Analyzing sectoral niche formation: The case of net-zero energy buildings in India

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\begin{abstract}
Large scale development of Net Zero Energy Buildings (NZEBs) is seen as a potential solution to deal with future energy challenges in the building sector. This article aims to assess the current status of NZEB development in India by using an integrated framework named Sectoral System Innovation Assessment framework (SSIAf). The article addresses the research question: "What does the SSIA framework tell about NZEB niche formation in India? The SSIA is developed using insights from the theoretical frameworks of Strategic Niche Management (SNM) and Sectoral Innovation Systems (SIS) with five key components: shaping of expectations, social network formation, institutions, learning process and market demand. A case study research design was used to analyze seven NZEB demonstration projects in India. The results show that the NZEB innovation niche has yet to develop into a mature niche, and is growing only slowly.

\end{abstract}

1. Introduction

Both in construction and in operation, buildings consume vast amounts of energy. This energy is mainly derived from fossil fuels (UNEP-SBCI, 2009). It poses a major challenge since these conventional sources of energy are limited and cause serious environmental damage including greenhouse gas (GHG) emissions. A transition towards low energy, low carbon and energy efficient buildings has gained much attention in recent decades but has seen mixed success (IEA and WEO, 2013). Many developed countries are currently preparing to transform their building sector (both new and existing) by deploying more Net Zero Energy Buildings (NZEBs)\textsuperscript{1} (EU-Commission, 2013). NZEBs are buildings that are self-sufficient in meeting their energy needs, first by reducing energy demand and then by using on-site renewable energy sources to meet the remaining needs (Hermelink et al., 2013). Torcellini et al. (2006) define NZEB as 'a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies.'

The large-scale uptake of NZEBs is expected to enable many countries to reduce their energy and carbon footprints and move towards using renewable sources of energy for their building sector (Iqbal, 2003). To achieve this, policies and innovative approaches are being developed and implemented (Jain et al., 2014). As such, governmental actors are one of the

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\textsuperscript{1} Net Zero Energy Buildings is also interchangeably termed as Near-Zero Energy Buildings.

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main facilitators of the introduction and diffusion of new sustainable technologies. In addition, actors from both the public and private sectors are expected to participate in creating an enabling environment for this socio-technical transformation (Schot and Geels, 2008). The large-scale adoption of NZEBs is not straightforward as building-sector stakeholders still view it as a complex concept, to an extent because it can be described in a wide range of terms and expressions without a standardized holistic approach. Its definition can vary depending on the project goals, the intentions of the investor, concerns about climate change and energy costs (Marszal and Heiselberg, 2009).

Many developed countries have demonstrated the NZEB concept as a practical option. They are now in the process of expanding the niche towards wider adoption through societal acceptance (Voss and Musall, 2011). In doing so, governments have also set ambitious targets to decarbonize their building sector (for example, the European Union (EU)) Directive on Energy Performance of Buildings (EPBD) specifies that, by the end of 2020, all new buildings should be “Net Zero Energy Buildings” (EPBD Recast, 2010). However, ambitious targets and innovative approaches are missing in most developing countries where sustainable transitions are still needed (Lachman, 2013). A good example is India in which only a handful of NZEB demonstration buildings have been constructed in recent years.

In India, the building sector is growing rapidly, with an estimate that 70% of the 2030 building stock had yet to be constructed (NRDC and ASI, 2012). In terms of energy consumption, this poses a large challenge as buildings are responsible for nearly 33% of India’s total energy consumption, which is mostly derived from fossil fuels (NRDC and ASI, 2012). A growing population, stable economic growth and rapid urbanization further increase the challenge of meeting the growing energy demand (Ofori, 2002). From this perspective, buildings which meet their energy demand through self-generation can become a favourable solution to deal with the energy challenges (demand–supply shortage, energy security, fossil fuel dependence) facing the country, especially in growing urban settings. To achieve this, a major systemic transformation will be required to fundamentally change the way in which buildings are designed, constructed, operated and refurbished throughout their life. This will be a formidable task since, despite efforts towards sustainable building solutions; the mainstreaming of energy efficiency in the building sector is still a challenge. This means that in recent years, a few NZEB demonstration projects have gained attention, showing early signs of the formation of a new niche. These NZEB building sector will require radical transformations or structural change on the societal scale once they are able to demonstrate the benefits. Such socio-technical transitions imply changes in structure, user practice, regulations, networks, infrastructure, culture and new technologies (Loorbach and Rotmans, 2005).

Theoretical frameworks such as Strategic Niche Management (SNM: Kemp et al., 1998; Hoogma, 2002; Raven, 2005; Schot and Geels, 2008) and Sectoral Innovation Systems (SIS: Malerba, 2004; Geels, 2004; Faber and Hoppe, 2013) provide insight into fostering technological and social change to initiate sustainable innovations at the niche and sector levels respectively. SNM is an analytical framework designed to facilitate and study the introduction and diffusion of new sustainable technologies through societal experiments (Schot and Geels, 2008). It is also argued that, to understand innovation activities at the niche level, it is important to understand sector-level innovations through a lens that highlights sectoral innovation systems (Webber and Hoogma, 1998). The latter is a more holistic approach than focusing on a single technological niche and provides a more comprehensive understanding of learning and innovation processes that are specific to a given industrial sector. In this paper, a new heuristic tool is proposed that combines insights from the conceptual SNM framework and SIS framework: the Sectoral Systems Innovation Assessment Framework (SSIAF) and can be used to analyse the innovation system surrounding a given technological niche in a given economic sector (the conceptual details are addressed in Section 2).

The aim of this article is to assess the status of NZEB niche innovation in India. The main research question is: “What does the SSIAF framework tell about NZEB niche formation in India?” The question will be answered by assessing NZEB demonstration projects in India. In this, SSIAF is used as the primary theoretical framework to assess the niche formation process at the sectoral level.

The article is structured as follows. Section 2 presents the theoretical underpinnings of SSIAF with origins in SNM and SIS. Next, Section 3 addresses the research design and methodology adopted in this study. Section 4 presents the results which then, in Section 5, are discussed and positioned in on-going academic debates. Finally, the main conclusions are presented in Section 6.

2. Background to the sectoral system innovation assessment framework

This article uses an assessment framework (SSIAF) that draws on insights from two distinct theoretical frameworks (and the research traditions they stem from): (i) Strategic Niche Management (SNM) and (ii) Sectoral Innovation Systems (SIS). Before presenting the SSIAF, the main conceptual notions of SNM and SIS will be presented, as well as their shortcomings and previous conceptual endeavours to combine insights from the two frameworks. Finally, based on these insights the SSIAF will be presented as an integrated framework that allows for analysing niche formation in a particular given economic sector.

2.1. Theoretical frameworks

2.1.1. Strategic niche management

The concept of SNM was introduced by the late 1990s as a theoretical framework and a policy tool to manage technological innovations and to facilitate the market introduction of sustainable technologies (Schot and Geels, 2008). The
theoretical background of SNM draws on insights from constructivist science and technology studies (such as the Constructive Technology Assessment; CTA) and evolutionary economics as developed by Nelson and Winter (1982) and Dosi (1982). SNM refers to the process of deliberately managing niche formation processes through real-life experiments. In a society, established, commonly used technologies are generally embedded in societal structures that provide substantial barriers to the introduction and diffusion of new sustainable technologies. The introduction of sustainable technologies often fails for reasons linked to technology, government policy and regulatory frameworks, demand and production, culture and society, and infrastructure (Kemp et al., 1998).

