SOCIAL CHANGE THROUGH DIFFUSION OF SUSTAINABILITY INNOVATIONS FROM THE BOTTOM-UP

CASE STUDIES OF RENEWABLE ENERGY AND SUSTAINABLE FARMING PRACTICES IN THE GLOBAL SOUTH

Der Fakultät Nachhaltigkeit

der Leuphana Universität Lüneburg

zur Erlangung des Grades

Doktor der Philosophie
(Dr. phil.)

vorgelegte Dissertation von
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geboren am 02.02.1977
in Florencia, Caquetá, Kolumbien

Eingereicht am: 13.06.2019

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Esta obra la dedico a mi familia

A mis hij@s
Alejandra, Derian y Luisa

A mi compañera
Monika

A Mi Madre y mi Padre
Magnolia y Mitiliano

A Mi Hermana
Rocio

Abstract

This doctoral research is located in the branch of sustainability sciences that has the realisation of sustainable development as its core subject of research. The most broadly accepted notion of sustainable development is that which evolves along the resolutions, declarations, and reports from international processes in the framework of the United Nations (UN). The consensual outputs from such processes feature global-generalised and context-free perspectives. However, implementation requires action at diverse and context-rich local levels as well. Moreover, while in such UN processes national states are the only contractual parties, it is increasingly recognised that other ('nonstate') actors are crucial to sustainability. The research presented here places the attention on bottom-up initiatives that are advancing innovative ways to tackle universal access to clean energy and to strengthen small-scale family farmers. This means, the focus is on bottom-up initiatives advancing local implementation of global sustainability targets, more precisely, targets that make part of the Sustainable Development Goals two and seven (SDG 2 and SDG7). The research asks how such bottom-up initiatives can contribute to the diffusion of sustainability innovations, thereby also contributing to social change. Three aims are derived out of that central question:

- Analytical: To understand the role of bottom-up initiatives in the diffusion of sustainability innovations and in the thereby involved social changes.
- Transformative: To contribute with my research to the actual diffusion of sustainability innovations.
- Methodological: To outline a research approach that provides a solid conceptual and methodological framework for attaining the analytical and transformative aims.

Conceptually, the research builds on theoretical insights from diverse strands of the broad field of sustainability transitions – mostly on conceptualisations from transition management, strategic niche management, and grassroots innovations – as well as on conceptual and methodological advances in transdisciplinary and in transformative research.

The doctoral research comprises four single studies, in which the notion of diffusion is explored at different scopes of social scales. It begins with a thorough analysis of diffusion programs of domestic biodigesters to rural households in countries of the global south. The focus is on the process by which this specific technical inno0vation results integrated (or not) into the daily realities of single rural households, that is, the adoption process. In the second study, the attention is on energy supply models based on different decentralised renewable technologies. Central to these models is the building of new (or strengthening of existing) local socioeconomic structures that can assume and ensure the proper operation and supply of energy services. The interest in this study is on the strategies that organisations implementing community-based energy projects apply to support the realisation of such local structures. The third study focuses on a network of bottom-up initiatives that have been advancing alternative approaches to family farming in Colombia. The network mainly comprises farmers associations, other organisations from civil society, and researchers who had been collaborating and experimenting with innovations in different innovation fields such as technical, organisational, financial, and commercialisation schemes. The aim of this third study is to provide insights into the challenges and difficulties faced by these actors in broadening the diffusion of the innovations they have been advancing. To perform this study, a methodological strategy is applied that combines a transdisciplinary mutual learning format with qualitative content analysis techniques. The fourth and last study is a conceptual disquisition. It develops a conceptual framework that (a) provides better accounts for the particularities of endeavours aimed at the diffusion of knowledge and practices from the bottom-up across local contexts and social scales, and (b)

advances first conceptual steps towards an explicit account for the role that innovation research (and innovation researchers) can assume for the actual realisation of diffusion.

The main findings or contributions of the doctoral research can be categorised into four subjects:

1) Bottom-up initiatives contribute to the diffusion of sustainable innovations by:
   (a) mobilising transformative resources for inducing diffusion in their scope of action; both their own as well as others' resources; and
   (b) creating spaces for experimentation in which interventions can be tested (and if necessary adjusted) in order to ensure the proper deployment of innovations.

2) In their efforts to advance the diffusion of sustainability innovations, bottom-up initiatives contribute to social changes for
   (a) ensuring the effective deployment of the innovations, for instance:
      - by supporting change in the sociotechnical configurations that enable and constrain the daily practices of single households, in a way that permits the innovation's proper operation; and
      - by reshaping local socioeconomic structures in order to ensure and sustain the supply of services and goods linked to the implemented innovation;
   (b) building local available storage of transformative resources, that is, the consolidation of local organisational structures that facilitate the building and binding of knowledge, financial capital, people's skills, access to networks among other resources.

Moreover, knowledge and practices from the bottom-up can transit to other social scales, and in this way contribute to social changes beyond their localities.

3) A conceptualisation of innovation diffusion, in which the work of academic researchers studying innovation is a constitutive part of transdisciplinary knowledge articulations that promote diffusion. In this way transdisciplinary research alliances can be envisioned in which researchers investigate about, with, and for bottom-up initiatives.

4) Contributions to the consolidation, systematisation, and dissemination of strategies that are applied by farmers associations in order to strength the economic, social, environmental, and cultural dimensions of Colombian family farmers.

The contours of two research horizons for further research are outlined, they can be briefly described as: (a) explorations of diffusion beyond bottom-up localities involving changes of socio-political structures and (b) the development of conceptual and methodological frameworks for the realisation of bottom-up transformative research alliances.

Zusammenfassung

Dieses Dissertationsvorhaben lässt sich am besten in den Bereich der Nachhaltigkeitswissenschaften verorten, der die Verwirklichung von nachhaltiger Entwicklung als seinen Forschungsgegenstand innehat. Der meistverbreitete Begriff von nachhaltiger Entwicklung lässt sich entlang der Resolutionen, Erklärungen und Berichte aus internationalen Prozessen im Rahmen der Vereinten Nationen (UN) verfolgen. Die auf Konsens basierten Ergebnisse solcher Prozesse weisen eine global verallgemeinernde und kontext-freie Perspektive auf. Die praktische Umsetzung erfordert jedoch auch Handlungen auf verschiedenartigen und kontext-reichen lokalen Ebenen. Auch wenn in solchen UN-Prozessen nur Nationalstaaten als unterzeichnende Parteien gelten, wird zunehmend anerkannt, dass andere (‚nonstate') Akteure für die Debatten und die Umsetzung von Nachhaltigkeit entscheidend sind. Die hier vorgestellte Forschung beschäftigt sich mit Bottom-up-Initiativen, die innovative Wege zur Sicherung des Zugangs zu bezahlbarer, verlässlicher, nachhaltiger Energie für alle und zur Stärkung kleiner Familiy Farmers fördern. Der Fokus liegt also auf Bottom-up-Initiativen, die die lokale Umsetzung globaler Nachhaltigkeitsvorgaben vorantreiben, genauer gesagt, auf Vorgaben, die Teil globaler Ziele für nachhaltige Entwicklung zwei und sieben sind (SDG2 und SDG7). Die Forschung fragt, wie solche Bottom-up-Initiativen zur Verbreitung von Nachhaltigkeitsinnovationen und damit auch zum sozialen Wandel beitragen können. Aus dieser zentralen Frage leiten sich drei Forschungsziele ab:

- Analytisch: Die Rolle von Bottom-up-Initiativen bei der Verbreitung von Nachhaltigkeitsinnovationen und den damit verbundenen sozialen Veränderungen zu verstehen.
- Transformativ: Einen Beitrag zur tatsächlichen Verbreitung von Nachhaltigkeitsinnovationen zu leisten.
- Methodik: einen Forschungsansatz zu skizzieren, der einen soliden konzeptionellen und methodischen Rahmen für die Erreichung der analytischen und transformativen Ziele bietet.

