Environmental Innovation and Societal Transitions xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Environmental Innovation and Societal Transitions

journal homepage: www.elsevier.com/locate/eist

Transnational linkages in sustainability experiments: A typology and the case of solar photovoltaic energy in India

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ARTICLE INFO

Available online xxx

Keywords:
Geography of sustainability transitions
Transnational linkages
Sustainability experiments
Developing Asia
Solar PV

ABSTRACT

This paper explores transnational linkages in sustainability experiments. Transnational linkages refer to diverse cross-border relationships and interactions that can complement local, regional and national capabilities enabling sustainability experiments. The paper develops a typology of transnational linkages and applies it to solar photovoltaic energy initiatives in India. Our analysis shows that transnational linkages appear to be almost universal in these experiments. Of seven solar photovoltaic technology domains present in the sample, experiments in only one – off-grid power plants – can be characterised as predominantly domestic. These findings underscore the significance of capabilities, resources and linkages spanning local, regional and national scales in innovative solar PV experiments in India, suggesting similar patterns for other socio-technical experiments. This study contributes to an emerging literature on the geography of sustainable transitions, which argues for a move away from a predominantly national framing in transition studies to embrace a multi-scalar understanding of transition processes.

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http://dx.doi.org/10.1016/j.eist.2015.01.001
2210-4224/

1. Introduction

The recent 'spatial turn' in the sustainability transitions literature is attracting increasing attention from both geographers and transition scholars (Shove and Walker, 2007; Truffer, 2008; Berkhout et al., 2010; Raven et al., 2012; Coenen et al., 2012; Rutherford and Coutard, 2014). This relatively young body of literature has been developing in three lines (Truffer et al., 2015; Hansen and Coenen, 2014). A major line of research is concerned with local and regional contexts, and the ways in which innovation and transition processes co-evolve with and transform these contexts (Murphy and Smith, 2013). In particular, research on city contexts has received considerable attention (Bulkeley et al., 2011). A second direction is concerned with understanding multi-scalar relationships and the ways in which spatially distributed spaces of innovation become connected or stay disconnected (Van der Vleuten and Hogselius, 2012; Späth and Rohracher, 2012). Technological innovation systems (Binz et al., 2012; Wieczorek et al., 2014), or regimes and niches are not confined to one spatial level (Raven et al., 2012), but cut across territorial boundaries through networks and infrastructures (Shove et al., 2014). Third, a growing body of literature explores the micro-level of transitions by moving away from the classical structure-agency dichotomy, and explores the practices that make (or break) transition processes (Shove et al., 2012; Jones and Murphy, 2011). This line of research includes studies on how local practices are shaped by power relationships embedded in a wider political ecology (Lawhon and Murphy, 2012).

This paper is concerned with the second line of research on multi-scalar relationships in transitions. It builds upon previous contributions that have argued that transition studies have often assumed the national level as the spatial scale at which transitions take place and suggested that the study of transnational linkages is a way out of this national bias (Berkhout et al., 2011; Raven et al., 2012; Hansen and Nygaard, 2013; Wieczorek et al., 2014). In particular, the paper makes two contributions: one conceptual, the other empirical.

First, we aim to unpack the notion of transnational linkages by developing a typology of transnational linkages. We are interested in explaining how innovative sustainable technologies emerge in rapidly developing economies. Put simply, how do advanced socio-technical experiments emerge in low- and middle-income country contexts (far from the technological frontier)?

Evidence suggests that linkages with international networks, access to technology, markets and capital, as well as the influence of international regulatory frameworks, are important mechanisms in enabling potentially radical socio-technical innovation in less-developed country contexts. Through connections to global networks and by tapping into global knowledge and resources, businesses and other actors in developing countries can become embedded in globally distributed innovation systems for new technologies with lower resource and environmental footprints (Wolf, 2004; Busch et al., 2005). This can contribute to the acceleration of the process of environmental upgrading, and potentially leapfrogging of the sustainability performance of leading sectors in emerging economies (Goldemberg, 1998; Munasinghe, 1999; Binz et al., 2012).

We situate our attention to transnational linkages in the broader context of studies of system innovation and socio-technical transitions. Experimentation is a key concept in the transitions literature – referring to a practice-based innovation approach that embraces uncertainty and unpredictability. It has been developed as part of the *socio-technical* view of system innovation, and in particular the multi-level perspective (Schot and Geels, 2008). Berkhout et al. (2010) argue that there is much evidence of sustainability-oriented experimentation in low-income countries, which have the potential to generate new and more resource efficient socio-technical systems enabling more sustainable development pathways in these countries. In the context of globalisation, many sustainability experiments are embedded in transnational networks and flows. These networks and flows operate across spatial scales. Networks form the linkages, or 'pipelines' (Bathelt et al., 2004; Moodysson, 2008), through which flows of resources such as knowledge, human capital, technologies, finance and standards, become available to initiators of experiments, and provide access to foreign markets. So far, there has been no systematic mapping of transnational linkages in sustainability experiments.

Second, this paper moves beyond single-case study analysis to explore empirically transnational relations across a wide range of experiments, developing a new analytical approach to mapping and assessing transnational linkages. Evidence for over 200 solar photovoltaic (SPV) experiments in India is

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used to explore the pattern of transnational linkages. SPV is seen as a promising renewable technology with large technical potential due to an abundance of solar irradiance in India (IEA, 2011), strongly supported by state and national government policies. As part of a mix of renewable electricity sources, SPV is a means of providing secure electrification, particularly in rural areas, as well as making a contribution to the reduction of CO_2 emissions from electric power generation. Over the past 15 years, SPV has witnessed substantial development in India, including much technological, business and consumer experimentation. This paper demonstrates that transnational linkages are an essential part of experimentation on SPV in India, complementing and strengthening domestic factors and resources, suggesting similar patterns for other socio-technical systems.

Following from this, our research question is: How can transnational linkages in sustainability experiments be conceptualised and what transnational linkages exist in sustainability experiments in the solar-PV domain in India?