SNM advocates for radical innovation through socio-technical experiments in which various stakeholders successfully collaborate and exchange information, knowledge and experience (Caniëls and Romijn, 2008). This involves several actors within the dominant sectoral regime making it a multi-actor approach. It sees governments (as one of the participating actors or stakeholders) as instrumental in facilitating wider transitions (Schot et al., 1999; Rip and Kemp, 1998; Weber et al., 1999). This can be achieved by setting up a set of successive experiments or by policy instruments (proposed by governments) that support niche development (e.g., subsidy schemes, regulatory exemptions, or pilot projects). SNM theorists explain the success or failure of a niche by analysing the interactions between the three main niche processes: (i) shaping of expectations, (ii) building social networks and, (iii) learning processes (Mourik and Raven, 2006; Caniëls and Romijn, 2008; Schot and Geels, 2008).

However, some have criticized SNM claiming that it is difficult to assess whether SNM actually works (e.g., (Lachman, 2013)). SNM conveys the idea that a transition can be accomplished through the execution of appropriate management such that transitioning is largely viewed as a managerial task. This view does not align with the concept of a complex society, one that cannot be managed like a business firm (Shove and Walker, 2007). Criticisms of related theory (in particular the Multi Level Perspective; MLP) also apply to SNM because SNM builds on these theories (Lachman, 2013). These approaches are considered to be heavily “flavoured” by the context in which they were conceived, and therefore as potentially less suitable for other contexts. This is a limitation in that most MLP and SNM related studies were conducted in developed countries, and only a few in developing countries. For this reason, calls have been made for more research on approaches to transitions in non-OECD and developing countries who are arguably “more in need of sustainable transitions” (Avelino and Rotmans, 2011).

When building on early transition-based policy concepts, such as SNM, there is a need to improve the understanding of the politics and policies of sustainable transitions. On the conceptual level, issues of power and politics were initially somewhat neglected (Meadowcroft, 2009; Shove and Walker, 2007) but have garnered more attention in recent years (e.g. Avelino and Rotmans, 2011; Grin et al., 2010). In a similar vein, agency and power through the strategic interplay of different types of actors, including demand-side actors, civil society and grassroots movements, were considered as under-researched (Markard et al., 2012; Shove and Walker, 2007; Seyfang and Hexaline, 2012; Seyfang and Smith, 2007). In particular, the MLP has long been criticized for underplaying the role of agency in transition studies (Smith et al., 2005).

2.1.2. Sectoral innovation systems

An innovation system can be seen as a network of organizations, people and institutions within which the creation, diffusion and commercial exploitation of new technologies takes place (Malerba, 2004). The Innovation Systems literature, and in particular the Sectoral Innovation Systems (SIS) literature, emphasizes how the characteristics of an economic sector determine the scope of innovation within it (Beerepoot and Beerepoot, 2007). Within SIS, the core building blocks are: knowledge and technology, actor and networks and institutions (Malerba, 2002, 2004, 2007). Faber and Hoppe (2013) elaborated on the SIS framework and used it to assess sustainable energy transitions in the Dutch construction sector. In their view, SIS contain building blocks in four core dimensions: (i) knowledge and technology, (ii) actors and networks, (iii) institutions and (iv) market demand creation (adding the last one to Malerba’s initial set of building blocks).

Although the Innovation System (IS) literature offers many benefits, it also suffers from various limitations. The focus is somewhat on the functioning of systems and element weaknesses rather than system change itself. Moreover, there is little attention given to reasons behind these weaknesses. The IS approaches tend to over-emphasize large actors such as industry, institutes and firms. There is a bias towards producers and suppliers and a tendency to neglect smaller actors such as citizen-led grassroots movements (Shove and Walker, 2007). Moreover, the IS approach neglects the demand side of markets. According to Geels (2004), most attention in IS studies are directed towards the study of the development of knowledge and that there is a need to also emphasizing the diffusion and application of technology and its impact on society.

Typically, IS approaches measure and assess innovation system performance at the level of the system and sub-systems. An indicator commonly used to measure the overall performance of a system is the diffusion of the innovation under study (Bergek and Jacobsson, 2003; Bergek et al., 2015). However, innovation diffusion is also used implicitly as the main indicator of system performance (with less attention paid to other theoretically relevant indicators). One of the key areas identified for further refinement and alignment in IS approaches is performance assessment (e.g., defining indicators for different types of systems and different IS sub-functions (Markard and Truffer, 2008)). To an extent for this reason, IS approaches have been criticized for being “inwardly oriented” by not paying sufficient attention to the system’s environment (Markard and Truffer, 2008).
2.2. Integration of concepts from the SNM and IS traditions in the literature

Several attempts have been made to integrate insights from the Innovation System and Transition theoretical frameworks, notably frameworks that have been established by Markard and Truffer (2008), Meelen and Farla (2013), and Weber and Rohracher (2012). We will address them shortly.

Markard and Truffer (2008) reviewed both theoretical concepts and explored commonalities and differences. They acknowledged that Technological Innovation Systems (TIS) and MLP are closely related concepts in studying far-reaching technological changes. Based on the results of this comparison Markard and Truffer developed a combined approach. It provides certain benefits: (i) it more explicitly considers innovation processes at the micro-level of organizations; (ii) it takes into account mutual interdependencies between actors and institutions; (iii) it provides consistent performance comparisons; and (iv) it facilitates systematic identification and assessment of the broad range of TIS factors that influence innovation processes. The authors went on to present a path towards a framework that combines the strengths of the two approaches to allow a better understanding of radical innovation processes and socio-technical transformations. Ideas were formulated to embed technological innovation systems that can contain one or more niches.

Meelen and Farla (2013) made a plea to combine the TIS framework with MLP to better capture the relationship between technology evolution and sectoral change. They combine insights from the two theoretical frameworks to develop an integrated framework that can be used to analyse sustainable innovation policy. In the framework, the multilevel view from the Transition Management (TM)/SNM approach has been integrated with the functions approach of the (T)IS literature. This integrated policy framework shows that specific policy goals and measures can be found at specific points in an intervention related to the interfaces between landscape, regime, IS and niches. The integrated framework suggests that the stimulation of (T) IS only makes sense when this is closely aligned with landscape and regime developments (Meelen and Farla, 2013).

Another attempt at a conceptual integration between the IS and SNM/MLP traditions is the "sustainable transitions failures framework" by Weber and Rohracher (2012). Insights from transition studies (MLP/SNM) are used in a policy framework that is based on the IS approach and the notion of ‘failures’ (factors that prevent sustainable innovations). This framework draws on a combination of market failures, structural system failures and transformational system failures (Weber and Rohracher, 2012). The focus of related research is often unsustainable value change, and sustainability issues such as climate change. Empirical research has shown that the framework is useful, but that it is difficult to address the comprehensive set of failures, and that many are intertwined. In addition, although designed as a ‘policy framework’, the failures framework neglects valuable conceptual insights that are available from the policy studies discipline (Hoppe, 2016).

Although the afore mentioned merger frameworks as presented by Markard and Truffer (2008), Weber and Rohracher (2012), and Meelen and Farla (2013) offer clear benefits over solely using SNM/MLP or (T)IS theoretical approaches their benefits should also be viewed from perspectives of those who will be using it for research. For instance, the failures framework (Weber and Rohracher, 2012) problematizes a large set of barriers that prevent sustainable transitions from happening, which can serve as barriers to which policy makers can design interventions to overcome them. However, we consider this framework to be very comprehensive, time consuming to apply in empirical research, and pre-emphasizes barriers instead of having a more integrated view that also address (enabling conditions) to niche formation, which includes strategies and interventions to overcome the observed barriers.

