dynamics (SD) model	Quantitative: simulations of different consumers in households adopting to solar PV technology
4	Decentralised laboratories in the German energy transition. Why local renewable energy initiatives must reinvent themselves [24]	Supply side and demand side	Theory of Multi-Level Governance	Qualitative methods: interviews and desk research
5	Dynamics of energy transitions under changing socioeconomic, technological and climate conditions in Northwest Germany [25]	Supply side and demand side	Dynamic Interactive Simulation Model	Quantitative: dynamic interactive simulation model
6	Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems [9]	Overall energy sector	Integrated Community Energy Systems (ICES)	Qualitative: exploratory analysis, thought experiment
7	Energy transitions in small-scale regions – What we can learn from a regional innovation systems perspective [10]	Supply side	Regional innovation systems (RIS)	Qualitative: interviews with actors from different subsystems (more than 30)
8	Harvesting energy: Place and local entrepreneurship in community-based renewable energy transition [14]	Supply side	Socio-geographical and local entrepreneurship roots of community energy	Qualitative; literature review, and semi-structured interviews
9	Local authorities as niche actors: the case of energy governance in the UK [31]	Overall energy sector	Multi-Level Perspective (MLP)	Qualitative: interviews (6) and document analysis
10	Local energy policy and managing low carbon transition: The case of Leicester, UK [32]	Supply side and demand side	Network and Agent Interaction	Mixed: quantitative (historical secondary data analysis) and qualitative: semi-structured interviews
11	Local governments supporting Local Energy Initiatives: Lessons from the best practices of Saerbeck (Germany) and Lochem (The Netherlands)	Supply side	Strategic Niche Management (SNM)	Qualitative: case study analysis through extensive interviews and document analysis.
12	Local niche experimentation in energy transitions: A theoretical and empirical exploration of proximity advantages and disadvantages [27]	Overall energy sector	Strategic Niche Management (SNM) and Regional Innovation Systems (RIS)	Qualitative: case study
13	One, no one, one hundred thousand energy transitions in Europe: The quest for a cultural approach [18]	Overall energy sector	Social Representations Theory (SRT), Cultural approach	Qualitative: analysis, thought experiment

Continued

Table 2: Continued

No.	Title	Domain of interest	Methodology	
			Theoretical concept	Choice of analysis
14	Photovoltaic diffusion from the bottom-up: Analytical investigation of critical factors [33]	Supply side	The SWOT analysis and Analytic Hierarchy Process (AHP)	Mixed design methodology: SWOT is qualitative and AHP is quantitative
15	Scaling up local energy infrastructure; An agent-based model of the emergence of district heating networks [26]	Supply side and demand side	Agent based modeling (ABM)	A mixed method; qualitative modeling through companion modeling, and then ABM with simulations
16	Supporting energy initiatives in small communities by linking visions with energy scenarios and multi-criteria assessment [28]	Supply side	Visions development, scenario analysis and multi-criteria assessment (MCA), Scenario analysis is done using a simple numerical model	Mixed methods: Qualitative and quantitative methods; a simple numerical model
17	The establishment of citizen power plants in Austria: A process of empowerment? [15]	Supply side	Resource-based understanding of socio-technical regimes	Qualitative: semi-structured interviews of the actors
18	Towards a sustainable socio-technical system of biogas for transport: the case of the city of Linkoping in Sweden [29]	Supply side	Multi-Level Perspective (MLP) and socio- technical perspectives on system builders	Mixed quantitative (secondary data analysis) and qualitative, semi-structured interviews

Most studies have used qualitative methodologies in their studies, mostly with in-depth case studies [13, 15, 27–29], while some studies have used quantitative methods such as systems dynamic modeling [30], and agent-based modeling [26].

The most common theoretical concepts are Multi-Level Perspective (MLP) and Strategic Niche Management (SNM), which are aligned with the quasi-evolutionary socio-technical transitions theory.

3.1. Assessment of the selected literature using the framework by Turnheim et al. [1]

As mentioned before, Turnheim et al. [1] propose the most comprehensive of all frameworks to represent the salient characteristics of the sustainability/socio-technical transitions. Given the lack of such assessment frameworks for local energy transitions, the authors use this framework to analyse the selected core papers. As stated before, Turnheim et al. [1] propose dividing transitions studies into three types: 1) quantitative systems modelling, 2) socio-technical analysis and 3) initiative based learning, and in their work the authors say that local energy transitions fall under initiative based learning. The authors of this present work will present evidence to the contrary in this and the following sections.

The inductive analysis of the studies is conducted to glean how they have treated the characteristics postulated by Turnheim et al. [1]. In Table 3 the authors present the salient aspects for each literature coming under the core papers, under the five characteristics. A close inspection of Table 3 and the findings presented clearly articulate certain common strains within the different local energy transitions literature belonging to the core papers selected for this study.