The argument in the paper is organised in four sections. Following this introduction, Section 2 presents a typology of transnational linkages. In this section we categorise transnational linkages and conceptualise their relationship to sustainability experiments. Section 3 discusses the methodology for analysing Indian SPV experiments and its limitations. Section 4 presents results from the application of the framework to SPV in India. Section 5 concludes and discusses questions for future research.

2. A typology of transnational linkages

The transitions literature conceptualises the provision of human needs such as water, energy or mobility as enabled by socio-technical systems encompassing technological, social, institutional, economic and cultural dimensions. The 'rules of the game' embedded in institutions and infrastructures are called socio-technical regimes and provide order, stability and continuity to socio-technical systems (Geels, 2005). There is broad analytical and political agreement that radical change of these regimes is needed for transitions towards sustainability. Such transitions come about as the result of mutually reinforcing changes in socio-technical regimes, landscapes that provide a context for regimes, and experimentation by a variety of social agents with alternative technologies, services and practices, typically occurring in niches (Schot and Geels, 2008). Given that niches, regimes and landscapes are constituted by actors and networks acting across localities, transitions of socio-technical systems are constituted and shaped by interactions between spatially distributed actors (Raven et al., 2012; Shove et al., 2014).

The transitions literature is rich in conceptualisations of experiments (Sengers et al., 2014). Following earlier work, in this paper we use the concept of *sustainability experiments* – defined as planned initiatives that embody a highly novel socio-technical configuration likely to lead to substantial (environmental) sustainability gains (Berkhout et al., 2010; Bai et al., 2010). The initiatives are *highly novel* meaning that they are different from dominant, conventional ways of satisfying social needs and preferences within a specific context. They are *planned*, which implies that they are designed with sustainable development in mind. The reference to a *socio-technical* configuration suggests that they are socio-technical in nature, sharing both technological and social dimensions, where learning is not confined to technological learning, but includes changes in practices, services, user behaviour, institutions, ways of organising and so on. Sustainability experiments are often strongly goal-oriented and challenge-led. They are expected to lead to *substantial sustainability gains*, which encompass environmental, social and economic aspects of development. Sustainability experiments deliberately aim to contribute to broader visions of systemic change and are associated with alternative, more sustainable development pathways.

In this paper, we are interested in situating sustainability experiments in the context of globally distributed networks and flows. Based on a range of literatures related to technology, environment, development and growth we propose a typology of transnational linkages that can explain innovative sustainability experiments in low- and middle-income country contexts. To define transnational linkages we draw on studies on transnationalism. This literature conceptualises transnationalism as '. . .a condition in which, despite great distances and notwithstanding the presence of international borders . . . certain kinds of relationship have been globally intensified and now take place paradoxically in a planet-spanning yet common – however virtual – arena of activity' (Vertovec, 1999, p. 447).

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Despite this focus on relationships and flows crossing national borders, transnationalism does not imply abandoning the *national* as a category of analysis. Instead, the notion of the transnational concerns the emergence of a new governance scale beyond the direct control of national governments (Van der Vleuten, 2008).

Building on this work, we define transnational linkages as the cross-border relationships, infrastructures and interactions that enable flows and circulations of resources including people (actors), knowledge, technologies, institutions and finance. The *linkages* therefore refer to both structures and interactions, where interactions may be continuous, periodic and one-off.

2.1. Actor-related transnational linkages

Actor-related transnational linkages refer to the movement of people. They are critical for other linkages because people are important *carriers* of technology, knowledge, capital and institutions. For example, Bell and Pavitt (1993) consider mobility of people as a key mechanism for international transfer of technology because of the tacit elements of knowledge and skills that are necessary for changing products and processes. Hobday and Rush (2007) show that multi-national corporations are important in the cross-border transfer of technologies and institutions through their worldwide networks of subsidiaries and headquarters. Their transnational activities allow corporations to gain competitive advantage by having access to local knowledge and technical expertise, as well as local markets (Lewis, 2007; Perkins, 2007). Iriye (2004) and Binz et al. (2014) argue that academic networks often enable the flow of academic knowledge between developed and developing countries. Saxenian (2005) demonstrates how engineers from developing economies can accelerate the development of information technology industries in their home country by maintaining close professional and economic ties to technology and markets in Western economies, in particular the US.

The transnational circulation of skilled people is important for sustainability experimentation in developing economies, because this reconfigures and expands local actor networks and is a mechanism for making lessons mobile and accessible to other places (McCann, 2008). Yet this movement of people is not a neutral mechanism in shaping sustainability experiments. Actors *translate* rather than simply *transfer* skills and knowledge when they travel between places. In cases of unbalanced power relationships, for instance, foreign actor involvement may privilege corporate interests at the expense of local social or environmental interests, or continuity of experiments may become dependent on foreign interests who maintain control over the flow and direction of resources and results.

2.2. Knowledge-related transnational linkages

Knowledge held by people, is the most tangible way for capabilities to cross international borders, enabling the adoption, implementation and replication of (sustainable) technologies. Knowledge spillovers involve an exchange of ideas among individuals, so that knowledge-related transnational linkages are connected to actor flows. Having picked up technological know-how, employees diffuse it to local competitors through labour mobility (UNCTAD, 1999). Educated workers are also said to be more aware of technology and better able to use it (Caselli and Coleman, 2001; Kiiski and Pohjola, 2002). Dasgupta et al. (2000) and Cole et al. (2008) suggest that acquisition of domestic firms (including their human capital) by global firms is an important mechanism for knowledge spillovers. In particular, managers' international experience proves to increase the level of environmental compliance. Also international consulting firms are an important mechanism in transnational knowledge linkages. However, knowledge flows are not always embodied in interactions and flows of people or technology. Knowledge is also carried through educational materials, trade and scientific literature and data, blueprints and plans (codified knowledge flows), and increasingly advice can be provided by means of new media and the Internet (tacit knowledge flows).