In a similar vein, the framework by Meelen and Farla (2013) addresses issues that are of special interest to policy makers, and does not go much beyond this scope. For these reasons we feel it is necessary to develop a theoretical framework that involves and integrates key insights from SNM and IS, but copes with the problematic issues of the afore mentioned merger frameworks; i.e., by not only focusing on barriers and problems, by going beyond having a myopic (prescriptive) policy oriented vision, and by avoiding to construct a framework that is too complex and comprehensive to apply to case study research of (sustainable, sectoral) niche formation.

In sum, we feel that a theoretical framework should be developed that is able to: (i) analyze the status quo of a given sectoral niche formation and (ii) analyze the historical development of this given sectoral niche formation process. Moreover, the framework should acknowledge most of the benefits offered by the integrative framework by Markard and Truffer (2008), including systematic identification and assessment of the broad range of (T) IS factors that influence innovation processes. The proposed SSIA framework presented in the following sub-section is designed to empirically assess sectoral niche formation. It should allow for a better understanding of niche innovation process within a given sectoral domain.

2.3. Integrated assessment framework to analyse sectoral niche formation

In assessing the status of NZEB niche innovation, SNM and SIS, despite their stated limitations, both provide insights into the innovation process for the diffusion of sustainable technologies. Although the two frameworks were developed independently (SNM derives from transition theory) (in particular the MLP) and SIS from innovation systems (IS), they share conceptual grounds and both can be used to explain innovation phenomena (Markard and Truffer, 2008).

The SNM framework represents processes of radical innovation in a protected niche, and the SIS approach is used in this paper to complement this on the premise that SIS address sector level innovations (and the wider sectoral level context such as the building sector) which ultimately influence niche formation and growth. The resulting structural building blocks (which we see as ‘enabling conditions for niche development’) are used conceptually to assess the status of the NZEB
innovation niche. Fig. 1 presents the conceptual elements of the SNM and SIS frameworks. The arrows indicate conceptual commonalities.

The shaping of expectations, social network formation and learning process components are derived from SNM and are complemented with two additional structural blocks, namely institutions and market demand, from the SIS framework to form five fundamental theoretical blocks that will be used to analyse the status and the transformative processes of an innovation niche. The five building blocks jointly influence the sectoral niche formation process and the innovations that result from the formation of a new radical niche within a sector (see Fig. 2).

### 2.3.1. Shaping of expectations

The promises and expectations of a new technology are considered important in niche development processes in order to attract attention; mainly to clarify what the benefits of the niche will be (in our case the benefits of NZEBs). Interested actors and stakeholders such as business firms, end-users, policymakers and entrepreneurs participate in niche development processes on the basis of their expectations (Raven, 2005). According to Raven (2005), the process of shaping expectations is considered as good when (i) an increasing number of participants share the same expectations (converging towards a shared vision), and (ii) the expectations are increasingly based on tangible results from transitional experiments. Thus, positive expectations about a niche technology can support the concept to grow in scale, and attract more participants and resources, by translating the niche idea (in our case NZEBs) into the mainstream setting (Schot and Geels, 2008).

Fig. 1. SNM and SIS framework complementarities (Jain et al., 2014).

Fig. 2. Conditions enabling sectoral niche formation.
Table 1
Assessment criteria for sectoral niche formation.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaping of expectations</td>
<td>• An increasing number of participants share the same expectations (converging to a shared vision).</td>
</tr>
<tr>
<td></td>
<td>• Expectations are based on tangible results from transitional experiments.</td>
</tr>
<tr>
<td>Actor network formation</td>
<td>• Size of the sectoral actor-networks (including both primary agents and secondary agents, and both regime insiders and regime outsiders).</td>
</tr>
<tr>
<td></td>
<td>• Extent of formal and informal interactions.</td>
</tr>
<tr>
<td>Learning process</td>
<td>• Broad learning (on technology and knowledge, techno-economic optimization, technical and social alignment).</td>
</tr>
<tr>
<td></td>
<td>• Reflexive learning, self-governance, flexibility to change course.</td>
</tr>
<tr>
<td></td>
<td>• First- and second-order learning.</td>
</tr>
<tr>
<td>Institutional alignment</td>
<td>• Formal institutions (rules, laws, regulations, monitoring).</td>
</tr>
<tr>
<td></td>
<td>• Informal institutions (values, responsibilities, obligations).</td>
</tr>
<tr>
<td>Market demand creation</td>
<td>• Requirements and preferences</td>
</tr>
<tr>
<td></td>
<td>• Heterogeneity.</td>
</tr>
<tr>
<td></td>
<td>• Role of niche markets.</td>
</tr>
<tr>
<td></td>
<td>• Market structure, size and segmentation.</td>
</tr>
</tbody>
</table>

2.3.2. Actor network formation

Developing a niche may require new actors to get together and new social networks to emerge that provide and exchange the necessary resources (e.g. money, people and expertise). Mourik and Raven (2006) argue that social networks are favourable for a niche development when: (i) the network is broad (including firms, users, policymakers, scientists and other relevant actors from the science and technology domains, the policy domain, the social domain and including both regime actors and regime outsiders), and (ii) when alignment within the network is facilitated through regular interactions between the actors. Interactive processes are seen as key to innovation and a major driving force for sectoral change (Hofman, 2002; Malerba, 2007; Caniëls and Romijn, 2008).

2.3.3. Learning process

A learning process is considered likely to spur innovations if there is a broad focus which not only addresses techno-economic optimization but also the alignment between the technical (e.g. technical design, infrastructure) and social (e.g. user preferences, regulation and cultural meaning) aspects. Hoogma (2002) identifies five aspects that are considered important in learning about innovation/niche development: (i) technical development and infrastructure, (ii) user context (i.e. user characteristics and consumer needs), (iii) societal and environmental impacts, (iv) industrial development and (v) government policy and regulations. Finally, a protected niche space may enable innovators to benefit from new learning opportunities.

2.3.4. Institutional alignment

The concept of institutions includes various formal and non-formal rules, such as values, routines, common habits, established practices, laws and standards, which all shape the cognitions and actions of agents, as well as the interactions between agents (Malerba, 2004). Formal institutions refer to “the formal rules of the game”, including rules, laws, monitoring and sanctioning, and government policies. Informal institutions describe the rules that provide legitimacy to individual practices by referring to values, responsibilities, obligations, shared conceptions or common beliefs (Scott, 1995). Existing sector-level institutions may facilitate or obstruct the growth and innovation of a niche. As such, this component taken from the SIS framework will provide insight into the institutional frameworks that support or resist the niche formation process and innovation.

2.3.5. Market demand creation

Market demand stems from the preferences of end consumers as largely revealed in actual consumer choices (Geels, 2004). However, Malerba (2007) argues that, in evolutionary economic approaches, the range of preferences of both consumers and producers stems from asymmetry in information or skills, constraints on opportunity, or heterogeneity in intrinsic motivations. A large diversity in preferences gives rise to market fragmentation and, hence, to increased opportunities for radically new technologies to enter a niche market. The role of demand is important in understanding technological change and innovation in a given sector (Witt, 2011). Table 1 presents an overview of the key theoretical components of the assessment framework.

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### Table 2
Overview of analysed NZEB projects.