As mentioned before, most studies have analysed the local transitions process through socio-technical transitions theories such as Strategic Niche Management (SNM) [11, 13, 27] and Multi-Level Perspective (MLP) [24, 29, 31]. These theories explain the niche and regime interactions well, along with the innovation process. The analytical scale is local in terms of place (such as communities [14, 24]) and limited to the sub-national scale, and most of these studies are backwards looking, in terms of explaining and theorising after the fact. They help understand the transitions process as interactions between niches and regimes and landscapes, and in some studies the governance issues are framed as policy level explanations. For example, in [24] the governance of transitions is presented along the different structures present in the multiple bottom-up initiatives.

Table 3: The analysis of the selected core papers with the framework adopted from Turnheim et al.

Paper Title	Scale and temporality	Treatment of complexity	Innovation and inertia	Normative goals	Governing transitions
1 A grassroots sustainable energy niche? Reflections on community energy in the UK	Community energy scale is considered and analysis of the past is undertaken. Community energy is likened to niche's and their interactions with the regime are analysed.	Complexity is tackled through in-depth case study analysis, and no attempts at predictions. The Strategic Niche Management (SNM) explains the niche-level interactions and the networks which lead to collective learning.	While innovation is analysed, especially with respect to the transitions of each case, inertia is not explicitly analysed.	Both normative positioning and approach to sustainability are assumed implicitly, and are not explicitly analysed.	Governance is primarily addressed through networks and governance, and intermediaries and participants are represented in the analysis.
2 Challenging obduracy: How local communities transform the energy system	Scale matching from energy communities and their transformation into the regime are assessed. Temporally backwards looking analysis is present.	Analysis of community energy movement as a socio-technical transition movement. Predictive capacity is limited.	Innovation and inertia are both framed as opposition to present energy system.	Decentralisation and renewable energy generation are considered as normative goals.	While explicit actors and their agencies are discussed, the organisation behind the energy communities and networks are the point of interest.
3 Decentralisation dynamics in energy systems: A generic simulation of network effects	The analytical scale at the collection of household level, and ex-post and ex-ante analysis is presented.	Complexity is tackled through simulation of the energy system transition, with built-in predictive capacity. Also, actor heterogeneity is explicitly modelled, along with the pathways taken in the transition.	System inertia and innovation are not explicitly addressed.	Normativeness is prescribed through the diffusion of different power plants.	Governance is not explicitly addressed. But their actors and the networks which create different paths are analysed.
4 Decentralised laboratories in the German energy transition. Why local renewable energy initiatives must reinvent themselves	Scale is set at a de-centralised local energy initiatives and temporality is primarily backwards looking.	The analysis is done through the niche-regime-landscape interaction model and through rich analysis of the interviews. Explanatory focus is on the interaction and the supporting structures and barriers.	Emergence of innovation is not assessed, and inertia is not discussed as well.	Normative positioning is unclear in the analysis. But, implicitly, higher decentralisation and transition to decentralised energy initiatives are treated as a normative goal.	The multi-level governance perspective is used which gives explicit analysis of the different governance structures present in the case studies.
5 Dynamics of energy transitions under changing socioeconomic, technological and climate conditions in Northwest Germany	The regional-level scale is selected along with forward-looking temporal analysis of the local level energy transition.	Complexity is addressed through model simulation and through model validation through involved stakeholders. Different scenarios can capture the different pathways that are possible which lend a predictive capacity to the analysis.	Innovation and inertia are modeled as explicitly constraints in the simulation model.	Normative goals are lacking; the analysis is exploratory in nature. Normativity is not explicitly prescribed.	While actor heterogeneity is considered through the model validation process, governance of transitions is not considered in the analysis.
6 Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems	The scale is local integrated energy communities and backwards looking temporal analysis is presented	The framework of "integrated community energy systems" (ICES) is used to analyse the myriad local level energy transitions. The framework of analysis consists of structures, systems, barriers and motives along with the transition actors.	The emergence of ICES by themselves are considered as an innovation but inertia is not considered.	There is no single norm which is considered but rather community energy and sustainable initiatives are considered the end goal.	The governance issues are tackled through the ICES framework, in the complex transition process.