Transnational knowledge circulation benefits sustainability experiments when it brings previously missing, but necessary knowledge and skills to developing economies. Nevertheless, there is a likelihood that knowledge flows are patterned by incumbent regimes in high-income economies. As such, transnational knowledge circulation may act to reproduce unsustainable production and consumption patterns, rather than support experiments with alternative, more sustainable technologies. More

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generally, transnational knowledge diffusion may come with powerful and widespread assumptions resting in particular political paradigms, for instance, neo-liberal ideas on how to efficiently organise or develop new markets (Hall, 1989). Hence, it is important to scrutinise critically the ways in which international knowledge flows are shaping sustainability experiments and their outcomes in low-income economies.

2.3. Capital-related transnational linkages

Capital-related linkages refer to the flow of financial capital in the form of foreign direct investment, R&D funding, private equity, venture capital, technical cooperation grants, as well as official development assistance (ODA) by governments, and loans, grants and equity investments by development banks and other institutions. There is a huge literature on the role of transnational flows of investment and capital in technological learning and economic development. It is now widely accepted that the effects are complex and multi-directional, and that the policy context in the receiving country plays an important role in shaping learning and other impacts (Lall and Narula, 2004). Foreign investments may generate environmentally beneficial technology spillovers and raise environmental efficiency. Global firms are assumed to play a leading role in efficiency enhancing investments in subsidiaries, joint ventures and affiliates (Mielnik and Goldemberg, 2002). Investments in technologies that embody higher levels of environmental performance may raise a firm's environmental efficiency and competitiveness (Perkins and Neumayer, 2009). In contrast, other studies show little correlation between FDI and technology transfer across borders (van Pottelsberghe de la Potterie and Lichtenberg, 2001) or with the uptake of more environmentally efficient technologies (Andonova, 2003; Perkins and Neumayer, 2005).

Access to financial capital is a key concern in developing economies. Transnational capital circulation can serve to shape protective niche spaces for experimentation with alternative socio-technical configurations. A particular concern, however, should be highlighted here. Access to financial capital often comes with conditions, including reporting requirements or institutional reform. Transnational finance can therefore privilege some forms of learning, including techno-economic lessons above others, such as local embedding in cultural and political contexts, or even reshape local or national institutional contexts in ways beneficial to capital providers, rather than to building up domestic capabilities (Hansen and Nygaard, 2013). Further empirical research needs to engage with the ways in which transnational flows of capital are shaping the design and direction of green experimental trajectories in developing economies.

2.4. Institutions-related transnational linkages

Formal and informal institutions may provide capabilities and incentives for the domestic uptake of more environmentally friendly technologies, practices and performances (Perkins and Neumayer, 2009; Angel and Rock, 2005). Green procurement requirements imposed by global firms on suppliers may create pressures for the adoption of 'beyond compliance' environmental codes, standards and organisational practices (Neumayer and Perkins, 2004). Transnational corporations adopt international standards to enter foreign markets, and avoid the risk of environmental incidents and claims of double standards (Angel et al., 2007). The spillover of more stringent standards from highly regulated foreign markets into lower regulating jurisdictions occurs mostly through global supply chains (Vogel, 1997; Corbett, 2002). Export opportunities to countries with high environmental standards stimulate domestic adoption of this standard (Prakash and Potoski, 2006; Perkins and Neumayer, 2010). Less formal institutions can also constitute transnational linkages. For example, norms and routines often travel with actors across borders while dominant political views and values about responsible behaviour spread through businesses and institutional networks (Kautonen and Raunio, 2010; Goldman, 2007).

As such, transnational circulation of institutions can shape socio-technical experimentation in important ways. Analysis of responsible organisations that generate more sustainable products and processes, however, needs to be balanced with analysis of new practices and norms, such as high-consumption lifestyles that are also a feature of economic and social development in

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many countries. Evidence suggests that whilst environmental institutions in developing countries have produced a greening of production processes (Rock et al., 2009), these gains have been more than compensated for by growth in consumption. This suggests that experiments with more sustainable lifestyles beyond environmental technology deployment alone, and the promotion of rules and norms that might shape those lifestyles, are increasingly important as well (Jackson, 2009).

2.5. Technology-related transnational linkages

Finally, technology-related linkages refer to the cross-border diffusion of equipment, products and other technological artefacts. They take place through technology transfer initiatives, technology licensing and acquisition, and sourcing of equipment. They differ from knowledge-related linkages by being conceptualised in relation to materialised knowledge. Transnational diffusion of environmental technologies can lead to environmental upgrading and efficiency increases in developing countries (Huber, 2008; Perkins and Neumayer, 2005; Stern, 2005).

Transnational circulation of technological hardware is at the core of sustainability experimentation in developing countries as it is part of the design of experimentation. A key question is: where do these technological goods come from? Rather than assuming that they are transferred by transnational firms and from high-income economies, the geographical source of technological goods is an empirical research question. Moreover, whilst environmental performance can substantially improve through deployment of new technologies, they may also embody new social, organisational or user practices that have an opposite effect. Technologies are not neutral. How they shape sustainability experiments and their wider developmental impacts in receiving geographies is a key question for critical empirical analysis.

3. Analysing transnational linkages in Indian SPV experiments: methods

We understand sustainability experiments as occurring in a context of transnational linkages. Such linkages provide channels or pipelines (Bathelt et al., 2004; Moodysson, 2008) that connect local initiatives with networks, resources and developments in other places.[1] As discussed above, the ways in which they shape the design and outcome of sustainability experiments needs to be assessed empirically. This includes an analysis of the power relationships enacted through these linkages, the ways in which these re-configure (or reinforce) local structures in receiving geographical contexts and how they shape the design and outcome of socio-technical trajectories. A relational spatial analysis which analyses power in transnational linkages is beyond the scope of this paper, but we return to this question in the concluding section of this paper.

The methodological approach for exploring transnational linkages involved the construction of a database of solar-photovoltaic energy sustainability experiments in India. The database structure follows the analysis of transnational linkages presented in Section 2 of this paper (see also Annex 1).