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Type</th>
<th>Stage</th>
<th>Interviews/other sources</th>
<th>Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1: Indra Paryavaran Bhawan, New Delhi</td>
<td>Location: New Delhi, India Project area: 9565 m² Built-up area: 32,000 m² Certification: LEED Platinum, GRIHA 5-star Climate type: Composite EP1: 43.75 kWh/m²/yr.</td>
<td>Completed</td>
<td>3 Secondary research (articles, websites, publications)</td>
<td>Public sector</td>
</tr>
<tr>
<td>Project 2: Eco commercial Building: Bayer Material Sciences</td>
<td>Location: Greater Noida, India Built-up area: 891 m² Certification: LEED Platinum Climate type: Composite EP1: 71.56 kWh/m²/yr.</td>
<td>Completed</td>
<td>1 Secondary research (articles, websites, publications)</td>
<td>Private sector</td>
</tr>
<tr>
<td>Project 3: A Living Laboratory (CEPT University)</td>
<td>Location: Ahmadabad, Gujarat, India Built-up Area: 498 m² Certification: LEED Platinum, GRIHA 5-star Climate type: Hot and dry EP1: 58 kWh/m²/yr.</td>
<td>Completed</td>
<td>1</td>
<td>Autonomous University (CARBSE supported by public sector)</td>
</tr>
<tr>
<td>Project 4: Nalanda University Campus</td>
<td>Location: Rajgir, Bihar, India Project area: 446 acres Certification: Adopted GRIHA rating</td>
<td>Conceptual Planning</td>
<td>2 Participation in project meetings</td>
<td>Central University (public support and international funding)</td>
</tr>
<tr>
<td>Project 5: Head Office Building, Uttar Haryana Biji Vitran Nigam Limited (UHBVN)</td>
<td>Location: Panchkula, Haryana Project area: 8000 m² Built up area: 20,145 m² Certification: none Climate type: Composite EP1: 32 kWh/m²/yr</td>
<td>Tendering stage</td>
<td>1 Participation in project meetings</td>
<td>Public sector</td>
</tr>
<tr>
<td>Project 6: Indian Institute of Technology (IIT)</td>
<td>Location: Jodhpur, India Project Area: 850 acres Status: Master Planning Climate type: Hot and dry</td>
<td>Master Planning</td>
<td>2</td>
<td>University (Public funding)</td>
</tr>
<tr>
<td>Project 7: Centre for Energy and Environment, MNIT</td>
<td>Location: Jaipur, India</td>
<td>Conceptual Stage</td>
<td>1</td>
<td>University (Public funding)</td>
</tr>
</tbody>
</table>

### 3. Research design and methodology

The research design concerns an embedded case study approach. For the empirical study, all of the existing NZEB pilot projects in India were shortlisted. At the time of data collection, nine NZEB pilots could be identified as potential cases, of which seven

were used for primary data collection (see **Table 2** and **Fig. 3**). Three of these projects were completed NZEB projects (in the performance-monitoring phase) and four of those projects were either in the early design phase or in the construction phase. These projects can be considered front-runner and innovator projects in terms of using the NZEB concept, and thus can be considered as representative of projects contributing to the formation of a new niche.

Primary data were collected by conducting eighteen “in-depth” interviews, participation in meetings, and field trips to the selected project sites (by the main researcher, the first author of this paper), and a review of secondary data. The interviewees included building owners, architects, energy consultants, government officials, policymakers; building services designers (mechanical, electrical and plumbing (MEP), technology manufacturers and building occupiers. The interviews were divided into two sets: eleven participants who were directly involved with one or more of the above listed NZEB demonstration projects; and the remaining seven participants who had relevant knowledge about the sector and the concept of NZEB but no direct association with the NZEB pilots. This latter group was selected to provide a sector-level perspective on the formation of the new NZEB niche and so give insights into sectoral level innovations.

Semi-structured questionnaires were prepared for the in-depth interviews (see Annex A). The questions were largely based on the five components of the SSIAf to assess NZEB niche formation. All the interviews were conducted face-to-face, recorded and transcribed into text files, which were used for analysis in the Atlas.ti qualitative analysis software program. This program supports data (in this case interview transcripts) analysis by assisting researchers in locating, coding and

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1 Seven projects were selected on the basis of availability of primary data collection (interview participation). Nevertheless, all the nine projects were reviewed using available secondary data.

2 EPI: Energy Performance Index

3 GRIHA – Green Rating for Integrated Habitat Assessment

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annotating findings in text files, in weighting and evaluating their importance, and in visualizing the complex relationships (Muhr and Friese, 2004). The data were coded using a coding scheme that consisted of codes resembling the theoretical concepts of the SSIAf. This enabled a systematic assessment of the NZEB projects, and at a higher level of abstraction the NZEB niche formation process.

Each component of the SSIAf was a basis for developing codes for the transcribed documents. The five components became the main coding clusters in the Atlas. ti program and a set of sub-codes was further developed and matched with their occurrences. The sub-codes and their occurrences were then used to weigh and evaluate their importance as part of assessing the status of NZEB development in India, and hence support the data analysis.

4. Results

The results of the study are presented and analysed for each component of the SSIAf (see section 4.2). Each section elaborates on the sectoral perspective of NZEB niche innovation and its impact on the niche innovation process (assuming the conceptual building blocks are ‘partial enabling conditions’ for niche innovation processes). Before the results are presented, an overview of the building sector in India along with its energy consumption pattern is presented in sub-section 4.1. An integrated overview of the main results of the empirical study is presented in section 4.3.

4.1. Market description of the Indian building sector

The Indian building sector consists predominately of a residential sector and a commercial sector. Between 700 and 900 million m² of commercial and residential space is projected to be built each year until 2030 (MGI, 2010). Fig. 4 presents expected trends for the building sector in India (differentiated by type of building). In all sectors, the number of buildings is expected to increase rapidly although most growth is expected in terms of residential buildings followed by the commercial sector. Given the significant increase in estimated demand for buildings, it is imperative that the building sector to manage its projected growth in a feasible and sustainable manner. This high growth will lead to a significant increase in the energy demand of the building sector and hence energy efficiency in this sector is a prime concern for energy planners including relevant governmental agencies. The growth of India’s urban areas, both existing and projected, needs to be supported by clean energy solutions in order to manage the dramatic impact of energy consumption on urban cities (GBPNI and CEU, 2014).

The key stakeholders of the Indian building industry that have a significant role in promoting its energy efficiency include national government ministries, federal institutions, state government ministries, building sector associations, private sector construction organizations and service providers (architects, developers etc.), financial institutions, research and academia,
4.2. Results of the case study analysis

4.2.1. Shaping of expectations

NZEBS are considered dominant stakeholders as they are responsible for formulating policies and supporting and monitoring programmes related to the building sector in India. Additionally, several bilateral/multilateral aid agencies (US Aid, DFID, SDC, UNDP etc.) play an instrumental role towards an energy efficiency transition in the building sector through their programmes that include pilot demonstration projects.

Buildings consume large amounts of energy throughout their lifecycle through design, construction, operation, maintenance and retrofitting. Energy consumption is predominantly in the form of electricity used to provide a variety of services such as thermal comfort (space heating and cooling), lighting, water heating and various appliances (Jain et al., 2014). In India, building energy use has increased from 14% of total primary energy use in the 1970s to nearly 30% in 2004–2005, with a near-consistent 8% rise in annual energy demand in residential and commercial sectors (Rawal et al., 2012; NRDC and ASCI, 2012). Fig. 5 indicates electricity consumption in India in the various sectors, and Fig. 6 presents a more detailed breakdown for residential and commercial buildings.