Konzeptionell baut die Forschung auf theoretische Erkenntnisse aus verschiedenen Bereichen des breiten wissenschaftlichen Feldes ‚sustainability transitions' auf – meist auf Konzeptualisierungen aus ‚transition management', ‚strategic niche managment' und ‚grassroots innovation' – sowie auf konzeptionelle und methodologische Überlegungen zur transdisziplinären und transformativen Forschung.

Die Forschung umfasst vier Einzelstudien, in denen der Begriff der Diffusion auf verschiedenen sozialen Skalen untersucht wird. Es beginnt mit einer gründlichen Analyse der Diffusionsprogramme von Kleinstbiogasanlagen in ländlichen Regionen in Ländern des globalen Südens. Im Mittelpunkt steht der Adoptionsprozess, d.h. wie die spezifischen Innovation in die tägliche Realität einzelner Haushalte integriert wird (oder nicht). In der zweiten Studie geht es um Energieversorgungsmodelle, die auf verschiedenen dezentralen erneuerbaren Technologien basieren. Im Mittelpunkt dieser Modelle steht der Aufbau neuer (oder die Stärkung bestehender) lokaler sozioökonomischer Strukturen, die den ordnungsgemäßen Betrieb der technischen Innovationen und die Bereitstellung von Energiedienstleistungen übernehmen und sicherstellen können. Das Interesse dieser Studie liegt auf den Strategien der durchführenden Organisationen, um durch die Implementierung gemeinde-basierte Energieprojekte die Realisierung solcher lokaler Strukturen zu unterstützen. Die dritte Studie konzentriert sich auf ein Netzwerk von Bottom-up-Initiativen, die alternative Ansätze für Family Farmers in Kolumbien entwickeln. Das Netzwerk besteht hauptsächlich aus Kleinbauernverbänden, anderen Organisationen der Zivilgesellschaft und Forschern, die mit Innovationen in verschiedenen Innovationsfeldern wie technischen, organisatorischen, finanziellen und

kommerziellen Maßnahmen zusammenarbeiten. Ziel dieser dritten Studie ist es, die Herausforderungen und Schwierigkeiten dieser Akteure bei der Diffusion der von ihnen vorangetriebenen Innovationen zu erforschen. Um diese Studie durchzuführen, wird eine methodische Strategie angewandt, die ein transdisziplinäres gegenseitiges Lernformat mit qualitativen Inhaltsanalyseverfahren kombiniert. Die vierte und letzte Studie ist eine konzeptionelle Abhandlung. Sie entwickelt einen konzeptionellen Rahmen, der (a) die Besonderheiten der Diffusion von Wissen und Praktiken von Bottom-up-Initiativen jenseits ihrer lokalen Kontexte berücksichtigt und (b) erste konzeptionelle Schritte in Richtung einer expliziten Berücksichtigung der Rolle, die die Innovationsforschung (und Innovationsforscherinnen und -forscher) für die tatsächliche Realisierung von Diffusion einnehmen kann, vorantreibt.

Die Hauptergebnisse oder Beiträge der Forschung lassen sich in vier Bereiche unterteilen:

1) Bottom-up-Initiativen tragen zur Verbreitung nachhaltiger Innovationen bei, durch:
   a) die Mobilisierung transformativer Ressourcen, sowohl ihrer eigenen als auch der Ressourcen anderer Akteuren; und
   b) die Schaffung von Experimentierräumen, in denen Interventionen getestet (und gegebenenfalls angepasst) werden können, um den effektiven Einsatz von Innovationen zu gewährleisten.

2) In ihren Bemühungen, die Verbreitung von Nachhaltigkeitsinnovationen voranzutreiben, tragen Bottom-up-Initiativen zu sozialen Veränderungen bei, die:
   a) den effektiven Einsatz der Innovationen sicherstellen, beispielweise durch:
      - die Unterstützung der notwendigen soziotechnischen Umwandlung einzelner Haushalte, damit die Innovation in ihren täglichen Praktiken sinnvoll integriert wird; und
      - durch die Umgestaltung von lokalen sozioökonomischen Strukturen, um die Funktionalität der umgesetzten Innovation sicherzustellen und aufrechtzuerhalten; und
   b) den Aufbau lokal verfügbaren ‚Storage' transformativer Ressourcen ermöglichen, d. h. die Konsolidierung lokaler Organisationsstrukturen, die den Aufbau und die Bindung von Wissen, Finanzkapital, Fähig- und Fertigkeiten, Zugang zu Netzwerken und anderen Ressourcen erleichtern.

Darüber hinaus können Wissen und Praktiken von Bottom-up-Initiativen auf andere soziale Skalen übertragen werden und so zu sozialen Veränderungen jenseits ihrer Lokalitäten beitragen.

3) Die Entwicklung einer Konzeptualisierung von Diffusionsprozesse, bei der die Arbeit von akademischen Innovationsforscherinnen und -forschern ein konstitutiver Bestandteil transdisziplinärer Wissensartikulationen ist, in denen Innovationsdiffusion gefördert wird. Auf diese Weise lassen sich transdisziplinäre Forschungsallianzen bilden, in denen Forscher über, mit und für Bottom-up-Initiativen forschen.

4) Beiträge zur Konsolidierung, Systematisierung und Verbreitung von Strategien, die von Kleinbauernverbänden angewandt werden, um die wirtschaftliche, soziale, ökologische und kulturelle Dimension der kolumbianischen Family Farmers zu stärken.

Es werden Konturen von zwei Forschungshorizonten für weitere Forschungsvorhaben skizziert, die kurz beschrieben werden können als: (a) Erkundungen von Diffusionsprozessen über Bottom-up-Lokalitäten hinaus, die auf Veränderungen von gesellschaftspolitischen Strukturen abzielen, und (b) die Entwicklung konzeptioneller und methodologischer Rahmen für die Realisierung von bottom-up-transformativen Forschungsallianzen.

Resumen

Esta investigación doctoral se sitúa en la rama de las ciencias de la sostenibilidad que tiene como tema central de investigación la realización práctica del desarrollo sostenible. La noción más ampliamente aceptada de desarrollo sostenible es la que evoluciona a lo largo de las resoluciones, declaraciones e informes de los procesos internacionales en el marco de las Naciones Unidas (ONU). Los resultados consensuados de estos procesos presentan perspectivas universales generalizadas y sin contexto. Sin embargo, su realización requiere también la adopción de medidas a niveles locales diversos y ricos en contexto. Además, si bien en estos procesos de las Naciones Unidas los Estados nacionales son las únicas partes firmantes, cada vez se reconoce más que otros actores ("no estatales") son cruciales para avanzar en el camino hacia sociedades sustentables. La investigación que aquí se presenta dirige su atención a iniciativas de base que están promoviendo formas innovadoras de abordar el acceso universal a la energía limpia y de fortalecer a agricultores familiares. Esto significa que la atención se centra en iniciativas de base que promueven la realización de los objetivos de sostenibilidad global a nivel local. Más concretamente, los objetivos que forman parte de los Objetivos de Desarrollo Sostenible dos y siete (ODS 2 y ODS 7). La investigación se pregunta cómo estas iniciativas de base contribuyen a la difusión amplia de innovaciones sustentables, contribuyendo así también al cambio social. De esta pregunta central se derivan tres objetivos:

- Analítico: Comprender el papel de las iniciativas de base en la difusión de innovaciones sustentables y en los cambios sociales que conllevan.
- Transformador: Contribuir con mi investigación a la difusión de innovaciones sustentables.
- Metodológico: Esbozar un enfoque de investigación que proporcione un marco conceptual y metodológico sólido para alcanzar los objetivos analítico y transformador.

Desde el punto de vista conceptual, la investigación se basa en aportes teóricos procedentes de diversas vertientes del amplio campo de estudios sobre transiciones de sostenibilidad (*sustainability transistions*) – en su mayor parte en conceptualizaciones procedentes de la gestión de la transición (*transition management*), la gestión de nichos estratégicos (*strategic niche management*) y las innovaciones de base (*grassroots innovations*)– así como en los avances conceptuales y metodológicos en la investigación transdisciplinaria y en la investigación transformadora.