Data was collected for initiatives started in the period 2000–2012. We expected to identify key areas of recent experimentation, while also providing some insight into the historical evolution of solar PV technology in India. Existing on-line information on solar PV were used as a starting point. To ensure a systematic search for experiments, we identified relevant actor-categories for solar PV in India, and searched for their initiatives. This included a systematic online search of websites and databases maintained by:

- Governmental actors including relevant ministries, 27 state governments and their bodies
- Global and domestic solar PV industrial actors
- Indian knowledge institutes (identified through a Scopus search on solar PV publications)
- Domestic and international NGOs involved in solar PV projects

[1] Sklair (2001) and Coe and Bunnell (2003) refer to such connections as trans-local, non-local or extra-territorial linkages.

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- International organisations, such as the United Nations, the World Bank and the Asian Development Bank
- International aid organisations, such as the German GIZ

Some websites provided existing overviews of solar-PV projects. In other cases we browsed organisational websites for relevant data or used search-boxes on the websites to find project descriptions. Data on a total of over 200 Indian PV experiments were gathered and 65 of these were analysed in greater detail. This systematic search was complemented with consultation of a number of solar PV experts in India. The database was discussed with 16 Indian solar PV experts at a workshop in Kolkata in November 2013. The experts were representatives of the six emerging SPV trajectories. Using an exemplary experiment they first shared basic information about the experiment and the trajectory. Secondly, they discussed learning, network formation and expectation articulation processes in every trajectory. Thirdly, the experts examined the impact of the five transnational linkages on the development of this trajectory. Fourthly, all experts had a chance to express views about sustainability of the analysed pathways and experiments that constitute them. The research approach benefited from its embedding in a broader research programme on sustainability experiments in Asia, including detailed qualitative case study research of solar PV experiments and developments in India (e.g. Jolly et al., 2012), providing us with a thorough understanding of the political, industrial, economic and social developments influencing solar PV in India (www.sustainabilityexperimentsasia.org).

Analysis of the collected data followed a straightforward coding procedure. Binary information on the *occurrence* of transnational linkages (actors, institutions, knowledge, capital, technology) was coded: 1 reflecting presence and 0 reflecting absence. Transnational actors, institutions, capital and technology linkages were coded 1 in case of factual presence of any of the four in the experiment. Knowledge linkages were coded 1 whenever transnational actors or technology were involved in the experiment or when knowledge transfer occurred without mobility of people or transfer of artefacts. After the coding procedure, the data was used to make visual representations of the types of transnational linkages present in the dataset. Table 1 provides an example of the operationalization of the different linkages, including examples of the kind of evidence we searched for.

An important limitation of our methodological approach is the use of the Internet as the main data source. The risk is that important experiments not present online are missed. This may cause a bias in the database towards more formal experiments supported by industrial and governmental actors, since grassroots experiments and civil society initiatives may have a more limited online presence. It

Table 1
Operationalising transnational linkages.

Transnational linkages	Operationalised as:	Looking for evidence of:
Actors	Foreign individuals, organisations or networks participating in an experiment	Names of foreign actors mentioned as initiators, funders, owners or consultants in a project description
Knowledge	Knowledge derived from foreign or international organisations and networks that was used in designing the experiment	Specific acknowledgements of foreign knowledge providers in a project description, foreign education or work experience of involved actors
Capital	Financial support from foreign or international organisations and networks that was used in developing the experiment	References to international financial support in project description or on the websites
Institutions	International formal and informal institutions that structure the design and/or operation of an experiment	References to international regulations, standards, norms and practices that structured the design of the experiment, or international recognitions in the form of e.g. awards or endorsements
Technology	Use of technological components in the design of an experiment	Explicit reference to foreign technology providers such as suppliers of technology components, licenses or patents

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Table 2
Transnational linkages in a sample of 24 out of a total of 65 solar PV sustainability experiments in India (*1 denotes presence of the linkage, 0 denotes its absence, n/a means lack of data and no linkage counted*).

Experiment	Area of experimentation	Actors	Knowledge	Technology	Capital	Institutions	Initiator	Geo origin of initiator
LaBL	Lanterns	1	1	0	0	1	Knowl. Inst.	Nat
Christian Aid D-Light Solar project	Lanterns	1	1	1	1	1	NGO	Int
Aurore	Lanterns	1	1	1	n/a	1	NGO	Nat
Barefoot College, India	Lanterns	1	1	1	1	1	NGO	Nat
Capturing rays (MPGVM, India: Solar lanterns for market traders in Bhopal	Lanterns	1	1	n/a	1	1	NGO	Reg/Loc
WBREDA, India: Solar powers island mini-grids	Micro-grid	0	0	0	0	1	Government	Reg/Loc
Indira nagar micro grid solar project Rajasthan	Micro-grid	1	1	0	n/a	1	Government	Reg/Loc
Prepaid electricity for rural India- A gram Power Initiative	Micro-grid	0	1	n/a	n/a	1	Industry SME	Nat
145 MW grid connected solar project	Grid connected	1	1	n/a	1	1	Fin. Organis.	Int
Tirupathi – The green Temple	SHS/lanterns	1	1	1	1	1	Industry SME	Nat
Indian Solar Loan Programme UNDP	SHS	1	1	n/a	1	1	Government	Int
Women power (Solar PV yarn machines)	SHS	1	1	1	0	1	NGO	Reg/Loc
Solar lantern: Lighting People's Lives	Lanterns	1	1	0	n/a	1	NGO	Int
Lightning lives (Aryavart Gramin Bank)	Lanterns	1	1	1	0	1	Fin. Organis.	Reg/Loc
First solar PoA for India	Grid connected	1	1	0	n/a	1	Consultancy	Int
National Solar Power development Programme (Gujarat and Rajasthan)	Grid connected	1	1	n/a	n/a	1	Industry MN	Int
Off grid pay as you go solar	SHS	1	1	0	1	1	Industry SME	Nat
Solar PV Based Electric Power Project (2×25 kW), Magra, Rajasthan	Grid connected	0	0	0	0	0	Government	Nat