Continued

Table 3: Continued

Paper Title	Scale and temporality	Treatment of complexity	Innovation and inertia	Normative goals	Governing transitions
7 Energy transitions in small-scale regions - What we can learn from a regional innovation systems perspective	The analytical scale is at the small-scale regional level, where transitions in the small-scale regional level are considered as catalysts for major transition.	The analysis is framed through the lens of Reginal Innovation Systems (RIS), which looks at locally embedded actors and systems and their interactions.	Innovation and inertia are considered as arising out of the RIS's sub-systems' interactions with each other, and they are not covered in the analysis.	Normativity is not explicitly considered, but more regional and local level energy communities are considered better.	While interactions and the interplays are considered in the analysis, governance issues are not given much focus.
8 Harvesting energy: Place and local entrepreneurship in community-based renewable energy transition	Community level energy initiatives are considered here, and backwards looking analysis is presented.	Complexity is analysed through the "actors", that is technologies being considered as actors who start the complex dynamics of local energy transitions	The energy community initiatives themselves, and their place and local entrepreneurship are considered as innovations. Inertia is not explicitly considered.	The normative reasoning of social, economic or other needs for the local level transitions are implicitly assumed in this analysis.	Governance within the different 'levels' of place are analysed in this study.
9 Local authorities as niche actors: the case of energy governance in the UK	Analytically local actors' role in wider energy transitions are presented, in local communities, through backwards looking case studies.	In terms of complexity, how local actors brought about local and wider energy transitions is assessed through the Multi-Level Perspective (MLP).	Local actors themselves are considered an innovative niche, and how they promote and protect the niche is also explicitly analysed in this study.	Sustainability and renewable energy are considered as normative goals.	Governance in the general energy sphere, and its influence in local energy governance is addressed in this study.
10 Local energy policy and managing low carbon transition: The case of Leicester, UK	Analytically, the impact of household level transitions has on the transition of energy systems of communities are assessed in this paper, in a backwards looking timeframe.	In terms of complexity, external data are correlated with the autonomy municipal and local energy actors had in their respective communities. While quantitative in nature, the results are not presented in their predictive capacity.	Innovation and inertia are not explicitly considered in the study. While the transitions in the household and local level are assessed, the inertia associated is not articulated.	Better co-benefits such as reduction of energy poverty and the transition to renewable energy are considered as the normative goals.	The study is about energy governance and how local and national energy governance are at opposing ends of each other. So, the governance issues are discussed at a policy level.
11 Local Governments Supporting Local Energy Initiatives: Lessons from the Best Practices of Saerbeck (Germany) and Lochem (The Netherlands)	The scale is at a municipality level, and looking backwards	Complexity is treated through the framework of Strategic Niche Management (SNM), where the local energy initiatives are thought of as innovation agents bringing energy transition. The analysis is done through comparative case study analysis, which does not lend itself to generalisations or predictions.	While local energy initiatives are considered as innovation agents, inertia is not considered explicitly.	More renewable energy initiatives and sustainability are considered as normative, along with communities working together, and social benefits.	Governance of energy initiatives are discussed, but their interactions with multiple levels of governance are not analysed.
12 Local niche experimentation in energy transitions: A theoretical and empirical exploration of proximity advantages and disadvantages	The scale is local level transitions processes and the networks and proximity effects between them. The study adopts a backwards looking analysis.	The socio-technical transitions at local levels are assessed through Strategic Niche Management (SNM), and how different localities share their networks and the outcomes of those different transitions processes are also analysed.	Innovation is considered as a niche and inertia is considered through the niche's interaction with the regime and the landscape.	Normativity is considered through the ultimate transition itself, and through the second order learning ensuing due to the proximity effects.	Governing of the transitions are not tackled in the analysis.

Table 3: Continued

Paper Title	Scale and temporality	Treatment of complexity	Innovation and inertia	Normative goals	Governing transitions
13 One, no one, one hundred thousand energy transitions in Europe: The quest for a cultural approach	Analytically this study tries to find the commonalities between the local transitions processes and their place within the regional and national contexts. It has a backwards looking timeframe.	Treatment of complexity is by analysing local transitions through the lens of social, cultural, technical and other pertinent factors and trying to gauge the transition processes happening in different planes.	Innovation is tackled through the technical and social factors that the transition process entails, while inertia is implicitly tackled through the social factors and other artefacts.	Normative goals are not stated, though it is implied that sustainability and a drastically changed energy system are the end goals.	Governing transitions are not covered in this analysis.
14 Photovoltaic diffusion from the bottom-up: Analytical investigation of critical factors	Local community level bottom-up initiatives are analysed, the analysis is presented in a backwards looking manner.	The bottom-up initiatives and their transition processes are analysed through the Strength-Weakness-Opportunities-Threats (SWOT) framework, and Analytical Hierarchy Process (AHP) helps quantify them.	Innovation is implicitly treated as a strength in the SWOT analysis, but inertia is not articulated.	There are comparative pair-wise assessments of the transition processes, and normative goals are not stated.	Governance of transitions are not covered.
15 Scaling up local energy infrastructure; An agent-based model of the emergence of district heating networks	The scale is represented by local level energy infrastructure, and the relationship it has towards the national energy transition, and with a forward-looking timeframe.	The complexity of the local level energy transition is tackled through the modelling of agents and their behaviour in the local level transition. At the same, the different pathways are explicitly specified, articulating a predictive capacity.	Innovation and inertia are both tackled exogenously, through the technologies and the agents' behaviours.	The model analysis deals with explorative scenarios, and does not accommodate normativities.	Governance issues are not explicitly considered, but they are tackled through policy implications in the analysis, in terms of the governance at the local and national scale, especially the governance of the infrastructural decision.
16 Supporting energy initiatives in small communities by linking visions with energy scenarios and multi-criteria assessment	The scale is at a municipal scale, with forwards looking timeframe.	Future local community energy transitions are analysed by linking it to the visions of local actors. The analysis has predictive capacity, with the use of an energy simulation model, and linking the possible transition pathways with the actors' actions.	Innovation has been considered explicitly through the diffusion of new energy technologies in the system and inertia has been tackled through exogenous constraints	Many normativities are considered explicitly, such as sustainability, energy security, cost-effectiveness.	Governance of transitions have only been considered through the actor heterogeneity.
17 The establishment of citizen power plants in Austria: A process of empowerment?	The analytical scale is both local and regional level, with the electricity generation infrastructure and backwards looking temporally.	The transitions in the infrastructure through the citizen owned renewable power plants is analysed, and the complexity is viewed through the lens of socio-technical transitions theory. Predictive capacity is non-existent and a case study methodology gives in-depth analysis of the transitions process at the local level.	Innovation and inertia are implicitly assessed through the policy motives and barriers in the socio-technical transitions framework.	Inherently, citizen power plants and the transition of the infrastructure is treated as normative.	The governance issues are discussed with respect to communication and interaction of citizen power plants with the communities.