La investigación doctoral se compone de cuatro estudios individuales, en los que se explora la noción de difusión en diferentes ámbitos y escalas sociales. Comienza con un análisis exhaustivo de programas de difusión de biodigestores domésticos en del 'sur global'. La atención se centra en el proceso por el cual esta innovación técnica resulta integrada (o no) en las realidades cotidianas de los hogares rurales, es decir, el proceso de adopción. En el segundo estudio, la atención se centra en modelos de suministro de energía basados en diferentes tecnologías renovables descentralizadas. Un aspecto central de estos modelos es la construcción de nuevas estructuras socioeconómicas locales (o el fortalecimiento de las existentes) que puedan asumir y garantizar el funcionamiento y el suministro adecuados de los servicios energéticos. El interés de este estudio radica en las estrategias que las organizaciones que implementan proyectos comunitarios de energía aplican para apoyar el establecimiento de dichas estructuras locales. El tercer estudio se centra en una red de iniciativas de base que han estado promoviendo enfoques alternativos a la agricultura familiar en Colombia. La red está compuesta principalmente por asociaciones de agricultores, otras organizaciones de la sociedad civil e investigadores que han estado colaborando y experimentando con innovaciones en diferentes campos, tales como los técnicos, organizativos, financieros y de comercialización. El objetivo de este tercer estudio es proporcionar una visión de los retos y dificultades a los que se enfrentan estos actores para promover la difusión de las innovaciones que han estado avanzando. Para la realización de este estudio se aplica una estrategia metodológica que combina un formato de aprendizaje mutuo

transdisciplinario con técnicas de análisis cualitativo de contenidos. El cuarto y último estudio es una disquisición conceptual. Desarrolla un marco conceptual que (a) da mejor cuenta de las particularidades de la difusión de conocimientos y prácticas desde las iniciativas de base hacia otros contextos locales y hacia otras escalas sociales, y (b) elabora los primeros pasos conceptuales hacia una consideración explícita del papel que estudios académicos sobre innovación pueden desempeñar en la realización efectiva de la difusión de innovaciones en sostenibilidad.

Los principales hallazgos o contribuciones de la investigación doctoral se pueden clasificar en cuatro temas:

1) Las iniciativas de base contribuyen a la difusión de innovaciones sostenibles mediante:
   a) la movilización de recursos transformadores para inducir la difusión en su ámbito de acción (tanto recursos propios como de terceros) y
   b) la creación de espacios de experimentación en los que se puedan ensayar medidas específicas con el fin de garantizar la aplicación efectiva de las innovaciones en los contextos locales.

2) En sus esfuerzos por avanzar en la difusión de las innovaciones de sostenibilidad, las iniciativas de base inducen cambios sociales con el fin de
   a) garantizar el aprovechamiento efectivo de las innovaciones, por ejemplo:
      - apoyando el ajuste de las configuraciones socio-técnicas que posibilitan y limitan las prácticas cotidianas de las familias que adoptan la innovación, de manera que ésta pueda funcionar correctamente; y
      - reformando las estructuras socioeconómicas locales para asegurar y mantener la oferta de servicios y bienes vinculados a la innovación implementada;
   b) crear almacenamientos locales de recursos transformadores, es decir, la consolidación de estructuras organizativas locales que faciliten la creación y la vinculación de conocimiento, capital financiero, competencias y acceso a redes, entre otros recursos.

Además, los conocimientos y las prácticas de iniciativas de base pueden transitar a otras escalas sociales, y de esta manera contribuir a cambios sociales más allá de sus localidades.

3) Una conceptualización de la difusión de innovaciones, en la que el trabajo de los investigadores académicos que estudian innovaciones es parte constitutiva de las articulaciones transdisciplinarias de conocimiento que promueven la difusión. De esta manera, se pueden prever alianzas transdisciplinarias de investigación en las que los investigadores investigan sobre, con y para iniciativas de base.

4) Contribución a la consolidación, sistematización y difusión de las estrategias que aplican las asociaciones de agricultores para fortalecer las dimensiones económicas, sociales, ambientales y culturales de los agricultores familiares Colombianos.

Finalmente, se esbozan los contornos de dos horizontes de investigación para futuros estudios, que pueden describirse brevemente como: a) exploraciones de procesos de difusión desde iniciativas de base hacia otras escalas sociales y que impliquen cambios de estructuras sociopolíticas y b) el desarrollo de marcos conceptuales y metodológicos para la realización de alianzas de investigación transformadoras con iniciativas de base.

Content

1 Introduction

The present manuscript has two interrelated purposes: (a) it is a medium for reconstructing and reflecting on the way in which my doctoral research evolved, and (b) it represents the doctoral dissertation that fulfils part of the requirements for the official conclusion of my doctorate. The manuscript itself is the result of interweaving both purposes. This introduction's central aim is to make visible these two different (but interwoven) purposes. This is important because my doctoral research is located in the broad field of sustainability sciences, more precisely in the branch of sustainability sciences that has the implementation – the actual realisation – of sustainable development as its core subject of research. (Schneidewind et al., 2016) This is a field in which crucial and recurring controversies about science exacerbate, in particular the expectations for a context and value-free science (Proctor, 1991), its traditionally accepted autonomy (Gibbons, 1999), and the sharp separations between subject and object (Castro-Gómez, 2007) and between reflexion and action (Fals Borda, 2001). As an academic researcher, these controversies translate into vivid tensions between the strong normative and transformational character of one's own research, and the sincere concern for ensuring scientific rigour. Thus, the significance of the singular moment of the research process becomes evident, that is, the inalienability of perspectivity, of one's own physical ties and space-time situatedness, and the resulting non-repeatability of one's research experience. (Qin, 2016; Rose, 1997; Vilsmaier, 2013) Therefore, the reflection on one's own research practice becomes a constitutive contribution of the research, that is the reflection on and the visualisation of one's own positionality. For my particular research experience, the aim is not to completely resign from disciplinary conceptual and methodological tools. They are also constitutive components of the dissertation, and explicitly presented along with it. Instead, reflecting on my own positionality is an attempt to provide robustness to the conceptual and methodological contributions that I elaborate on in my research journey.

1.1 Reconstructing the research journey

The present manuscript is a medium for reconstructing and reflecting on the way in which my doctoral research evolved. It presents and explains why and how I undertook this endeavour, and consolidates the conceptual and methodological *findings found* along with the *research*. The (apparent) redundancy in the last statement is of particular significance, because along with the progress of the doctoral research, my own understanding and practice of *re-search* (as a verb) became increasingly closer to the deep etymologic roots of the word: 'search' derived from old French *cercher*, meaning 'to seek for', which in turn derives from the Latin *circare*, meaning 'go about, wander, traverse'; and the prefix *re-* as intensification, i.e. 'to seek for closely' or 'to wander intensively'[1]. In order to make explicit that particular understanding of my work, this document is organized as the reconstruction and reflexion of a *research journey*: i.e. a *closely search for* findings (*Erkenntnisse*) which takes place through *intensive going about/wandering across* concepts and theories. The term *journey* is used here in order to highlight that particular type of movement; one that can be characterised by an initial motivation to advance towards a horizon, in this case an *Erkenntnishorizont*. At the beginning, that horizon arises as a suspicion, a premonition of alluring contours but whose actual shape cannot be seized from the distance. Substantiating this premonition, clarifying the epistemic value of this horizon, implies the undertaking of a journey across the landscape in between. However, this cannot be simply an act of approximation, of coming closer. Horizon and landscape are cognates; they are 'related in origin', they share a common (*co-*) birth (*gnatus*)[2]. Intensively wandering the in-between landscape offers a way for revealing, for recreating the substance of the *Erkenntnishorizont*.

[1] https://www.etymonline.com/word/research
[2] https://www.etymonline.com/word/cognate

Through this act, the in-between nature of the landscape blurs. The landscape preceding the horizon becomes an arrangement of fields *within* which a closely search takes place; a search for signs, trails, vestiges that help in the re-creation of the epistemic value suspected as *Erkenntnishorizont*. As a research journey, this means to enter and to explore abstract, conceptual, and theoretical fields on the search for clues, concepts and interrelations that may help to both clarify the research horizon itself (*klären*) and build a deeper understanding about it (*erklären*).