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Table 2 (*Continued*)

Experiment	Area of experimentation	Actors	Knowledge	Technology	Capital	Institutions	Initiator	Geo origin of initiator
1+ MW rooftop solar project on Thyagaraj Stadium, New Delhi, India	Roof top	1	1	1	0	0	Government	Reg/Loc
Greenlight Planet	Lanterns	1	1	1	1	1	Industry SME	Int
Solar City Chandigarh	Solar city	0	1	0	1	0	Government	Nat
Solar PV Based Electric Power Project (2x25 kW), Chattisgarh	Off grid power plant	1	1	1	0	0	Government	Nat
Maharashtra Solar Park and Green Grid Development Investment Programme	Grid connected	1	1	0	1	1	Industry SME	Reg/Loc
40 MW Dahanu Solar Power Project, in Jaisalmer district, Rajasthan	Grid connected	1	1	1	1	1	Fin. Organis.	Int

may also cause a bias towards successful initiatives, because unsuccessful initiatives are less likely to be featured online. We tried to reduce these risks through qualitative research and discussed these issues with PV experts, including representatives of civil society organisations.

Another limitation of this approach is that it was difficult to assess the relative strength or weakness of the different linkages, and the ways in which they generate a positive or negative impact on the project in terms of its establishment, continuation, scaling-up or abandonment. The role of relational power across transnational linkages could also not be investigated using this qualitative web-based data. Because of this, it was decided not to weigh the linkages or to assess their impact on the outcome of the experiments, but to limit analysis to descriptive mapping and an analysis of patterns. Determining the relative importance, directionality and impact of transnational linkages would require a broader-scale and in-depth qualitative case study approach. We return to this issue in the concluding section.

Finally, a key challenge was to define which solar PV initiatives should be considered sustainability experiments and which should not. Given our definition, we took an inclusive approach by registering all initiatives that use solar PV in the database regardless of their scale, size or number of involved actors. The argument is that all these initiatives are radically novel in relation to conventional power generation in India, characterised by a large-scale fossil-fuel based power sector, and that these initiatives are part of an early-stage development intended to provide broad access to clean electricity.

4. Results

According to the IEA (2011) the Indian power sector faces major challenges. India is largely dependent on fossil fuel imports to meet its growing energy demands. Coal is in abundance in India but of poor quality. Imports of coal are expensive, which excludes it from being a viable economic option. Political urgency to curb CO_2 emissions enforces the use of renewable resources. According to the IEA (2011) the availability of renewable resources are quite limited, except for solar. Solar PV is perceived by many as a very promising technology with a large technical potential.[2] SPV is also seen as an opportunity for

[2] Annual solar irradiance is high (>1900 kWh/m^2/y and 300 clear sunny days per year compared to e.g. >800 kWh/m^2/y in Germany and less than 64 clear sunny days per year).

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Box 1: An example of a SPV sustainability experiment in India: Aurore Solar Home Systems (SHS), Tamil Nadu, 2004

- Problem framing:
  - To replace the use of ca 1750 l/y of diesel, brighter and safer light, to replace kerosene lamps and candles avoiding about 1300 t/y CO_2
- Actor-network (international/national):
  - Auroville Foundation (Aurore) – NGO National Initiator
  - WIPRO (software delivery) – Industry SME National Owner of technology
  - SREI Kolkata (infrastructure) – Industry SME National Owner of technology
  - IFCL Chennai – Financial organisation Local
  - MNRE (IREDA) – Government National Sponsor
  - Six NGOs including Greenpeace – NGO International
  - Bharat Heavy Electricals Ltd – Industry MN National Owner of technology
  - Tata BP Solar – Industry MN International Owner of technology
- Knowledge: (international/national):
  - Embedded in national and international actors
- Technology: Tata BP, Bharat Heavy Electricals Ltd, SREI Kolkata, WIPRO (international/national)
- Institutions: (international):
  - 2004 Ashden Award, UNDP recognised
- Capital: MNRE (national)
- Outcomes: project is replicated at national level

sustainable and secure electrification of rural areas, bringing power to the rural poor. Furthermore, SPV costs globally are falling. In India solar PV developments have been boosted by the National Solar Mission (Government of India, 2013), launched in 2008, and given new impetus in May 2014 with the election of Narendra Modi as the Indian Prime Minister. It opened up the solar energy sector to private domestic and foreign participation and capital, and generated many new experiments.

There is a wide variety of SPV sustainability experiments in India in terms of the size, location, impact, initiator and problem framings and goals. Many experiments are development projects with a strong socio-economic problem framing (e.g. electrification, poverty alleviation, safety, reduction of health impacts) but increasingly also include explicit environmental concerns (such as greenhouse gas emission reduction, energy efficiency, reduction of dependence on fossil fuels). A few of the experiments are initiated by international organisations like the UN Development Programme, the World Bank or the Asian Development Bank but there are also many initiatives by local communities. Box 1 shows an example of the data collected for one project initiated by the Auroville Foundation.

Our analysis reveals that the majority of the analysed experiments have several types of transnational linkage (see Table 2 for a sample). Out of 65 projects analysed in detail, in only three were we unable to identify any transnational linkages. Furthermore, we have clustered all 65 experiments into 8 groups of similar experiments in terms of their socio-technical design and function. These are areas where substantial experimentation is carried out and which represent emerging innovation trajectories in the PV niche in India. These areas include: grid connected power plants (16 experiments), lanterns (15), micro-grids (7), solar home systems (SHS) (7), off-grid power plants (6), roof top systems (5), solar cities (4) and other (4) (including a diversity of applications). The second column in Table 2 shows examples of this grouping exercise.