Continued

Table 3: Continued

Paper Title	Scale and temporality	Treatment of complexity	Innovation and inertia	Normative goals	Governing transitions
18 Towards a sustainable socio-technical system of biogas for transport: the case of the city of Linkoping in Sweden	The analytical place scale is based on a municipality and an extended temporally backwards point of view is adopted in this study.	The complexity is analysed through the Multi-Level Perspective (MLP) framework and socio-technical perspective on system builders. While predictive capacity is limited, there is theorising articulated, at the local energy transition level.	The local actors and their actions on the transition in the energy system is explicitly analysed, and inertia is implicitly discussed through the barriers to the transition.	The completion and propagation of biogas in the local municipality is implicitly assumed to be normative, along with the participation of local actors.	In terms of governance issues, the interaction at the local and national energy governance levels is analysed in the study.

The literatures assessed in this study through the framework of Turnheim et al. [1] do not leave room for the analysis of spatial scale and its impact on the transitions process. For example, in [13] the authors study how intermediaries and other actors help diffuse tacit knowledge, through the actor network. There is a geographically spatial aspect to this study of the transitions process. Yet, the spatial aspect of the diffusion of tact knowledge aiding the transitions process is a key characteristic of this literature. Another example could be the study of [30], where the density effects are closely looked at to see how they impact on the transitions process. Again, this is due to the spatial dynamics underpinning the transitions process and the framework is in-adequate in coping with this aspect.

In the studies which use socio-technical transitions theories normative goals are not explicitly mentioned, and the transition to general sustainable energy systems are implicitly held as normative. For example, in [9], the creation of energy communities are implicitly held as being the goal in the transitions process. While this is not in any way redundant, how this implicit normativity is captured in the study is not clear, thus creating unnecessary ambiguity.

Per the explanations of the approaches tended by Turnheim et al. [1] and our inductive analysis, the studies which are of the socio-technical analysis type are weak in treating the characteristics of “Normative goals” and “Treatment of complexity”. The examples of socio-technical theories are SNM and MLP. The uncertainty of the transitions process, which is a sub-criterion of “Treatment of complexity” is not considered in most socio-technical studies. The findings in Table 3 agree with this point of view of Turnheim et al. [1].

As mentioned in Section 2.2, and shown in Figure 2, representation of decision makers and sources of innovation (sub-criteria) belonging to ‘governing transitions’ and ‘innovation and inertia’ (characteristic), respectively are closely aligned with the specific complexities of local energy transitions. In the next section, this study presents features highlighted in peer-reviewed literature to be included in a suggested framework to assess local energy transitions.

On the other hand, in studies which complexity is analysed quantitatively, and normative goals are explicitly stated (such as [30]), governance of transitions are not analysed.

Another characteristic which is explicitly analysed is the pathways of the transitions and its dynamics, in the quantitative modeling studies. While SNM and MLP are clear in their explanation of the niche-regime interactions and niche-niche interactions, they often fall short of explicating the pathway dynamics that are possible through quantitative models. For example, the literature [26] clearly articulates how the different district heating projects contribute to the overall uptake of the innovation over time, and the proportion of the different types of project and their contribution to the diffusion. This is the pathway dynamics that are explicitly tackled in this particular literature studying this transitions process.

Upon closer scrutiny, another important aspect which should be noted is whether these local energy transitions studies should fall under initiative-based learnings (the definition of initiative-based learnings, as given by Turnheim et al. [1] is discussed in Section 2.2). While the authors of this study agree that these studies (core papers) have considered the myriad actors and their actions, and the learnings that accrue through this, the primary method behind these studies are not limited to this type. In fact, as presented before, most of the studies use socio-technical transition theories for their understanding of the transitions processes, while some use quantitative methods. This finding is significant because it implies that at present local energy transitions processes are primarily understood through socio-technical theories or through quantitative modeling studies, in conjunction with initiative-based learnings. Yet, both socio-technical studies and quantitative models have different strengths and weaknesses. While the socio-technical approach is good at espousing the innovation and governance issues, they fall short in explicating the normative goals or even taking them into account. Likewise, while quantitative modeling is good at explicating the normative goals and in scrutinising the analytical scale better, they fall short in explicating the governance issues. The analysis of these core papers along the framework postulated by Turnheim et al. [1]) clearly show that different approaches have different positive and negative aspects. The authors of this study agree that no type is complete by itself, as concluded by Turnheim et al. [1] and that the approaches should be used complementarily.