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client motivation garnered further interest among the project design and construction teams, creating a common project goal with a high visibility (drawing wider societal attention). To this extent, the innovation in the design and construction of these NZEB projects did garner wider attention. Expectations were also raised by four of these NZEB pilots being educational buildings or large-scale university campuses (projects 3, 4, 6 & 7 in Table 2), thereby attracting attention from academia and the research community. This is considered positive as it strengthens the expectations attached to this new niche. The projects received support from the government in the form of subsidies, additional budgets for public sector pilots, and through collaboration in bilateral NZEB programmes (USAID PACE D − TA7 program).

However, on the sectoral level, actors were somewhat sceptical about the new NZEB concept and doubted the technical and economic benefits, which to some extent slowed the innovation process. This was mostly due to the lack of quantified benefits and outcomes, a consequence of most projects still being in the development stage. Developing robust and specific expectations and articulating a sound vision, of NZEBs may take more time, with the possibility of changing expectations in the future. The lack of solid data on the performance of these buildings and the economic implications acts as a brake on the expansion of an innovation niche. A vision or concrete goals for the uptake of NZEBs in the building sector is needed, but is presently missing, and this is largely a task for the government. Additional successful pilots are considered essential to attract interest from the building sector for innovation.

4.2.2. Actor network formation

There was a high level of interaction between team members in each of the analysed NZEB project’s boundaries. All of the completed NZEB projects adopted an integrated design approach8 that brought all the project stakeholders into the discussion from the conceptual design stage,9 thereby showing a considerable level of interaction and building of new networks between the project team members. This was despite most of the public-sector projects using a hierarchical system, with formal interaction and decision-making processes, which to some extent probably hampered the innovation process and discouraged informal network formation.

The project team configurations were diverse and appropriate for demonstration projects. Additional experts became involved as they were needed to achieve pre-set NZEB goals. Active participation and high levels of satisfaction were observed among those team members having sufficient knowledge and expertise about the NZEB concept (including passive design architects and LEED10 consultants taking a leading role in the project, HVAC11 experts). However, additional effort was needed to keep other stakeholders abreast of events and motivated.

The collective participation of the various actors within a niche is theorized to lead to an increased level of innovation, to knowledge creation, and to a reduction in complexity, risks and uncertainty (Mourik and Raven, 2006). However, this was not observed within the NZEB projects studied. In particular, there appeared to be a lack of interaction and an absence of social network formation between completed and on-going NZEB projects. Apart from a few formal interactions through conferences, each project developed in isolation from the other NZEBs in the country. As a consequence, there is a lack of coordination and alignment between on-going NZEB projects on the aggregated niche level. In the longer run, the failure to verify existing NZEB buildings will lead to ambiguity.

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On the sectoral level, building sector stakeholders were apprehensive of the new NZEB concept. Many factors contributed to this situation including the NZEB actors operating in isolation. A consequence of this was that established building sector stakeholders were not being reached to form part of a new social network. Various other factors appeared to be considerable challenges: the high capital costs of NZEBs, a lack of verified and monitored data in the public domain, a general lack of awareness, a lack of credible information about NZEBs, and a general resistance to change. All of these contributed to increasing the gap between the niche insiders and niche outsiders, effectively blocking social network formation.

4.2.3. Learning process

None of the NZEB demonstration projects (either completed or in the design/construction phases) showed a high level of learning, hampering further innovation. Learning was seen to be situational and fragmented, often focused on first-order learning such that lessons were not transferred to other NZEB demonstrations projects. As such, the transfer of direct learning experiences did not take place. Technical solutions and knowledge about NZEBs were available but more aspects needed to be explored, especially concerning situational NZEB site definitions and aspects of buildings from a life-cycle perspective.

Key decision-making was in the hands of a small number of expert team members (energy consultants and project clients) who did not share critical information about project failures. In fact, the projects that were investigated tended to shy away from sharing performance information from the occupied NZEBs. In general, learning is expected to take place through interactions between project team members (within an individual project) and also between demonstration projects. The latter is viewed as important because it is assumed to enhance network formation and make the setting of expectations more robust. We would argue that this is highly needed for the successful up scaling of NZEB innovation projects, but currently lacking in the present scenario. The role of educational institutions (as pilots) is seen as important since buildings with an educational function can stimulate holistic learning about the NZEB concepts and address both occupants’ needs and experiences and the benefits of NZEBs for society at large.

On the sectoral level, the innovation process is slowed by the failure to learn from NZEB demonstration projects. It was also difficult to understand the technical explanations of the NZEB concept, and the learning process needs to focus on disseminating knowledge in a simpler way that matches the relevant stakeholders in the building construction value chain thus increase second-order learning.

4.2.4. Institutional alignment (formal and informal)

Currently, building sector institutions do not seem to be well aligned with NZEBs. To some extent, there is a separation between energy efficiency and renewable energy (since each aspect is looked after by different central government institutions). One of the main instruments — the Energy Conservation Building Code (ECBC) — is a voluntary code that indicates a minimum energy performance standard for commercial buildings. Future code implementation and compliance will lead to a promising shift towards the adoption of energy efficient buildings, which will support innovation. Similarly, from the renewable energy perspective, there have been some policies — such as the solar roof-top policy, feed-in tariff mechanisms and net metering — that can be considered supportive in achieving NZEB goals. All of the investigated NZEB demonstration projects received government subsidies to integrate renewable energy technology in the buildings. In most cases, this was perceived as very positive, but a sign that it is still a ‘technology niche’.

Informal institutions such as values, common practices, responsibilities and obligations also play an important role in niche innovation. An inherent shared practice observed in the studied projects was that NZEB actors refrained from sharing project failures. Moreover, radical innovators seemed obliged to highlight the successes of the demonstration projects in which they are involved. Since most of the NZEB demonstrations projects involved public sector buildings, they are typically scrutinized because they use special budgets available for such demonstration projects. As a consequence, actors tend to refrain from sharing information on project failures. This shared reticence limits innovation in subsequent demonstrations. Further, government communication protocols and hierarchical systems put additional pressure on the project teams and client representatives to report project successes (to senior officials).

On the sectoral level, institutional fragmentation was observed, and this slowed the innovation process, limited the learning process and hampered network formation. Several national and state public authorities appeared only to be involved with their own separate activities. Developing an integrated well-aligned comprehensive institutional framework was considered to be of critical importance by most of the actors that were interviewed.

4.2.5. Market demand creation

There appears to be a low level of demand for energy innovations in the building sector, particularly for NZEBs. The fact that there were only a handful demonstration projects in India indicates that NZEBs are in an early stage of niche formation (or rather in an R&D stage) and more of a ‘technology niche’. The replication of such projects is expected to take considerable time in terms of experimentation and testing (following the verification of existing NZEBs). Here, government initiatives (standards and policies) for creating a market demand are considered important. Since existing energy standards do not incentivize people to explore energy innovations, they tend to stick with conventional business-as-usual construction practices. This ‘locks out’ the potential adoption of innovative sustainable technologies in the building sector.