We observe that the linkages are relatively well-distributed, with actor and knowledge linkages slightly more common (see Fig. 1). Foreign knowledge is the main asset sought by the initiators of the SPV projects. Collaboration with an international actor in the consortium (often an internationally operating company of Indian origin) or international training of a national, regional or local actor are key mechanisms in knowledge linkages. Actor and knowledge linkages are thus strongly interrelated in our sample. Only in case of two experiments: Solar City Chandigarh and a Gram Power initiative, no transnational actors could have been identified but knowledge transfer did occur. In the first case, the US Department of Energy was consulted on building guidelines, best practices and other tools to advance the development of near-zero urban energy cities and communities while Brookhaven National Laboratory and Lawrence Berkeley National Laboratory were advising India's Ministry of

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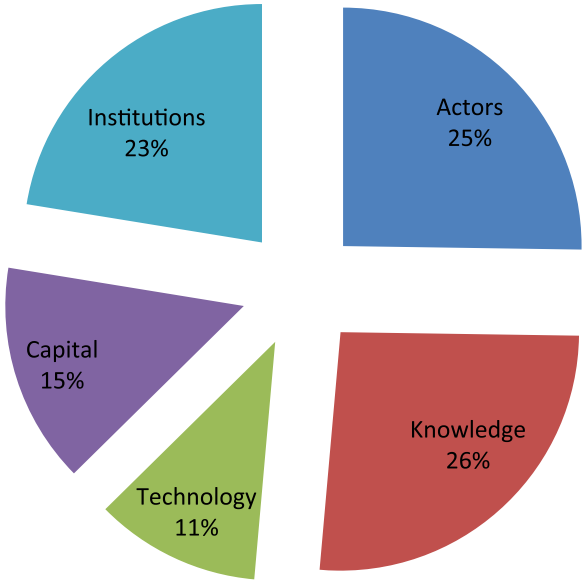

Fig. 1. Pattern of transnational linkages in 65 SPV sustainability experiments in India. (*Note*: the total number of transnational linkages in these experiments is 214 (out of 325 theoretically possible.)

Urban Development, Ministry of Commerce and Industries, and Ministry of New and Renewable Energy (MNRE) on planning and implementation of these cutting-edge urban planning tools in the context of solar city initiative. In case of the second, micro-grid project, the Gram Power is a national actor but its team brings together a number of members of Indian nationality educated abroad (mainly in the USA) and international consultants who counsel Gram Power on e.g. expansion strategies. Institutional linkages are present a lot in the form of international endorsements. Some projects are almost entirely Indian, but have received an international award or recognition. No specific adjustment to or transfer of foreign standards, regulations or practices could have been observed. Capital and technology are the least common transnational resource. This could entail a higher level of capability formation taking place in SPV in India, and may indicate that solar PV developments are seen as a nationally important energy strategy.

In Fig. 2 we show the distribution of transnational linkages per experiment and by area of experimentation. Most transnational linkages per experiment occur in lanterns, with an average of 4.33 per experiment and in the domain of solar home systems (4.0). The fewest transnational linkages were recorded for micro-grids (3), roof-tops (3) and off-grid power plants (2.5). We observe an intriguing relationship between the level of transnational linkages per experiment and the type of initiating actors of experimentation. Lanterns and solar home systems are areas of experimentation that demonstrate the largest numbers of international actors as initiators, namely, 33% and 43% respectively, compared to micro-grids (0%), roof tops (0%) or off-grid power plants (0%). This suggests that international initiators stimulate occurrence of other types of transnational linkages.

A more detailed analysis of who initiates the experiments shows that regional and local governments (mostly state or city-level) play an especially important role in setting up sustainability experiments, followed by other national, regional and local actors (see Fig. 3). In fact, almost 78% of all analysed projects were initiated by Indian (local, regional or national) actors, with a tendency for larger experiments such as power plants and roof top installations on industrial and public office buildings to be domestically initiated. International organisations tend to focus on smaller-scale technologies, such as lanterns or solar home systems. A possible explanation for this is that prior to the National Solar Mission, most innovation efforts were carried by international businesses targeting rural areas with these technologies. This may have changed with the National Solar Mission, which, on the one

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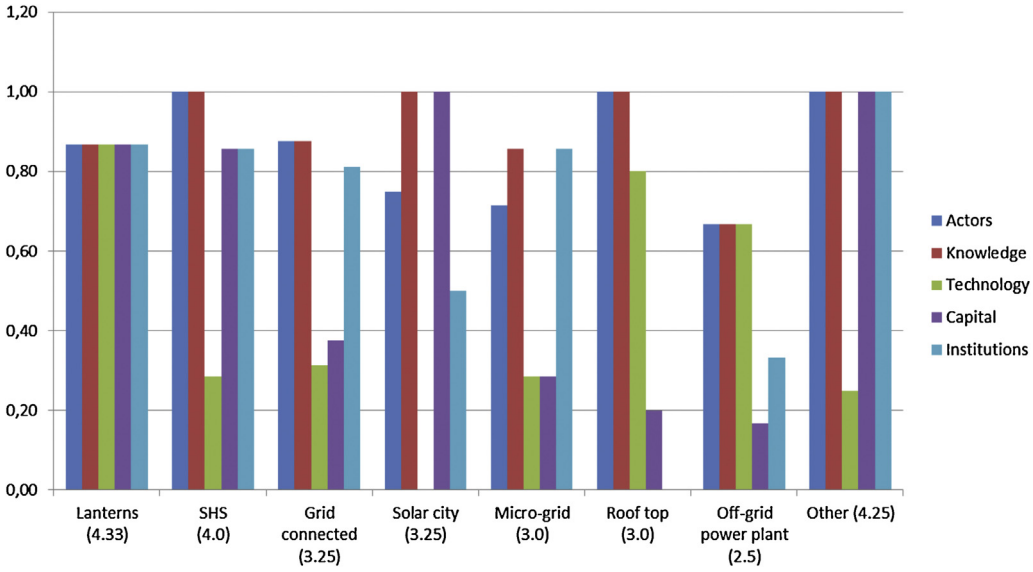

Fig. 2. Distribution of transnational linkages per experiment in 65 SPV experiments by domain of experimentation. (*Y* axis: number of transnational linkages per experiment in a domain. Number in parenthesis is the average number of all transnational linkages per experiments).