The reconstruction of and reflexion on my doctoral research starts by the attempt to define what can be considered the initial motivation for my research journey; where and how did the research horizon emerge. To that end, the second chapter starts by briefly introducing the initiative called 'WISIONS of Sustainability'. It emphasises the initiative's particular approach to the implementation of the global sustainability vision of universal access to clean energy. This appears to me to be the most appropriate way to define the starting situation of my research journey. First, WISIONS has been my main field of activity in the Wuppertal Institute since October 2004, when I assumed my first position in the institute as a student assistant. However, what is more significant is that through my engagement in WISIONS, I have been repeatedly and closely confronted with tensions and unsettled challenges linked to, and probably constitutive of, attempts of translating the notion of sustainability into real-life experiences. These tensions – so it appears to me – are exacerbated in the particular situation of a research institute such as the Wuppertal Institute, which sets itself transformative aims as part of its mission, in addition to the traditional epistemic function expected from any organisation which is part of the science realm of society. Starting from the field of action and the approach of WISIONS, I made a first move towards a more abstract, generalised register by describing those tensions and unsettled challenges in terms of the Institute's general aims to contribute to the actual implementation of sustainability. These tensions represent the initial contours of the research horizon that motivated my journey. The consolidated shape of that horizon, that is the actual phenomenon towards which the *re-search* advanced, is presented in the third chapter in the form of one central guiding question from which three research objectives were derived. It is important to highlight here that this question and corresponding objectives did not represent a fixed starting point from which the rest of the remaining disquisitions emerged. They were not a-priori fixed statements that preceded the practical research work and the results obtained therefrom. They are instead an important part of the findings found along the research journey.

After presenting the final shape of the research horizon, I turn in chapter 4 to the task of building a coherent description of the cognate landscape to that horizon. This task comprises a further move towards abstraction and generalization. Chapter 4 can be understood as a mapping exercise at an abstract, conceptual level. In this Chapter, the landscape where my explorations took place is reconstructed by systematically organizing the diverse traces and clues collected along the journey. The aim is to outline the final contours of those concepts that I found essential for clarifying and explaining the actual phenomenon, which is the actual subject of the *re-search*. Subsequently, Chapter 5 provides a general description of how that exploration took place. The basic methodological principle of the research journey is the systematic exploration of concepts and theories with promising potential for substantiating the research horizon. This takes the form of an iterative procedure. Each iteration – which I call *stages* of the journey – corresponds to one of the four studies that forms the core of my cumulative doctoral work. This procedure necessarily took place in time and space; however it is important to emphasize that I am not considering a strictly chronological logic for organizing the reconstruction and reflexion exercise that is documented here. Rather, the iterative procedure follows a logic of increasing comprehensiveness. Thus, from one stage to the next, the level of abstraction and/or generalisation pursued by the studies increases. The articles that document those four studies are reproduced from chapter 6 to chapter 9. The findings collected along these four stages are recapitulated and systematically interwoven – i.e. set in mutual conversation – in Chapter 10. The aim of that chapter is to advance towards a deep understanding of the research horizon. The

final chapter outline possible horizons for further research journeys by organising interesting trails found along the research journey but that could not be deeply explored.

1.2 Structure of the doctoral dissertation

The present manuscript represents the doctoral dissertation that fulfils part of the requirements for the official conclusion of my doctoral program. It takes the form of a *kumulative Dissertation* that entails two main components: (i) a series of individual articles published in scientific journals or in the review process for being published; and (ii) one *Rahmenpapier*, i.e. an additional 'framework' article which "should present the internal connection of the [individual] articles, the partial aspects examined in the individual articles, the methodological approach followed and the results achieved."[3]

This doctoral dissertation comprises four articles. Three of them have been already published and the fourth one was submitted to the Journal Environmental Politics on 28th May 2019, and was still in review process on the date this dissertation was printed. The four articles are reproduced in chapters 6 to 9. The specific version of the article used for this reproduction depends on the copyright agreements linked to each publication, which is described at the beginning of the corresponding chapters. Table 1 lists the individual articles that are part of this doctoral dissertation. Detailed descriptions about the contributions of the authors for the compleetion of each of the articles can be found in the Annexes of this manuscript.

Table 1 List of individual articles that make part of the cumulative dissertation.

Nr	Title	Authors	Journal	Publi-cation Year	DOI
1	Understanding the diffusion of domestic biogas technologies. Systematic conceptualisation of existing evidence from developing and emerging countries	Willington Ortiz, Julia Terrapon-Pfaff, Carmen Dienst	Renewable and Sustainable Energy Reviews	2017	http://dx.doi.org/10.1016/j.rser.2016.11.090
2	Introducing Modern Energy Services into Developing Countries: The Role of Local Community Socio-Economic Structures	Willington Ortiz, Carmen Dienst, Julia Terrapon-Pfaff	Sustainability	2012	10.3390/su4030341
3	The diffusion of sustainable family farming practices in Colombia – an emerging sociotechnical niche?	Willington Ortiz, Ulli Vilsmaier, Álvaro Acevedo-Osorio	Sustainability Science	2018	10.1007/s11625-017-0493-6
4	Transcending the locality of grassroots initiatives. Diffusion of sustainability knowledge and practices through transdiciplinary research	Willington Ortiz, Ulli Vilsmaier	Environmental policy *(Submitted)*	N.A	N.A.

The *Rahmenpapier* that forms part of this doctoral dissertation has been divided into two parts, in order to provide a structure to the manuscript that better reflects the argumentative flow of the whole doctoral research. The first part comprises the first five chapters of this manuscript

[3] Own translation of the relevant passage from §15 of the "Richtlinie zur kumulativen Dissertation" of Leuphana University's Faculty of Sustainability, as issued on 15 January 2012

and provides a description of the research field and objectives, the conceptual framework, and the methodology of the entire doctoral research. The second part of the *Rahmenpapier* is set after the four individual articles are presented, and comprises two final chapters (i.e. Chapter 10 and 11), in which the main conceptual and methodological findings of the whole research are summarized and further research fields are outlined.

Besides the articles listed in Table 1, other types of outputs or milestones were directly linked to and provided important inputs for the realisation of this doctoral research, such as the participation to scientific conferences, the participation to multi-stakeholder events and the supervision of master students' research. A selection of such milestones can be found in the Annexes.

2 The field of interest: The initial motivation for a research journey

In 2004, the International Conference for Renewable Energies took place in Bonn under the auspices of the German Federal Government. The conference provided a renewed impulse and high-level political backing to the commitment to transform energy systems worldwide, that is, "to substantially increase with a sense of urgency the global share of renewable energy in the total energy supply."[4] The conference also reinforced the particular relevance of securing universal access to proper energy services in order to advance the millennium development goals (MDGs), which provided at that time the internationally accepted compass for advancing sustainable development in the so-called "developing countries". Further discussions and studies in this particular field highlighted the promising potential of decentralised renewable energy technologies for supporting the implementation of the MDGs. (Flavin and Hull Aeck, 2005; UN-Energy, 2005) However, it also became clear that solid practical knowledge was still scarce, in particular knowledge about how renewable energy technologies can be deployed for meeting those specific goals, which were not set in terms of energy needs, under the diverse set of local contexts where the MDGs were supposed to be reached.