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12 Gap in the designed and actual energy performance in the building (failing to achieve net zero status in a year)
The involvement of end-users, and their preferences, can play an important role in the innovation process (Malerba, 2004). This can lead to co-development of new technologies by experimentation and garnering a particular technology to a specific demand (Faber and Hoppe, 2013). However, in the demonstration projects analysed, user involvement was restricted and limited. Hence, the users’ preferences (as building occupants) and their sensitization towards the use of NZEBs were badly missed. When it came to NZEBs, it was observed that the housing sector’s participation in energy innovations was negligible with house owners lacking sufficient motivation (due to financial implications and the lack of understanding of tangible benefits). Moreover, project developers tend to shy away from innovations due to perceptions of ‘split incentives’. It seems that construction companies and other actors in the building industry in India are not prepared to produce energy efficiency buildings in large numbers.

Perceived upfront costs, a lack of knowledge on the techno-economic feasibility, a lack of awareness of the possibilities, a limited workforce in the industry with the skills to deliver NZEBs and the limited technical know-how were the main barriers that were consistently highlighted during the case study analysis which also resulted in limited demand for NZEBs. For societal transformation and innovation to occur, private sector participation will be necessary on a large scale. However, due to lack of feasible business models and access to finance, clients and project owners were disinclined to accept the NZEB concept and adopt innovation. However, a parallel uptake of solar energy technologies was seen to be a result of subsidies and incentives from the government. Similar support from the government through policies and programmes (including financing an increased number of NZEB demonstration projects) is seen as crucial by actors in the building sector.

4.3. Overview of the main results

In Table 3, an overview is presented of the main results using the SSIAf concepts.

5. Discussion

The results reveal that, so far, the NZEB concept has not developed into a successful innovation niche. This is to a large extent due to the limited development of some of the SIS building blocks (institutions and market demand), reflecting relatively poor conditions for NZEB technology to mature. There are several reasons for this. Many NZEB demonstration projects were organized in an overly self-contained way—and this hampers the niche innovation process. Each of the five SSIAf components were independently evaluated and assessed, highlighting the limited success of the pilots in inducing further sustainable development of the niche. Only a small number of actors (and mainly NZEB project actors) seem to have positive and optimistic expectations of NZEBs. The expectations for the niche were not yet robust as there was a lack of tangible results. The new social network tended to be narrow with interactions taking place only within the demonstration projects and only during the project timelines. Both formal and informal social interactions were also limited. The lack of a cohesive agent-network may be a sign that the niche is growing only slowly.

Our results support the views of those transition scholars who see social network formation as a crucial condition for the growth of a niche (e.g. Hofman, 2002; Schot and Geels, 2008; Caniels & Romijn, 2008). Authors have stressed that suboptimal involvement of mainstream actors (i.e. the building sector) in the niche formation process and insufficient internal niche interactions may eventually result in the complete failure of the niche (Schot and Geels, 2008). In the cases studied, actor networks were rather narrow and excluded sector outsiders (such as non-governmental organizations, policymakers, research institutions and financial institutions) which led to some scepticism over the realized projects, and a lack of second-order learning, that restricted sectoral innovations. Similar shortcomings were observed by Malerba (2004) and by Faber and Hoppe (2013) who found that actor-networks were a key driver of sectoral change and defining a new sectoral structure (which is required to spur sectoral innovation).

Another recurring finding is that the nature of social networks determines the depth and breadth of learning processes. The NZEB projects tended to focus on first-order learning only (based on ‘hard facts’ and data), and this impeded potential niche expansion. The institutional settings apart from government subsidies did not provide incentives for innovation: the formal rules were not yet aligned with NZEB innovations although they were to an extent for energy efficiency in buildings. Similarly, several barriers were observed resulting in a lack of demand for NZEBs on the building-sector level, indicating that niche formation had yet to result in sectoral change.

We consider applying SSIAf useful in assessing the status of NZEB niche innovation in the building sector in India. The integration of the SNM and SIS frameworks showed that they were complementary and this contributed well to answering the main research question. The use of SSIAf enabled us to systematically assess the niche development process, and probably better than either of the two frameworks separately. For example, while the SNM focuses on its primary components of shaping of expectations, the actor network formation and the learning process to understand the niche formation process, it alone fails to gain from insights as to which institutional alignment (formal and informal) and creation of market demand components can contribute to the niche innovation process.

13 In general, it is the end-user who, in the long run, gains most of the benefits of energy-efficient buildings.
14 Second-order learning enables changes in cognitive frames and assumptions (derived from Grin and Van de Graaf 1996).

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Table 3
Overview of the main results of the empirical analysis.

<table>
<thead>
<tr>
<th>Assessment criteria for the NZEB innovation niche (SSIAf components)</th>
<th>Observations</th>
<th>Results (regarding NZEB niche formation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Shaping of expectations b. Increasing number of participants sharing the same expectations (converging into a shared vision). c. Expectations are increasingly based on tangible results from transition experiments.</td>
<td>NZEB project actors have positive expectations of the sustainable technologies demonstrated. Expectations are not based on tangible results, hence neither robust nor specific. Possible to alter existing expectations in future. Actors outside the NZEB projects do not have positive expectations from NZEBs (due to lack of tangible results), slowing the innovation process.</td>
<td>Niche development is in a pre-development stage. Positive expectations are shared only by NZEB project actors and not by mainstream building actors. Expectations are still not specific or based on tangible results (they are general and do not give guidance for setting goals). Expectations are not converging to a shared vision or NZEB goal.</td>
</tr>
<tr>
<td><strong>Actor Network formation</strong> a. Size of the sectoral actor-networks (including both primary agents and secondary agents, and both regime insiders and regime outsiders). Extent of formal and informal interactions.</td>
<td>There was a high level of interaction between actors within each demonstration project. There was a relatively low level of interaction across the different demonstration projects (each one was developed in isolation). There is a very low level of interaction between actors in NZEB projects and mainstream building stakeholders.</td>
<td>Networks tended to be narrow and weak. Minimal involvement of outsiders in the experiments (reducing second-order learning). The network interactions are not deep: the people who are engaged are not able to mobilize commitments and resources and are based around the NZEB projects. Lack of formal interactions through conferences, workshops etc. Informal interactions are based around the projects.</td>
</tr>
<tr>
<td><strong>a. Learning Process</strong> b. Broad learning (on technology and knowledge, techno-economic optimization, technical and social alignment). c. Reflexive learning, self-governance, flexibility to change course.</td>
<td>There is a low level of learning from both completed and on-going NZEB demonstration projects. There is a lack of learning on the techno-economic feasibility, and the technical and social alignment of NZEBs. There is a lack of learning from existing NZEB demonstration projects (limited one-on-one interactions with niche actors).</td>
<td>Projects tend to focus on first-order learning based on accumulation of facts and data. Lack of second-order learning. Limited learning from the demonstration projects – only within the NZEB project actors.</td>
</tr>
<tr>
<td><strong>Institutional alignment</strong> a. Formal institutions (rules, laws, regulations, monitoring). Informal institutions (values, responsibilities, obligations).</td>
<td>Formal institutions (policies, regulations, standards and protocols) are currently not aligned with supporting NZEBs. Demonstration projects have received support through renewable energy technology subsidies (which were considered beneficial). There is a lack of alignment of institutions and government policies towards NZEBs (institutional fragmentation).</td>
<td>Institutions are supporting NZEB project-based innovations, fostering ‘technological niche’ development. The existing institutional structure is less supportive of sectoral innovations. Institutions also hamper the learning process between the niche and the regime.</td>
</tr>
<tr>
<td><strong>Market demand creation</strong> a. Requirements and pReferences b. Heterogeneity. c. Role of niche markets. d. Market structure, size and segmentation.</td>
<td>Perceived high upfront costs, lack of techno-economic feasibility, lack of awareness of the NZEB concept, limited industrial capacity and lack of policies to support NZEB uptake are seen as barriers to uptake. Government policy instruments have potential to create market demand and initiate innovations. More demonstration projects are needed to create sufficient evidence-based knowledge about NZEBs (as a reliable and affordable building concept). More private sector participation is required to spur the uptake. Lack of feasible business models to attract private sector players.</td>
<td>The existing niche has yet to develop into a ‘market niche’. No demand for more NZEBs Barriers to uptake: Perceived high capital cost. Lack of technical knowhow in the industry and lack of capacity. lack of government support. lack of knowledge and awareness of NZEBs.</td>
</tr>
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</table>