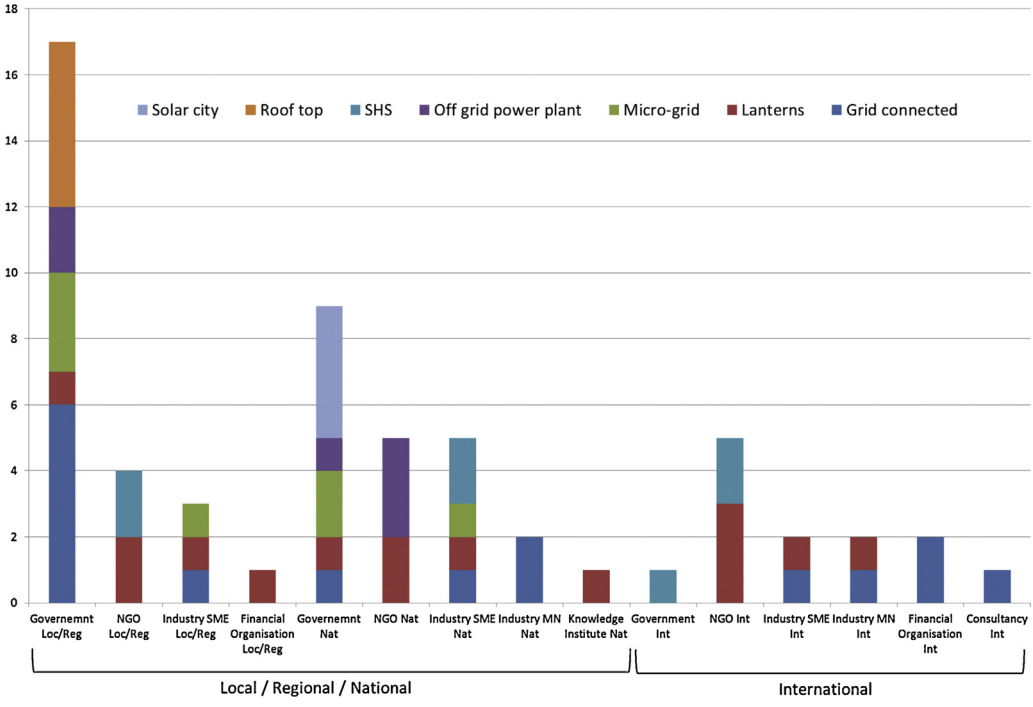

Fig. 3. Initiators of 65 Indian SPV experiments showing area of experimentation.

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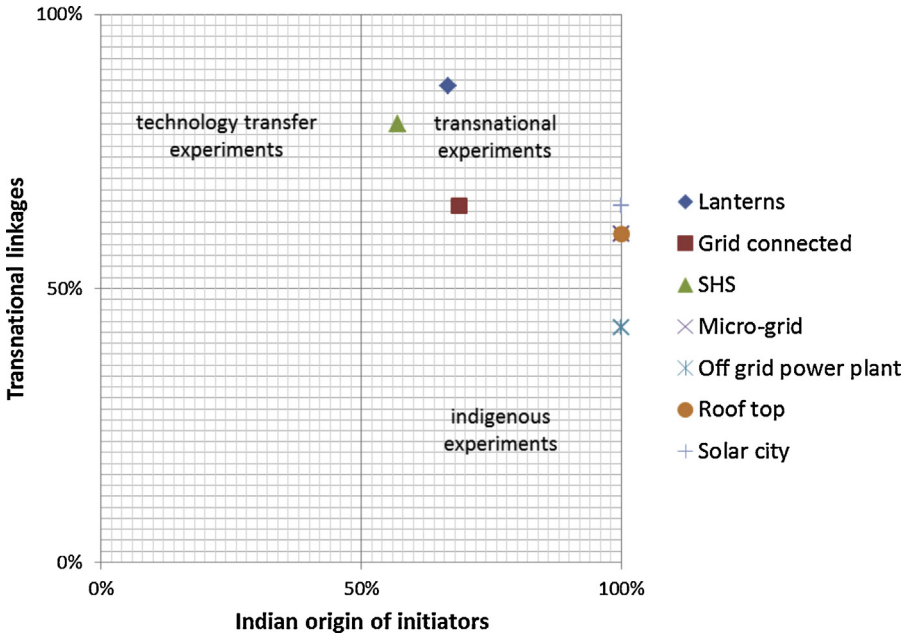

Fig. 4. Different kinds of experimentation depending on the origin of initiators and the embedding of the experiment in transnational linkages.

hand made new application domains more attractive to international businesses, but on the other, opened up ample opportunities for domestic actors' activities.

Fig. 4[3] plots the level of transnational linkages (expressed in percentage) against the level of Indian origin in our sample of SPV sustainability experiments.[4]

SPV experiments that are found in the top-right quadrant are experiments that are mostly initiated by Indian actors, but which are deeply embedded in a network of transnational linkages through flows of actors, knowledge, institutions, capital or technology. We call these experiments *transnational experiments*. The bottom-right represents clusters of SPV experiments that are initiated by Indian actors and are not strongly embedded in transnational relationships. We call these *indigenous experiments*. SPV clusters in the top-left quadrant, on the other hand, are strongly driven by an international community as initiators while also having strong transnational linkages. Indian actors do not play a major role and we classify these experiments as *technology transfer experiments*. The lower-left quadrant is technically impossible: an experiment cannot be internationally set up and have no transnational linkages. We find that all but the off-grid power plant cases can be classified as transnational experiments: initiated in India, but with strong transnational linkages.

5. Conclusions

This paper aims to contribute to the emerging geography of sustainability transitions literature that is concerned with better understanding how transition processes cross national boundaries.