2.1 WISIONS of Sustainability

It is in this dynamic that the Wuppertal Institute, together with the foundation ProEvolution, launched the initiative 'WISIONS of Sustainability' (wisions.net) in 2004. While the initiative's specific objectives and shape have been adapting to the continuously evolving global discussions on sustainability, a twofold aim of facilitating practical demonstrations and fostering dissemination of lessons from field experiences has been central to the permanent development of WISIONS. Along the way, the initiative's focus has sharpened in two main dimensions: (a) the fields of action and (b) the geographical scope. With regard to the fields of action, WISIONS started with the explicit aim of promoting the realisation and the dissemination of "projects of potential strategic global importance" in three fields: resource efficiency, renewable energy, and energy efficiency (WISIONS, 2004). With time, the attention was concentrated on innovative ways of applying renewable energy technologies to meet "energy related needs" (Dienst et al., 2010). With regard to the geographical scope, at the beginning any geographical scope was explicitly defined. However, most of the demonstration projects that were supported and experiences that were highlighted by the initiative were located in the global south. With time, this broader focus on project concepts and experiences in the global south was consolidated and made explicit. (Dienst et al., 2016)

In the sections belonging to the *Rahmenpapier* of this dissertation, I use the phrase "global south" as a label that refers to extremely diverse geographical regions and peoples, with very little in common. If there are common features, they are more likely related to their role as the "other", or the "non-modern", which these regions and peoples have to play in the dialectical conception and the geopolitical deployment of the "modernity myth" (Dussel, 1994). While the geographical reference implicit in the word 'south' is unsatisfactory for referring to features emerging from the historicity of places and peoples, it provides a less unsatisfactory label than 'developing countries', which is still used in the 2030 Agenda for Sustainable Development. The 'developing countries' label is unsatisfactory because, as presented in Section 3.1, in this dissertation I operate with a concept of (human) development that recognizes and accounts for the persistent situatedness of any attempt for defining the types of beings that are worth of

[4] Extract from Point 2 of the "Political Declaration" issued on 4 June 2004 as result of the International Conference for Renewable Energies.

being lived. Consequently, and considering the urgent need "to shift the world on to a sustainable and resilient path" (United Nations, 2015), it is not meaningful to differentiate between countries and peoples that are already 'developed' (i.e. people representing a benchmark for desirable development, without need for further developing, without need of shifting on to sustainable ways of living) and countries and people that are still 'developing'.

Furthermore, two main features of the WISIONS approach has strongly influenced my research journey: (a) the particular sort of innovations the initiative has been looking for, supporting, and advocating for, and (b) the serious concern for understanding and operationalising sustainability in terms of local situations.

While the field of action has matured and consolidated on the application of decentralised renewable energy technologies, WISIONS understands the promotion of renewable energy technologies and the provision of clean energy services as a *means to* the realisation of sustainability, and not as an *end in itself*. This is more clearly reflected in the requirements set for the support of demonstration projects. The initiative looks "for project concepts that demonstrate how to apply small-scale renewable energy technologies to meet energy-related needs and improve energy access for people in the focus" (WISIONS, 2019). The attention is not necessarily on innovating energy technologies themselves, but on innovative ways to apply them meaningfully. Innovation is interpreted in a broad sense that is not limited to technological innovation; therefore "projects may comprise other innovations, related, for example, to organisational, financial, managerial or political aspects." (ibid)

Since its inception, the initiative has set a strong emphasis on the local embeddedness of the experiences it supports and/or highlights. WISIONS looks for demonstration projects that takes the form of "community-based solutions, where the residents in the community are beneficiaries as well as agents of change" (Dienst et al., 2010). The involvement of local actors in the conception and realisation of the projects or activities proposed for support has been set as important criterion for selection. This has in turn translated into building relationships with local energy practitioners, which are organizations and individuals that "are based and operate in the target areas and offer a direct link to communities and end-users of the energy services" (Dienst et al., 2016). Moreover, with time increased attention has been paid to strengthening the capacities of such local energy practitioners. This has led to the conception and operation of other types of support. Beyond demonstration projects, the initiative facilitates different formats for "knowledge development and sharing between practitioners and [other] stakeholders" (ibid), as well as the establishment and operation of networks of practitioners as a means to strengthen individual capacities and to increase the weight of their voices at local and international debates.

2.2 Tensions in the endeavour to implement sustainability

Framed in the context of the Wuppertal Institute, the WISIONS initiative represents an attempt at translating and operationalising consensual outputs from global debates about sustainability into practical actions at local levels, and in global south contexts in particular. It is an endeavour for bridging the challenging gaps that result from the several dimensions in which the differences between local and global can be expressed. Moreover, it comprises the tensions between epistemic (understanding, knowing, explaining) and transformative (deciding, acting, implementing) aims entangled in the mission of the Wuppertal Institute.

2.2.1 The tension between global and local

The notion of sustainable development – as commonly used today – is 'global' from its origins. The continuous evolution of that notion can be traced along the resolutions, declarations and reports from international processes in the framework of the United Nations (UN), starting with the UN Conference on the Human Environment that took place in Stockholm in 1972, moving through milestones like the 'Rio Conference' in 1992 (Michelsen and Adomßent, 2014), and

moving up to most recent milestones like the so called '2030 Agenda for Sustainable Development' and the 'Paris Agreement', both issued in 2015. The consensual outputs from such processes largely determine the most general accepted notions of sustainable development. Such outputs feature a generalised and planetary perspective. They set and describe "areas of critical importance for *humanity* and *the planet*" (United Nations, 2015)(italics added). The generalised, global character of those outputs imply that the description of each critical area is expected to be valid or to have some applicability for articulating development challenges in large sets of contexts. However, in order to achieve that level of generalisation, statements about the important issues are free of context. In order to be able to guide action at local levels, general statements about sustainable development need to be re-contextualised. They need to be amended or translated in such a way that the particular situations of the (local) places and the specific challenges and chances of the (local) people are also reflected in the notion of sustainable development that should guide action locally (Fenton and Gustafsson, 2017; Graute, 2016).

Moreover, the implementation approaches formulated at those global processes within the UN's framework rely on a "highly centralistic top-down control mechanism that is assumed to mechanically trickle down and accelerate even collective action" (Schmieg et al., 2018). Under those global schemes, nation-states are the main actors for advancing implementation. They are the central agents of change. This is in part related to the fact that only national states are contractual 'parties' to the international agreements upon which such processes are based. While it is increasingly recognised that other (nonstate) actors are crucial for advancing implementation, mechanisms for coordinating and articulating action from nonstate actors into the international implementation process are still rudimentary at best (Chan et al., 2019; Schmieg et al., 2018).

The tension between bridging global and local levels is schematically illustrated in Figure 1. Selected examples of global and bottom-up initiatives are mapped according to their geographical scope (local, global) and their approach to action (bottom-up, Top-down). The common denominator is that all of them aim at advancing sustainability issues. However, each of them pursues its aims in its own fashion. Two bottom-up initiatives are depicted, which are linked to local endeavours for improving the livelihood of indigenous communities in Borneo (Create Borneo), and peasant and indigenous farmers in Colombia (Asproinca). Both initiatives were supported by WISIONS in the past. They have been experimenting with decentralised renewable energy technologies that can be manufactured and operated locally, in particular with micro-hydro power turbines in Borneo, and domestic biodigesters in Colombia. However, their interventions are framed into broader aims, like the protection of local water basins, the sustainable management of local forests, and the political recognition of rights over their local territories. Financial and technical support for their activities comes mainly from national and international civil society organisations and academics (applied research). On the other corner of the mapped space, three global sustainability initiatives are depicted: the Convention on Biological Diversity (CDB), the Framework Convention on Climate Change (UNFCCC), and the organisation Sustainable Energy for All (SE4All). They correspond to global sustainability aims. Through their work in implementing sustainability innovations in their geographical scopes, Create Borneo and Asproinca are effectively advancing action on the goals of all three global initiatives. However, their actions are disarticulated from the debates and action supportive mechanisms that comprised the global initiatives. The gaps between those local and global sustainability endeavours are of different natures. For instance, action emerges as response to different problem framings: at the local level the problems addressed and the targets are strongly related to the livelihoods of the rural population, while at the global level the problems are defined along sectors and statistically measurable parameters. Action at the local level presumes that local communities can be important agents of change. Action at the global level presumes that nation-states should play the key role in advancing sustainability. Different and interesting aspects of this tension could be outlined. In the frame of WISIONS, the main motivation, the suspected research horizon, relates to the question about the actual

contributions of such bottom-up initiatives "to shift the world on to a sustainable and resilient path" (United Nations, 2015).