The institutional alignment component was seen to have a positive influence on the learning process and on social network formations. Formal institutional support (subsidies, incentives) motivated early adopters to go for NZEBs in the first place, which led to additional learning for the actors involved. Institutional support in terms of policies and strategies was, to an extent, conducive to raising expectations and legitimizing government support for new sustainable technologies. Using the SNM framework alone would have overlooked opportunities that the integrated framework highlighted. Similarly, existing barriers to large-scale adoption were highlighted by including market demand creation component in the SSIAf. This component was taken from the SIS framework and is relevant since it supports speculative growth of the niche. However,
using the SIS framework alone would have excluded an assessment of the learning process in our niche projects, despite learning potentially creating disturbances in an existing stable regime which can lead to sector-level innovations. As such, the SSIAF has merits when it comes to assessing a niche innovation at the sectoral level and hence builds upon the strengths of the two earlier frameworks.

The empirical study showed that the SSIAF components showed many mutual interdependencies. For example, the shaping of expectations and goals was to an extent dependent on other components such as the learning process (in resetting visions), and institutions influenced one another. Similarly, the strength of the actor network had a strong influence on the other four components. Also it was seen that the five components are valued differently in all the potential development phases of an innovation niche, as such creation of market demand was low and close to negligible owing to the early phase of niche formation, however technological learning and actor formation are deemed of high value to ensure the strong formation of a new niche as also supported by various transition scholars (e.g. Hofman, 2002; Schot and Geels, 2008; Caniels and Romijn, 2008).

Most of the interviewees deemed broadening of the actor network as necessary, and believed that government interventions were necessary to foster this, a view recognized by other scholars (e.g. (Caniëls and Romijn, 2008)). Informal institutions show significant interdependencies in terms of shared visions and patterns of thinking (Faber and Hoppe, 2013). Integrated concepts could also serve as foundations for policies aiming to promote radical transformative change.

Other frameworks, such as the MLP, also provide insights into technological transitions and regime shifts on both the niche and the regime levels, and also address changes at the landscape level. However, since the main aim of this paper has been to assess the NZEB innovation niche, the MLP is less appropriate as it does not provide an insight into sector-level innovation. This aspect is well covered by SIS (and incorporated in the SSIAF), which focuses on how the characteristics of a sector may determine the scope of innovation within that sector. It is possible that using the MLP alongside the SIS framework could bring further insights. However given that the MLP focuses on regime shift from a technological and social perspective, and the SIS framework emphasizes a sector’s capacity for innovation and through this regime shift, we would argue that these conceptual differences justify the integration of the SIS and SNM frameworks as against using MLP.

Although SSIAF has many benefits – i.e. offering a broad conceptual understanding of sectoral niche formation, allowing for the identification and assessment of conditions that enable or disable sectoral niche formation, is arguably easier to use than more comprehensive frameworks (i.e. the failures framework, Weber and Rohracher, 2012), by presenting a systemic status quo which is attractive to policy makers and strategists to address when generating ideas for policy making, and by offering a way to analyse structural proximity of actors (e.g., niche and regime actors) – following the lessons from our case study analysis, there is also room for criticism and suggestions for improvement.

First, SSIAF analysis was found to be rather static. The framework analyses sectoral niche formation as a ‘snapshot’ in time, and does not really allow for analysing niche development as a set of sequential historical events. Second, the framework assumes a form of developed niche formation, whereas the NZEB case study showed that niche development was basically in a state of ‘pre-development’; i.e. the local projects were hardly coordinated from a niche platform at an aggregated level, which heavily impeded cross-project coordination and learning. Third, the focus on the economic sector and the status quo rather led to neglecting the multi-level character of the niche formation process (concepts and processes that are appreciated by the frameworks of Markard and Truffer, 2008; Weber and Rohracher, 2012; and Meelen and Farla, 2013). This limitation could possibly be resolved by adopting notions from these frameworks. To some extent, the SSIAF also gives insufficient attention to the environment and the context of sectoral innovation systems and niches (geographical conditions). Here, one could adopt some of the problem-oriented concepts from the sustainable transition failures framework (Weber and Rohracher, 2012). Other potential avenues for conceptual enhancement would be to explore analytical frameworks that give sufficient room for policy and politics (See for an overview: Hoppe et al., 2016) and pay attention to the contextual setting (e.g., Bressers et al., 2002). Fourth, like the failures’ framework in data collection the use of SSIAF leads to collecting a comprehensive set of data, which is rather time consuming for the researcher. Fifth, it remains unclear why the five theoretical components of SSIAF do not have different weightings when analysing niche formation; i.e. in early niche development market demand creation probably deserves a lower weighing than learning about technological performance and side effects of a given technology. Perhaps, further conceptual development of the framework should assign different weightings to the theoretical components depending on the stage that niche formation is in; e.g., differentiating between pre-development stage, early development stage, late development stage and ‘breakthrough’ stage. Sixth, the framework assumes focusing on a single niche, whereas focusing on a given economic sector should allow for a more holistic view, and therefore the identification of multiple niches within an economic sector.

We also want to address a methodological limitation that should be kept in mind when reflecting on the results of this study. It entails the fact that the selected cases were located in India, against the background of a developing country. This arguably contributed to focusing on a sectoral niche that was still in its pre-development stage. In future research we suggest SSIAF to also be used in empirical research comprising case studies of niches that are more developed, i.e. in further stages of niche formation (e.g., early niche formation, late niche formation). Analysing and comparing cases in different development stages would allow researchers to learn more about mechanisms that influence sectoral niche formation. This would probably entail to (also) select cases of sectoral niche formation in developed countries. Moreover, an attempt could be made to re-design SSIAF in order to make it more useful to dynamic forms of research, and not just to assess a status quo as a ‘snapshot in time’.

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Finally, the case study revealed the importance of donor aid to niche formation in India. One could wonder what the absence of this condition would mean. Moreover, it gives thought to how bottom-up development of local experimental projects and in the end niche (pre-) development is dependent on such a condition. In this sense, theoretically it makes sense to discuss whether donor aid can be labelled either as a ‘landscape event’ – because the condition is of great importance to niche formation, and cannot be labelled a regime characteristic as it transcends the sectoral level; i.e. it is an international intervention or event – or rather as an instrument at the micro level; (niche) to foster niche formation.

6. Conclusions

This article started by introducing the NZEB concept and how a transition towards large-scale uptake of this concept could enable countries such as India to deal with future energy challenges, and particularly those in the building sector. This would require structural changes encouraging innovation in the existing building sector regime. This article attempts to assess the current status of the NZEB innovation niche by posing and then answering its main research question: “What does the SSIA framework tell about NZEB niche formation in India?” The article explores transition and innovation theories (SNM and SIS) and develops an integrated framework, the SSIAf, to assess the current status of NZEB development in India. This has five theoretical building blocks: shaping of expectations, social network formation, learning process, institutional alignment and creation of market demand.