The findings also reinforce another premise that the authors of this present study intuited at the beginning of the study. The reference [2] has presented extensive information on the shortcomings of socio-technical transitions theories in studying transitions. These shortcomings are proven valid when they are transferred to the analysis of local energy transitions processes too. At the same time, they also give credence to the premise that in literatures, local energy transitions are mostly treated as broader energy transitions happening at a local scale. The findings in Table 2 show this clearly. Thus, the question whether socio-technical transitions theories, such as MLP and SNM which are widely used to study broader transitions are sufficient to understand local energy transitions processes, becomes pertinent.

3.2. Analysis of the peripheral papers

This section will present the analysis and findings from reviewing the peripheral literature chosen in this study, as mentioned in Section 2.1 (Selection of scientific literature). The papers have been read and inductively analysed to capture any unifying features that were given in the peripheral papers of local energy transitions selected in this study. The Section 3.1 systematically assessed the core papers. The aim of this section is to identify the features and explain them, and lay the foundation for the discussion in the following chapter, as to including the identified features into local energy transitions studies.

Table 4: The unifying features identified in the peripheral literature regarding local energy transitions

	Paper title	Spatial scales and levels	Ownership of transition	Different priorities	Institutional structures	Situative governance
1	A practice approach to study the spatial dimensions of the energy transition [34]	Impact of spatiality on the transitions process				
2	Decentralised combined heat and power in the German Ruhr Valley; assessment of factors blocking uptake and integration [42]	Impact of different geographical locations	Impact due to agency and ownership of process	Impact of differing priorities; sometimes the transition is by itself important regardless of the cost	Impact of civil society participation on the institutional structure	
3	Does civil society matter? Challenges and strategies of grassroots initiatives in Italy's energy transition [43]				Institutional structure fostering or hindering transition process	Different levels adaptive of governance and its impacts
4	Exploring the transition potential of renewable energy communities [44]				Regulatory frameworks and relationship with differing institutions	Governance of different actors

Continued

Table 4: Continued

	Paper title	Spatial scales and levels	Ownership of transition	Different priorities	Institutional structures	Situative governance
5	Grassroots innovations in community energy: The role of intermediaries in niche development [45]			Impact of learning as a priority	Networking between different stakeholders	
6	Growing grassroots innovations: exploring the role of community-based initiatives in governing sustainable energy transitions [46]			Actor interactions as the main motive of transition		
7	Local power: exploring the motivations of mayors and key success factors for local municipalities to go 100% renewable energy [4]			Different priorities influencing the transitions decisions and processes		
8	Local renewable energy cooperatives: revolution in disguise? [47]	The spatial aspects of propagation of transitions movements				
9	Participation in Transition(s): Reconceiving Public Engagements in Energy Transitions as Co-Produced, Emergent and Diverse [36]		Public participation seen as the main driver of transition		Impacts of transitions due to the politics of system change	Differing actor dynamics and adaptive governance for transitions
10	Putting an energy system transformation into practice: The case of the German Energiewende [48]	The spatial aspects of decentralisation and impact on transitions				
11	Situative governance and energy transitions in a spatial context: case studies from Germany [35]					Situative governance through actor heterogeneity and power
12	Social planning for Energy Transitions [38]		Ownership of transition creating a wider socio-energy system, as opposed to a techno-energy system			
13	Stakeholder participation in municipal energy and climate planning – experiences from Sweden [49]		Stakeholder participation as a driver for ownership of transition			
14	Sustainability transitions: A political coalition perspective [39]				Political structure and its influence on transitions	Political inertia changing the governance of transition

Table 4: Continued

	Paper title	Spatial scales and levels	Ownership of transition	Different priorities	Institutional structures	Situative governance
15	Towards a low carbon future: a phenomenology of local electricity experiments in Germany [50]					Different governance structures under high-uncertainty
16	Triggering transformative change: a development path approach to climate change response in communities [41]		Ownership of transitions being fluid			Multi-level governance and its impact on transitions
17	What drives the development of community energy in Europe? The case of wind power cooperatives [40]	Transition seen as a socio-ecological system, impacted by spatial scales			Transition seen as a socio-ecological system, impacted by institutional structures	
18	Whose energy transition is it, anyway? Organisation and ownership of the Energiewende in villages, cities and regions [37]		Ownership of transition being antithetical to a technocratic transition system			

Table 4 presents the significant features identified in the peripheral literature, through inductive analysis. These features were gleaned from the analysis of the peripheral papers, after the understanding of the core papers through the framework of Turnheim et al. [1]. The five main features were identified and the following sub-sections 3.2.1 to 3.2.5 introduce the features thus identified.

3.2.1. Spatial scales and levels

Faller [34] says that frameworks studying local transitions have ignored the fact transitions processes happen as a result of transitions practices, and these practices should be situated within the context of transitions processes, which take place at different spatial locations. At the same time, Fuchs and Hinderer [35] argue that the spatial context should be considered when governance is considered.