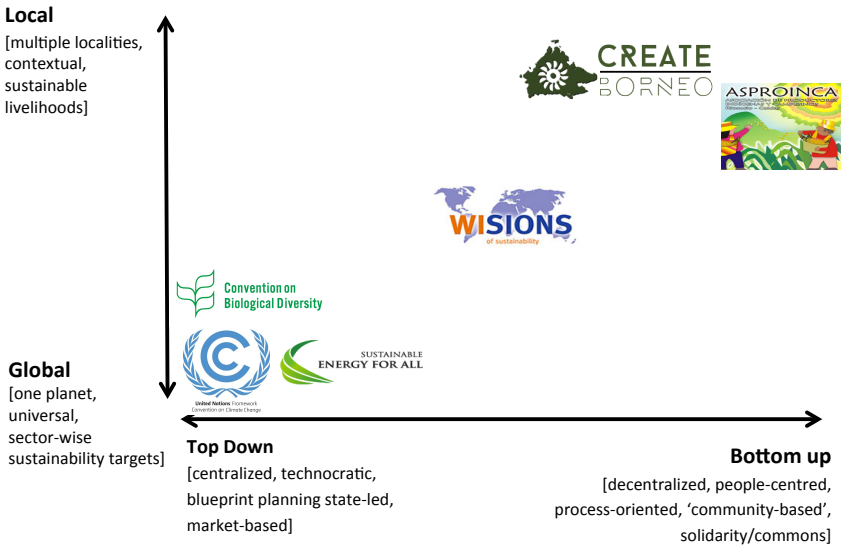

Figure 1 Schematic illustration of the tension between global and local endeavours advancing sustainability.

2.2.2 The tension between understanding and acting

The question of how to effectively implement sustainability is central to the sustainability sciences. This question becomes a strongly controversial issue when reframed as a demand for research modes that "actively advance the [societal] transformation" (WBGU, 2011), because adding a transformative aim to the conventionally exclusive epistemic purpose of scientific research, reopens or reinforces enduring controversies like the 'value-free' nature of science or its societal role (Grunwald, 2015; Schneidewind, 2015; Strohschneider, 2014). One particularly challenging issue is to clarify how that transformative aim can be advanced through research. In its flagship report "World in Transition: A Social Contract for Sustainability", the German Advisory Council on Global Change points at innovation development and diffusion as an alternative to advance transformative aims: "Transformative research supports transformation processes in practical terms through the development of solutions and technical as well as social innovations, including economic and social diffusion processes and the possibility of their acceleration"(WBGU, 2011).

Indeed, the interest in innovation and innovation research has increased in the light of the recent debates over sustainability and its implementation. As a result, the object of innovation research has shifted from a focus on 'green technologies' to questions of transformation processes of entire production and consumption systems, and its analytical perspectives have expanded from the question of optimal economic incentives such as price signals, to the development of analytical concepts for the transformation of complex socio-technical systems (Smith et al., 2010). Of particular relevance to my research motivation are extended analytical perspectives that focus on civil society involvement in the crafting of innovations, and which in this way reopen the debate "on the formability of society and the place of its changes" (Beck and Kropp, 2012).

Thus, focusing on innovation appears to be an appropriate way to outline the research horizon, i.e. to inquire on the contributions of bottom-up initiatives to broader sustainability endeavours. Focusing on innovations, or more precisely on the processes by which innovations move across places and countries, peoples and nations, may allow for both the understanding of how bottom-up initiatives can actually contribute to global sustainability goals, and the effective support of such initiatives in that role through research.

3 Objectives: The journey's horizon

Research question:

How can bottom-up initiatives contribute to the diffusion of sustainability innovations and in that way contribute to social change?

Analytical aim:

To understand the role of bottom-up initiatives in the diffusion of sustainability innovations and in the involved social changes

Methodological aim:

To outline a research approach that provides a solid conceptual and methodological framework for attaining both the analytical and the transformative aims, i.e. research where:

- social processes of innovation diffusion from the bottom-up can be traced, and
- innovation diffusion and the involved social changes can be promoted

Transformative aim:

To contribute, with my research, to the actual diffusion of sustainability innovations

4 Conceptual framework: The wandered landscape of concepts

This chapter's aim is to describe the final contours of those concepts that are essential for clarifying and explaining the role of bottom-up initiatives in the diffusion of sustainability innovation and the involved social changes, i.e. the conceptual landscape that was intensively explored, in order to substantiate the *Erkenntnishorizont* of my research journey. The chapter finalises by building an outline of the conceptual landscape by emphasising on the main interactions between the concepts presented.

4.1 Sustainable development

The central motivation of my research is to effectively shape/perpetrate sustainable development. It is also the normative premise that provides the general orientation to the whole research journey. I would like to start by outlining the concept of development, which is apparently the less normative portion of this section. A simple etymological description of the word 'development' already unveils some intricacies, as it is a composition that produces a noun (by adding the particle '–ment') out of a verb stem. The verb stem derives from the old French word 'desveloper' (unwrap, unfurl, unveil, reveal the meaning of, explain), which itself is a composition made of the particle 'dis-' (undo) and the verb stem 'veloper' (wrap up, furl). Two qualities of the word development are of particular relevance here: (a) it refers to a process of change, and (b) it presupposes implicit potentialities. Development is thus a change characterized by the instantiation of possibilities that are intrinsic to the subject in consideration. In other words, development is a process that unveils immanent possibilities of being. This is still an extremely broad contour of development. In order to outline more specifically the development my research journey is dealing with, I resort to two contrasting strands of conceptualizing human development: Amartya Sen's capability approach to development, and a body of critique of hegemonic development discourses, which is often referred as 'post-development', in particular the line of critique developed by Arturo Escobar.

4.1.1 Development as freedom of being and doing

Sen's conceptualization of freedom as "both the primary objective of development and its principal means" (Sen, 2001) provides an excellent starting point. Sen's elaborations depart from a critique to an equation that relates development and economic growth, which has been the most pervasive assumption in the realm of economics and politics. However, his analysis quickly turns to a philosophical discussion, in order to inquire on the nature of human development. By emphasising functionings, i.e. the "ability to do certain things and to achieve certain types of beings" (Sen, 1988), the capability approach proposed by Sen moves the attention to the foundational features that development can entail, when directed to the evaluation of living as such, and not merely to the utility or happiness generated by that living. Moreover, after elaborating on a concept of development that is based on the evaluation of the set of functionings (capabilities) from which human beings are able to decide and to enact freely, he turns to the problematic nature of identifying the valuable functionings that should be set as the right measure for development. He recognises two valuation problems: the fact that valuation of functionings may differ from one person to other (value heterogeneity). And the fact that the change involved in development might ultimately alter the valuation of the people involved (value endogeneity). The difficulty (or impossibility) of resolving "disputes on the relative importance of different types of functionings" calls for the necessity of settling for partial orders in the valuation and measurement of development, and "to build into the concept of development the possibility of persistent incompleteness in ranking".

Sen's considerations of development remain descriptive. His interest in the concept remains focused on finding – at least incomplete – solutions for the valuation and measure of development. In this way, the potential epistemic value of bringing the concept beyond a mere evaluative category remains unexplored. However, by linking (or equating) development to freedom and by enunciating the valuation problem, Sen's approach opens the way for shaping a category that entails relational or even dialogical features. It is difficult to figure out a way of operationalising his approach without moving into dialogic practices, or at least without considering how power (more precisely power disparities and oppression) determines the actual valuations of development. This is precisely the field where the critique of post-development studies can help to outline a more complete contour of the concept of development.

4.1.2 Power and the discourse of development

The particular concern of post-development studies is on how the discourse of development organises the production of certain types of knowledge and forms of power by relating one to the other. The mainstream discourse of development provides representations of underdeveloped subjectivities endowed with features such as powerlessness, poverty and ignorance, which implicitly assume 'western' standards as the benchmark against which to measure the situation of 'Third World' population and 'Developing Countries' (Escobar, 1995). Moreover, the analysis of these scholars demonstrates how the development discourse creates efficient apparatus for producing knowledge about, and the exercise of power over, the 'underdeveloped'. The mechanisms by which the development discourse is deployed for the creation and reproduction of hegemonic power asymmetries are diverse, with some noteworthy examples as follows: i) The ability to create client categories (labelling) such as 'small farmers', the 'malnourished' and the like, which determine the access to resources, so that people must adjust to such categorisation to be recognized as a 'client' (beneficiary, target group). ii) The relationships between the 'client' and the (development) agents are organized by schemata and standards that are anterior to their interaction. These are documented in the form of 'facts' that are detached from the local historical context of the reality that they supposedly represent. iii) Explanations of underdevelopment are usually associated with characteristics internal to the poor; the 'non-poors' and the development institutions are notoriously not considered as factors for the explanations. iv) Problem definitions and theories are not only built based on preconceived schemata, the characterization of problems also reflects the kind of interventions that the development institutions operate; for example they emphasise national level planning and aggregated statistical variables.