The results show that the NZEB innovation niche has yet to develop into a mature niche, and is growing only slowly. It is evident from the marginal expectations that building sector stakeholders have regarding NZEBs. This is largely due to the lack of tangible results, despite the project actors being positive towards NZEBs regardless of their isolated character. New social networks were only strong within individual NZEB projects and there had been a failure to create a cohesive network with other NZEBs and with actors outside the NZEB projects. Consequently, the spurring on of the innovations through network activities was limited. There was also a lack of interactions between the niche and the wider regime, and the NZEB niche therefore lacked the nurturing required to facilitate stabilization and growth towards maturity. The strength of the SSIAf was that it provided an in-depth analysis of each of the independent components of the framework. Several interdependencies were observed among the components and we were able to elaborate on the dynamic nature of the niche that is currently growing at a slow pace.

Based on the identified shortcomings of the SNM/MLP and Innovation Systems approaches, we presented the SSIAf and positioned it among other integrative frameworks (TIS–MLP and SNM–TIS). The distinction is that the SSIAf is demarcated by a given industrial sector (in our case, the building sector). Having sectoral boundaries, it is more limited than the more comprehensive integrative framework suggested by Markard and Truffer (2008). As such, the SSIAf is more strongly oriented towards actors and agency, paying greater attention to strategic actor interactions. Another component that differs from Markard and Truffer’s suggested framework is the SSIAf’s institutional component, which gives more attention to market, and societal rules and sectoral policies. The distinction with the approaches of Weber and Rohracher (2012) and Meelen and Farla (2013) is that the SSIAf does not have a strong policy orientation. In its current form, the SSIAf is basically a heuristic tool – as other IS approaches – to assess a given innovation system and niche market formation (such as here, NZEBs) on its inherent capability and capacity to spur and successfully diffuse the given innovation and generate a wider market uptake.

Acknowledgements

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Appendix A: Questionnaire.

<table>
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<tr>
<th>Integrated Assessment Framework (Sectoral System Innovation Framework-SSIAf)</th>
<th>Case study questionnaire for niche actors</th>
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<tbody>
<tr>
<td><strong>Component 1</strong></td>
<td><strong>Shaping of Expectations</strong> – (shared visions, expectations based on tangible results)</td>
</tr>
<tr>
<td><strong>Component 2</strong></td>
<td><strong>Actor networks and interactions</strong> – (broad social network, formal and informal interactions)</td>
</tr>
<tr>
<td>Q 5. Is a wide range of relevant actors involved in the pilot demonstration project, and is the group diverse? How does this actor-network appear? (members, size of network). Who is the key actor (in influencing decision-making)?</td>
<td></td>
</tr>
<tr>
<td>Q 6. How often do niche network interactions/meetings take place? How is the niche network managed and by whom?</td>
<td></td>
</tr>
<tr>
<td>Q 7. Is there a network platform on NZEB niche development? (e.g. an NZEB alliance or consortium)</td>
<td></td>
</tr>
<tr>
<td>Q 8. How are NZEB niche actor interactions facilitated by the government?</td>
<td></td>
</tr>
<tr>
<td><strong>Component 3</strong></td>
<td><strong>Institutions</strong> (formal: rules, laws, regulations, sectoral policies, monitoring and sanctioning etc.; informal: common habits, routines, established practices, laws and standards, responsibilities, obligations, beliefs etc.)</td>
</tr>
</tbody>
</table>

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Q8. To what extent are rules, regulations, policies and monitoring aligned with NZEB niche development?
Q9. What is the role of national and regional governments in providing protection to the NZEB demonstration projects? (subsidies, tax rebates, financial incentives, co-financing etc.)
Q10. How do informal institutions (such as common habits, beliefs, standards, established practices) support the NZEB niche development process?

Component 4

**Learning Process** (Technical and knowledge, Techno-economic optimization, Technical/social alignment (user preferences, regulations, cultural meaning), Environmental impact, Reflexive self-governance (i.e. the flexibility to change course)

Q 11. Have NZEB pilot demonstrations been successful in making the technical, economic and environmental feasibility of NZEBs explicit? (clear definition, standards, costs benefits, sound outcome indicators etc.)
Q 12. How has the newly acquired knowledge on NZEB been disseminated among the various stakeholders including end-users (e.g. NZEB web portal, magazine articles, open days, newspapers, public media) and how is knowledge exchange managed in the niche actor network?
Q 13. Have user preferences or user involvement been given importance in the project’s progress? Are end-users aware of specific aspects of occupying NZEBs that directly influence their comfort? (Metering, smart metering, mechanisms for energy saving, expertise on automated systems, guidance, manuals, user-behaviour etc.)
Q 14. Did niche actors illustrate explicit reflexive learning in experimenting with pilot projects (e.g. monitoring the niche development)? Did it proceed according to the plan, and if not was the experimentation strategy revised? Did they critically reflect on their role and the way they do things in designing and constructing NZEB demonstration projects?

Component 5

**Market Demand** – (requirements and preferences, market structure, size and segmentation)

Q 15. To what extent were end-users (and NZEB clients) satisfied with the results of NZEB pilot projects?
Q 16. What are the main barriers to developing a market demand for NZEBs? How is the creation of a market demand expressed in NZEB demonstration projects? In what ways is the creation of a market demand reflected? (e.g., awareness-raising campaigns, advertisements, marketing strategies, field trips for potential users to demonstration project sites).

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Integrated Assessment Framework (Sectoral System Innovation Framework-SSIaF)
(Case study questionnaire for sector-level actors outside the NZEB niche)

Component 1

**Shaping of Expectations** – (shared visions, expectations based on tangible results)

Q 1. What are the expectations of the regime actors regarding NZEB niche development? (positive or negative + argumentation)
Q 2. Have these expectations changed after NZEB pilot demonstration projects have been successful? (positive or negative and why)
Q 3. Has government support (funding, incentives etc.) to NZEB demonstration projects influenced the expectations of the regime actors?

Component 2

**Actor networks and interactions** – (broad social network, formal and informal interactions)

Q 4. What is the level of formal and informal interactions between niche and regime actors over NZEBs? (High or low − through conferences, workshops etc.)
Q 5. Which barriers do regime networks impose on NZEB niche development?

Component 3

**Institutions (formal): rules, laws, regulations, sectoral polices, monitoring and sanctioning etc.; informal: common habits, routines, established practice, laws and standards, responsibilities, obligations, beliefs etc.)

Q 6. What key sectoral policies and regulations target NZEBs? (e.g. ECBC code development, energy efficiency finance, building regulations)
Q 7. How stringent or flexible are the formal institutions towards NZEB niche development?

Component 4

**Learning Process** (Technical and knowledge, Techno-economic optimization, Technical/social alignment (user preferences, regulations, cultural meaning), Environmental impact, Reflexive self-governance (i.e. the flexibility to change course)

Q 8. Are regime actors learning from demonstration projects about major regime barriers preventing niche development? (sectoral policies, regulations, user preferences, cultural values, infrastructure, etc.)
Q 9. What is the role of educational institutions in building technical and knowledge development regarding NZEBs?

Component 5

**Market Demand** – (Requirements and preferences, market structure, size and segmentation)

Q 10. What reasons can be identified for the low current market demand for NZEBs?
Q 11. What characteristics of the building market go against increasing the market demand for NZEBs?

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References


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