The spatiality, in terms of geographic, physical and cultural location, and the different levels of spatiality and their interactions are all important in the context of local energy transitions. For example, a similar culture could be in different geographical locations but might spur on similar transitions processes and the framework to study transitions should be able to take this into account. Similarly, physical locations could be dependent on physiological conditions which spur on the transitions process but might not be in geographical proximity to each other.

3.2.2. Ownership of the transitions

Chilvers and Longhurst [36] make the point that often in local energy transitions the varied methods, objectives and processes of participation of the different actors are completely ignored. Thus, the nature and the mechanics of the local energy transition is often not accurate. Ownership is empirically tied to agency and participation in transitions studies. Ownership is defined as the concept of laying claim to the transitions process and/or the artefacts surrounding the transitions per se [36]. Along with the different participatory models brought out by that literature, Moss et al. [37] point out that local energy transitions is an issue of ownership: to think of it technocratically and to think of local energy transition as a socio-technical transition is a travesty to the inimitable characteristics underpinning local transitions, especially in the current times of co-owned, co-produced or co-created transitions (coining of terms by authors). Thus, some of the points of ownership are;

- Co-produced or co-created transitions and their assessment,
- Cooperatives at the helm and their governance structures,
- Collaborative and symbiotic nature of said transitions,
- Adaptive capacity and, in general, resilience of societal systems, and
- Conflicts and mediation

3.2.3. The different priorities of the local communities and with the inherent synergies and oppositions–sub-optimal results

Busch and McCormick [4] show that local communities have different objectives, which are sometimes not in conjunction with the national or even the regional goals, and as such are even prepared to accept sub-par results, in terms of the transitions they are aiming for. They have used the "Theory of Planned Behaviour" to map out said differences, but this aspect is also interconnected with the issue of ownership.

3.2.4. The different institutional structures, and the interplay between levels of institutional structures

The plurality of actors of different types, in differing levels requires different institutional structures, as noted by [38, 39]. For example, the local municipal council has a say over land-use, but the feed-in-tariffs are set by national agencies, and the aggregators are regional operators, in the case of decentralised electricity generation [40]. Thus, this is also an important element of local energy transitions. But it should be considered in conjunction with situative governance, which is explored in the next sub-section.

3.2.5. Situative governance

Situative governance as explained through the theory of Multi-Level Governance (MLG) [41] is the core of Burch et al. work. In that, they suggest that local transitions happen because of effective situative governance, which governs the multiple actors and institutions. Thus, situative governance should be considered as a unifying thread of institutional structures and ownership. Also, situative governance also implies governance under higher uncertainty, which is a characteristic inherent in local energy transitions.

This section has identified five additional features (when compared to Turnheim et al. [1]) which is part of local energy transitions and hence ought to be assessed, studied and articulated when studying and understanding local energy transitions. In short, the authors argue that local energy transitions are not limited to the characteristics given by Turnheim et al. [1]. As such, in the framework proposed by Turnheim et al. the two sub-criteria marked in red in Figure 2, Section 2.2 (*Sources of innovation and Representation of decision-makers*) are somewhat related to the governance feature identified in the group of peripheral literature. But they are not sufficient. The five features presented here are essential in capturing the nature of collaborations and differential priorities which underpin the local energy transitions and practices. This would be a contribution to the general study of local energy transitions. The forthcoming Sections 4.1 and 4.2 would further articulate this point.

4. Discussion

This section discusses the core papers, and situates the five features identified in Section 3.2, among the core papers. In the following section (Section 4.2) the authors of this paper propose an extension to Turnheim et al.'s [1] framework, which may help better in the understanding of local energy transitions process.

4.1. Situating the identified features among the core literatures

In the previous section the authors identified five features of local level energy transitions that are not represented in the most comprehensive framework by Turnheim et al. [1]) that is used to assess energy transitions. Those are: spatial levels and scale, ownership of transition, differing priorities, institutional structures and situative governance. Along with this, the authors identified that the pathway dynamics (PD) is also not studied in local energy transitions papers. The rest of the Section 4.1 discusses these identified features in the context of the core papers.

The authors have arranged and discussed the five features among the core papers, and as such all 18 of the core papers are discussed in Sub-sections 4.1.1 to 4.1.5, but not all the 18 papers are discussed in the context of each feature. The aim of this discussion is to not get into lengthy prognostication of these papers, but rather to highlight how the core papers could have benefitted from an analysis of the five identified features, or in some cases articulate how the features are treated in the papers. The discussion serves as a justification of why these features are important in explicating local energy transitions.

4.1.1. Spatial levels and scales

The spatial levels and scales take an important place in some studies selected in the core literatures. The [27] points out that spatial parity provides advantages and needs to be discussed in local level energy transitions. Also, while socio-technical transitions theories talk about niche-regime interactions, they often do not account for spatial niche-to-niche interactions, which is assessed by [27].