4.1.3 Situated and located knowledge

Looking through Sen's conceptualisation, the findings of post-development studies can be seen as clear illustrations that the subjects and the contexts in which they act do matter when dealing with the valuation problem of development. This is because disparities in their abilities "to do certain things and to achieve certain types of beings" also determine the outcomes of the "disputes on the relative importance of different types of functionings". Thus, it is not enough to build the "possibility of persistent incompleteness" into the concept of development. Moreover, it is also important to recognize the persistent situatedness of development. Any definition of or decision on the valuable set of functionings comprising development might be better understood as "situated knowledge" (Haraway, 1988), i.e. the product of a process that involves complex relationships among social actors and which "is not value neutral and objective in any way that can be regarded as being outside of culture and society" (Engelstad and Gerrard, 2005). Thus, the contour of the (sustainable) development concept that consolidated along the research journey, is one that accounts for the process by which the specific definition of development – that is expected to be operationalised through the diffusion of sustainability innovations – is produced.

Besides the social actors involved in the process, the context is also relevant. Two dimensions are of particular relevance to characterising that context, or in other words, to contextualising the knowledge about what form of sustainable development is pursued. On the one hand, as illustrated by the post-development studies referred-to, accounting for hierarchical structures is an important dimension when contextualising development, i.e. the social relationships of subordination that features stability across time and space and for which the production of knowledge acts as a mean for reproduction. On the other hand, it is important to account for the specific space, for the place where sustainable development is supposed to be or become possible. Besides the geographical location, the physicality of place and the meanings and values linked to it are what make place particularly important for defining and operationalising sustainable development. Place matters for the formation of identity, community sentiment, and common values (Hummon, 1990; Keith and Pile, 1993), and in this way it plays a role in the definition of the "types of beings" that are worthy of being achieved. Moreover, place "stabilizes and gives durability to social structural categories, differences and hierarchies" (Gieryn 2000), which in turn are determinants of the ability to access and to mobilize the resources needed to operationalise development. I will refer to this as the 'socio-spatial context' of development.

4.1.4 Sustainable: accounting for plurality in space and time

The proposed concept of development is one that, while considering the valuation problem, does not attempt to fix it – even not if solutions are based on "partial orders". Instead, human development may be better considered as a dialogical category, in other words one in which meaning "emerge[s] only from a dialogical process of coming into being" (Akkerman and Niessen, 2011). In the case of development, one's own meaning or notion of what types of beings are worth living, cannot be considered in isolation from other's notions of desired development. This is precisely the relationality that transports the most common notions of sustainability. For instance, departing from the intergenerational and intragenerational approach to sustainability, the notion of sustainable development emerges when placing notions of worthy types of beings from different humans in conversation. The notion that emerges is less a perfect convergence of understandings, resolved divergences, or consensus reached, than a motion for coming closer, and facilitating acceptance and cooperation. Recalling the persistent situatedness of human development, such a conversation implies placing multiple places, and – in the case of intergenerational sustainability – multiple times in relation to each other. Again, the emphasis of such a dialogical process is less on building a synthesis that resolves differences (as would be the case of a dialectic endeavour), than on the recognition and acceptance of the difference. Therefore, a notion of sustainable development built in this way is one that accounts and allows for plurality in space and time.

4.2 Social change

Along the research journey, the 'social' (in 'social change') points at arrangements of human interactions with humans and non-humans, which features a certain stability in time and space and which in turn provides the means for, and sets limits to, human doings and beings. The outlined contour already evokes two central concepts of the structuration theory: structure "as recursively organized sets of rules and resources, [which] is out of time and space, save in its instantiations and coordination as memory traces" (Giddens, 1984); and the duality agency/structure, which claims that "the constitution of agents and structures are not two independently given sets of phenomena, a dualism, but represent a duality" (ibid). I took advantage of the conceptualisations stemming from the structuration theory, in order to grasp or make sense of the persistent arrangements of human interactions that appeared particularly relevant to understanding the diffusion of sustainable innovations, i.e. to move towards the research horizon of my journey. However, in order to move towards that horizon, I found that it was inappropriate to focus only on sociological conceptualisations (like rules and institutions), and leave aside explanatory components from other non-sociological realms that appeared to play a role in the production and reproduction of those arrangements of interactions that enable or constrain the diffusion of innovations. Therefore, the contour of the 'social' that spans the

entire journey is one that covers explanatory components from other realms like technique (i.e. interactions among humans and non-humans modulated through physical properties), economy (like the interactions that regulate the supply of products and services through monetary exchange between the involved actors), and politics (interactions and procedures which determine how decisions and actions are taken on issues that concern complete social arrangements). These realms were not considered together or continuously along the journey. Instead, the decision to emphasise one or the other depended on the particular features of the specific phenomena or social arrangement addressed at each stage. The particular emphasis at each stage of the research was made explicitly by using combined terms such as socio-technical, socio-economic, or socio-political.

The concept of 'social change' that evolved throughout the research in order to grasp diffusion is one that is able to account for modifications on several levels. For example, installing a domestic biodigester modifies the farm's physical configuration, which implies interactions that can be better traced in the technical realm. Additionally, it also challenges the daily routines of the adopting family, as well as the meanings and values ascribed to animals and animal manure. A sociological perspective can help to grasp these types of interactions among humans and non-humans. Moreover, the installation of the apparatus also presupposes the availability of actors able to provide the technical knowledge and skills for constructing and installing the biodigester, and frequently the establishment of specially designed financial mechanisms. Therefore, accounting for economic interactions may help to improve the understanding of the challenge of diffusion. Furthermore, the building of these supply capacities and the establishing of these financial mechanisms are part of the tasks assumed by programs promoting the diffusion of the technology, which are often coordinated by central state entities and executed through more or less complex institutional configurations involving state, private, and civil society actors. Considering the political particularities of the cases in question can shed light on the respective diffusion processes. Therefore, with respect to the aim of my research journey, 'the social' (in 'social change') points at relatively stable or recurring arrangements of those different but interrelated types of interactions, and 'social change' accounts for modifications experienced by those arrangements when diffusion is pursued.

The scope or the shapes of the specific social arrangements that are considered during the research varied according to the particular part or feature of the diffusion process that is being traced. For example, the focus varies during the first three stages of the research journey: from the adoption process of biodigesters at the household level, to the implementation of community-based energy projects in rural villages, and ends up at the consolidation and diffusion of sustainable family farming practices among a network of civil society initiatives.

4.3 Innovation

For this research journey, innovation is a broad concept that includes knowledges, practices and objects that are perceived as new by potential adopters. The perceived novelty is not only related to the knowledge the individual or group of adopter(s) had about the innovation before its adoption. Novelty is related rather to the innovation's effective deployment (Rogers, 1983). Taking into account the conceptual contours of 'social change' previously described, novelty implies the reconfiguration of certain social arrangements so that the new knowledges/practices/objects are effectively integrated in (can make sense within) those modified arrangements. In turn, this integration may lead to new possibilities of as well as constrains to human doings and beings. What is resonating here is the idea from sociological studies, that an invention does not become an innovation until an institutional renovation (*Erneuerung*) has taken place, which finally secures its status as a successful/meaningful innovation (Rammert, 2010). Central focus of the doctoral resaerch is on how that *Erneuerung* takes place, and I am thus interested in tracing 'social change'; a concept that in the frame of my research journey is not only restricted to institutional changes, as previously described.