[3] The category *other* was excluded from this analysis.

[4] The level of Indian origin was calculated as the number of experiments initiated by Indian actors out of all experiments in a specific domain. For example 10 out of 15 lantern experiments were initiated in India (67% of experiments of Indian origin). The level of transnational linkages was calculated as the number of transnational linkages out of all *possible* linkages in a domain. For example, in the 15 lantern experiments a total of $15 \times 5 = 75$ transnational linkages are possible. We count 65 corresponding to 87% of transnational linkages.

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Specifically, the paper sets out a typology of transnational linkages in sustainability experiments and applies this typology to analysing linkages in over 200 innovative solar photovoltaic projects in India for the period 2000–2012. We regard this study as exploratory, defining a research field that requires substantial further work. Here we draw conclusions and make suggestions for further research.

First, we have shown that sustainability experiments in this particular set of new solar photovoltaic technologies in India are highly transnational in nature. Almost all experiments in our sample exhibit some form of transnational embedding, whether through flows of actors, knowledge, institutions, capital or technology. The case of solar PV in India suggests that closely related actor and knowledge flows are particularly important in sustainability experimentation. Only in two cases and as far as the available data indicated, no specific transnational actor flows could have been identified while knowledge transfer did occur. In the case of the Gram Power initiative, knowledge was provided in the form of consultancy advice while in the case of Chandigarh solar city, in the form of guidelines and best practices' transfer. What we have termed technological linkages were found to be the least common. In the case of experiments initiated by Indian stakeholders, the transnational linkages provide the experiments' actors with access to a global knowledge pool and foreign assets such as capital or technology. These linkages are suggested to be ways of complementing local capabilities and resources. Whether or not these findings can be generalised to other sectors or regions needs to be assessed, in particular through comparative studies between domains and countries. Through this application to the solar PV domain in India we believe we have demonstrated the typology's usefulness in mapping transnational linkages. However, more detailed data are necessary to clarify the possible overlap between the different types of linkages, particularly actor-knowledge and knowledge-technology flows. Second, studying transition processes from a transnational perspective does not mean that national, local or regional scales are unimportant. On the contrary, our study has demonstrated that in many cases Indian actors were initiators of the experiments, but that they have drawn on transnational linkages to gain access to resources and markets in order to develop novel socio-technical configurations. This is in line with studies on transnationalism, which argue that transnational networks and organisations do not replace the national scale, but rather become a new arena for national actors to pursue and defend their national or local interests (see also Sengers and Raven, 2015).

Third, taking a transnational perspective on sustainability experiments opens the way for more globally distributed models of innovation, less tied to more bounded notions of technology transfer, capability development and a global technological frontier. Entrepreneurs, activists and local governments in developing countries are strongly involved in experimenting with new, more sustainable socio-technical systems. They engage with transnational networks and infrastructures to gain access to resources and markets, thereby configuring innovative capabilities in lower-income settings, something conventional growth and innovation theory cannot explain. The implications of such a new model of innovation and development and its relationship with classical approaches in the development economics is a topic for further research.

Fourth, in the case of solar PV in India, our database allowed us to identify seven domains of experimentation. We anticipate a process of niche formation taking place in Indian SPV in the coming years organised around these socio-technical domains. This process is likely given the commitment of the national government of India to support solar initiatives such as the National Solar Mission programme, and the relative openness of the Indian economy to foreign participation and investments. However, whether a transition of the electricity system towards the substantial use of solar resources is actually underway needs further research. In particular, such a transition requires not only promising and developed niches, but also changes in incumbent regimes, and the broader macro-economic and institutional landscape. Whether these are underway, and the ways in which such changes are embedded in transnational and multi-scalar dynamics, is another theme for follow up research.

Finally, another area for research relates to questions of assessing the relative (positive and negative) impacts of transnational linkages on sustainability experiments (and their outcomes) in relation to local, national or regional ones. This paper drew on a database to map transnational linkages for experiments using mainly internet-sources. We were not able to map the ways in which such linkages impact the 'effectiveness' of sustainability experiments, for example in terms of their socio-technical design, up-scaling or discontinuation. Although we believe that transnational linkages have a positive impact on innovation and development, we have not tested for such outcomes. We were also not able

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to capture how power relationships enacted through transnational linkages are influencing the design and outcome of experimentation. Depending, for example, on the kinds of interests enacted through transnational linkages, experiments may become truly transnational phenomenon that enable local and regional capacity building or, on the other hand, represent a new form of dominance that takes advantage of resources (including low-cost labour) in developing countries and leads to new transfers to high-incomes countries. Such an agenda would be concerned with questions regarding the ways in which transnational linkages shape local embeddedness of experiments and profoundly change local practices (or not) – questions that are also key to the geography of transitions research agenda.

Acknowledgments

Research reported in this paper has been carried out in the context of the NWO-WOTRO Integrated Programme on Experimenting for Sustainability in India and Thailand: A transitions perspective on sustainable electricity and mobility initiatives (W 01.65.330.00). We would also like to thank the editors and two anonymous reviewers for their valuable comments that helped improve this article.

Annex 1. Data contained in SPV experiments in India database[5]

The database contains the following information about sustainability experiments:

- Factual information about the experiment such as the location and start/end date.
- The problem framing or goals of the experiment such as environmental, social or economic challenges.
- Spatial reach of these problem framings and goals (local, national or international).
- Names and type of actors involved in the experiment such as policy, industrial or civil society actors.
- The geographical origin of actors.
- The role of these actors in the project such as initiator, owner, user or sponsor.
- The knowledge linkages involved such as in the form of foreign education of key actors or their work experience.
- Technology linkages including the type and origin of the technology used.
- Financial linkages such as the size and origin of the budget
- Institutional linkages such as the kind of linkages (e.g. international recognition) and the geographical origin.
- Outcomes of the experiments such as still in operation, replicated or discontinued.

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[5] The database is not openly accessible.

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