In both [10] and [9], while technological, and institutional factors are considered, spatial features and the spatial context is not explicitly considered. As Coenen et al. [24] mention, the analyses presented in the papers mentioned above would be enriched by the spatial context as well, since this will enhance the explanation of the transitions.

In [14], the crux of their analysis has been based on the local initiatives having place-based relevance in propagating energy transitions. They also consider technologies as being 'space-based actor' and setting in motion a social revolution. The spatial scale is an important analytical point-of-view in local energy transitions.

4.1.2. Ownership of transitions

Ownership of transitions as a means of driving transitions is looked at by [24]. How the national policies helped local communities owning renewable initiatives to thrive are assessed along with other enabling factors for local energy transitions.

How agency and participation in local networks helps energy transitions is analysed through Actor Network Theory in [17]. Sometimes ownership of transitions is an important enabler or in some cases, a motivating factor as [15] mentions, for local energy transitions. Most local energy transitions ownerships are different compared to national or even global level energy transitions. They have different ownership structures, such as co-ownership of technologies or patents among other things, which needs to be considered when one studies the said transitions.

4.1.3. Differing priorities

In [29], the authors say that at the beginning of the transition to biogas, one of the reasons for local communities to consider biogas was as a waste-disposal method and for improving local air-quality. While the national government's policies helped, the uptake was driven by completely different priorities, among the local actors.

In most local energy transitions, the local communities see the transitions as more than just means to an end, but rather as being important for other reasons as well. These reasons could range from economic upliftment of the society [33], networking and learning among the community [13], empowerment of the society [15] and even cultural unity [18, 28]. Thus, the normative goal should be wide enough to accommodate these differing and sometimes sub-optimal priorities which may be the nature of local energy transitions.

4.1.4. Institutional structures

Analysis of institutional structures are considered with socio-technical transitions theories. But, they are mostly considered with the technological regime, where institutional structures prop-up the regime-change. But, as discussed in [10], most local energy transitions' institutional structure should be amended to accommodate local energy cooperatives, and other intermediaries.

Also, while considering the techno-economic details and the pathway dynamics in a transition study, it is also important to assess whether the supporting institutional structure will have an effect, and if it will, what sort of an effect it would be, to make the assessment of the transition more meaningful [25]. How the multitude of actors, such as prosumers and intermediaries are considered becomes important in local energy transitions, according to [30]. For example, [11] articulate that some energy communities have equal decision making power while some depend on executive decision-making power by some local authority. The institutional structures and their analyses becomes essential to accommodate the multiple actors and their interactions.

4.1.5. Situative governance

In [35], the authors base their analysis on the situative governance structures and associated issues which are endemic to local energy transitions. Situative governance is called for when transitions happen under high uncertainty, and they do so in most local energy transitions [26]. Lemon et al., [32] also stress that situative governance is an important part in ensuring that transitions and their benefits reach local communities, and that such governance structures are in place. Situative governance becomes an important feature to consider in assessing local energy transitions, because of the involvement of multiple actors as pointed out by [25, 31]. The feature of situative governance is important when considered in conjunction with ownership of transitions and institutional structures.

4.1. Proposing an extension to the assessment framework of Turnheim et al. [1]

This section proposes an extension to the framework presented by Turnheim et al. [1], and the extensions stem from the five features discussed in the preceding sections. Figure 3 gives the proposed extension, where along with the five original characteristics (Scale and temporality, Treatment of complexity, Innovation and inertia, Normative goals and Governing transitions) a new characteristic titled "Institutions" is added. In Figure 3, the newly added characteristics and sub-criteria are shaded in green.

The "Institutions" characteristic has the sub-criteria of "Ownership of transitions", "Participatory models" and "Power and agency dynamics". As discussed in Section 3.2, this characteristic encompasses the characteristic that local energy transitions have complexities arising out of varied ownership and participatory models, which lead to more varied and complex power and agency dynamics, which in turn would affect the outcome of the assessment of local energy transitions. The power and agency dynamics are brought on by the differing priorities of local communities, with its inherent synergies and conflicts, and along with the different participatory models and ownership (as mentioned before, co-produced or co-created transitions) within the local energy transitions and their studies would be enriched with this extension.

As discussed in Section 4.1, spatial scales and levels are important in local energy transitions, as spatial interactions come into more focus in local level transitions studies. Thus, the authors also propose adding a sub-criterion "Spatial scale" to the already existing "Scale and temporality" characteristic.

In addition to the discussions presented in Sections 4.1 and 4.2, the authors also propose adding a sub-criterion to the characteristic "Treatment of complexity" as per Section 3.1. The pathway dynamics is important in understanding the local transition process, and in understanding the effects of the transitions themselves. As such, "Treatment of dynamics", either in its descriptive or normative form [5], needs to be accounted for in local energy transitions studies. Thus, the authors extend the "Treatment of complexity" characteristic with a sub-criterion "Treatment of dynamics".

Overall, authors agree with various literatures which have called for an integration and combination of several methodologies to deal with socio-technical [5, 8], and energy transitions [22, 51, 52]. A combination of methodologies will shed more light on the complexities

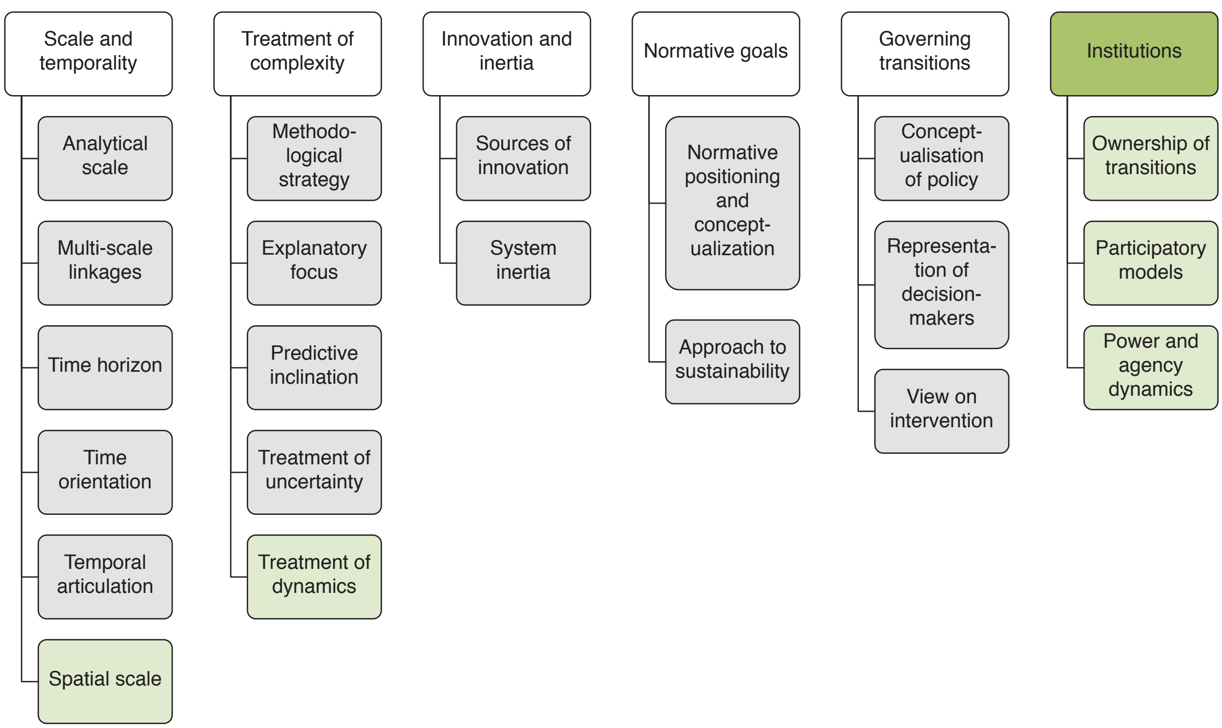

Figure 3: The proposed extended framework to assess local energy transitions, as stylised by the authors

arising in studying and understanding local energy transitions and processes.

The extension of the Turnheim et al. [1] framework is tendered because of the deep inductive analysis carried out of a set of 18 core, and 18 peripheral papers. This proposition could be strengthened by empirical studies and theorising as well. This would increase the validity of the proposed extended framework and will better articulate how the understanding of local energy transitions processes are enhanced by extending the said framework.

5. Conclusion

The findings with regards to the core papers selected in this study show that most studies have analysed the local transitions process through socio-technical transitions theories such as Strategic Niche Management (SNM) and Multi-Level Perspective (MLP). These theories explain the niche and regime interactions well, along with the innovation process. The analytical scale is local in terms of place and limited to the sub-national scale, and most of these studies are backwards looking, in terms of explaining and theorising after the fact. But, they fail to treat complexity of the transition in terms of the pathway the transition takes and the dynamics of that pathway of the transition. The studies which use a primarily quantitative methodology, such as system dynamics or agent-based modeling, have normative goals which are explicitly stated, but these studies do not tackle the governance of transitions extensively.

While socio-technical transitions theories have some inherent shortcomings, our findings point out that in the core papers selected, local energy transitions were mostly studied as broader energy transitions, and the shortcomings discussed in [1] are still present in these literatures. This finding calls for better scrutiny of understanding local energy transitions.

While the Turnheim et al. [1] framework is the most comprehensive in terms of analysing sustainability transitions, the authors find through the analysis of the peripheral papers that local energy transitions share most of the features of energy transitions and processes but, also have certain additional features which are often overlooked. The five such features that are critical when studying local energy transitions are spatial scales and levels, ownership of the transitions, differing priorities of the actors, different institutional structures, and situative governance issues.

Finally, the paper proposes extending the framework put forward by [1] by adding a characteristic titled "Institutions" with sub-criteria "Ownership of transitions", "Participatory models" and "Power and agency dynamics". At the same time, it also prescribes adding the sub-criterion "Treatment of dynamics" to the characteristic "Treatment of complexity" and adding the sub-criterion "Spatial scale" to the characteristic "Scale and temporality", respectively.

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