4.4 Diffusion

Departing from the concept of innovation, diffusion refers to the processes by which innovations (knowledges/practices/objects) transit across different social arrangements. This method of outlining the concept of diffusion is linked to two important realisations that were consolidated during the research journey. On the one hand, one is likely to lose relevant information about the diffusion process if one traces the transit as departing from nowhere, that is to say without accounting for the social arrangement(s) from which knowledges/practices/objects of interest are departing as successful/meaningful innovations. Therefore, tracing the diffusion process requires taking into account the interplay of at least three entities: the departing social arrangement(s), the innovation itself, and the adopting social arrangement(s).

On the other hand, none of these entities can be regarded as invariable. They may all experience adjustments, changes in their forms as consequence and as requirement for the realisation of diffusion. The innovation, which is the subject of diffusion, may experience adjustments and adaptations to the particularities of the new social arrangement where it is expected to make sense. Adjustments may also be needed within that social arrangement, in order for the novel knowledges/practices/objects to be adopted and meaningfully integrate into the corresponding doings and beings of that social arrangement. Moreover, the experiences gathered through the diffusion process may give also rise to adjustments in the social arrangement where the transit started. This is probably a less intuitive feature of diffusion. It can be better illustrated by the cases in which mainstream configurations of production and consumptions adapt and integrate innovations that originally emerged as an alternative to contest precisely those mainstream configurations. That has been the case for technologies like wind energy, and practices like organic farming. In such cases, the social arrangements where those innovations emerged experienced profound changes. For instance, they transformed from initiatives based on voluntarism to commercial firms, or they resulted in fragmented sections, some of which were closer to the mainstream, and others that radicalized the original challenging stance in contrast to the mainstream (Smith, 2007). I refer to this particular type of immanent change in diffusion as reform.

Therefore, the diffusion concept that consolidated during the journey is one that accounts for immanent changes of form (transformations) in all the three entities: adaptation (the innovation adjusting to new/receiving social arrangements), adoption (the receiving social arrangement integrating the new innovation), and finally reform (the departing social arrangement reacting to the experience of diffusion).

4.5 Bottom-up

The notion of bottom-up can be traced to debates about and practices of planning and development interventions during the 1980s and 1990s, both in the global north (Sabatier, 1986; McCay and Jentoft, 1996) and the global south (Cernea, 1992; Alonso, 1995). It designates approaches that were conceived in contrast to planning and development politics of nation-states, which are therefore referred to as 'top-down' approaches. This contrasting turn represented a response to discontentment with the intensification of detrimental dynamics of the environment (UNEP, 2002) and rising social inequalities (Gasparini and Lustig, 2011; OECD, 2011), at a time when neoliberalism became the most pervasive political model adopted by nation-states around the globe (Albo, 2008). This turn to 'bottom-up' took different shapes. In the case of Latin-America, for instance, a surge of alternative approaches to rural development and the emergence of several grassroots movements can be traced back to that period. The former took the form of agroecology-based projects promoted by non-governmental organizations (NGOs), which incorporated elements of indigenous knowledge and modern agricultural science (Altieri and Masera, 1993). The latter had a more critical stance, as the interest is "not in development alternatives but in alternatives to development, that is, the

rejection of the entire paradigm altogether" (Escobar, 1995). While all those projects and movements had significant differences, they shared some basic features, such as an interest in local culture and knowledge, and emphasis on local capacities and participation. Moreover, these bottom-up approaches are often linked directly to emancipatory movements that emerged in the region during the 1960s and 1970s, like the pedagogy for liberation (Freire, 1970), and the participative action research (Fals-Borda and Rahman, 1991). Therefore, I use the notion of 'bottom-up' here as a container for processes, initiatives, and dynamics in 'the social' that feature transformative characters (i.e. that aim at inducing changes in existing social arrangements in their localities), which emerge and develop without direct relationships – and often in contrast – to national development politics and policies, and that feature strong emphasis on action and on inducing change in their corresponding localities, in contrast to national or larger geographical or administrative actions.

4.6 Transformative research

Important features of this concept have been already explained in previous chapters. I recall here part of those expositions and place them in relation to other conceptual aspects elaborated in this chapter in order to outline the final contour of the concept. Research is a practice that comprises the exploration of abstract, conceptual, and theoretical fields on the search for clues, concepts and interrelations that can help to clarify and build understanding of a research horizon. The adjective 'transformative' refers to an explicit recognition of and demand for the "societal impact" of (scientific) research (Schneidewind et al., 2016). Thus, transformative research is expected to contribute actively to the social transformation processes, which are at the same time constitutive part of the subject of epistemic interest (ibid). It adopts an explicit normative stance. For my own research – which is located in the broad field of sustainability sciences – this normative stance translates into a commitment to the persistent conversation for building the notion of sustainable development and to envisioning and implementing strategies for its actual realisation.

Summarising, transformative research refers to a particular sort of practice that entangles both epistemic and transformative aims. It is a closely search, an intensive wander through conceptual landscapes in which understanding and realising possibilities to operating/inducing social change are an essential part of the search's purpose. This closely search is guided by a normative stance: the change pursued is one that leads to social arrangements, which provide the means for, and set limits to, human doings and beings; human doings and beings in perpetual conversation, in dialogical interrelation, with the plurality of doings and beings sustained by Earth, today, yesterday and tomorrow.

4.7 Final outline of the conceptual landscape

Figure 2 illustrates the final outline of the conceptual landscape. Sustainable development represents the central normative premise for the research journey. The specific notion of what sustainable development should be is considered situated and located knowledge. This feature is illustrated by accounting for the socio-spatial context to which sustainable development is related to. The first central assumption is that the realisation of sustainable development requires social change, that is to say that modifications of social arrangements are needed, in order to allow and limit the human doings and beings, so that they align with the corresponding notion of sustainable development. A second central assumption is that innovation and social change are interrelated, and that this interrelation is modulated by processes of diffusion. One central hypothesis is that bottom-up initiatives can contribute to the diffusion process, and in that way also contribute to social change. A second hypothesis is that transformative research can support diffusion processes in which bottom-up initiatives are involved. To clarify and explain these two hypothesis constitute the objective of the research journey.

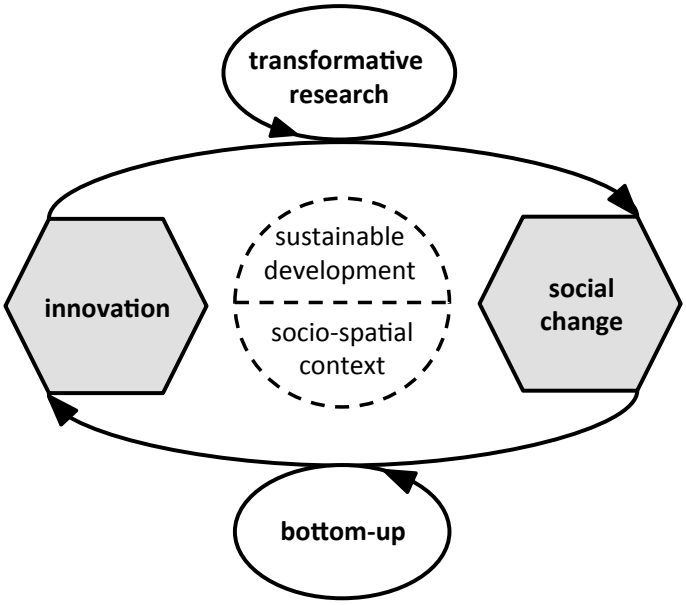

Figure 2 The landscape of concepts explored along the research journey.

5 Methodology: Charting the research journey

The research journey comprised four main stages. Each stage comprised the realisation of one of the four studies (and corresponding articles), which build the core of my doctoral research. They represent four iterations, four wanderings through the conceptual fields that appeared convenient for exploring the notion of diffusion, which is central to the initial contour of the research horizon. The four iterations conform to a procedure in which the notion of diffusion is explored at different scopes of social scales; it follows an expanding logic. It starts by analysing diffusion processes at relatively narrow social arrangements, i.e. rural households (the scope of the first article), and ends with the development of a conceptual framework that offers a general conceptualisation of transits of knowledges and practices from the bottom-up and across different social scales (the central aim of the fourth article). This systematic iteration logic is illustrated in Figure 3.

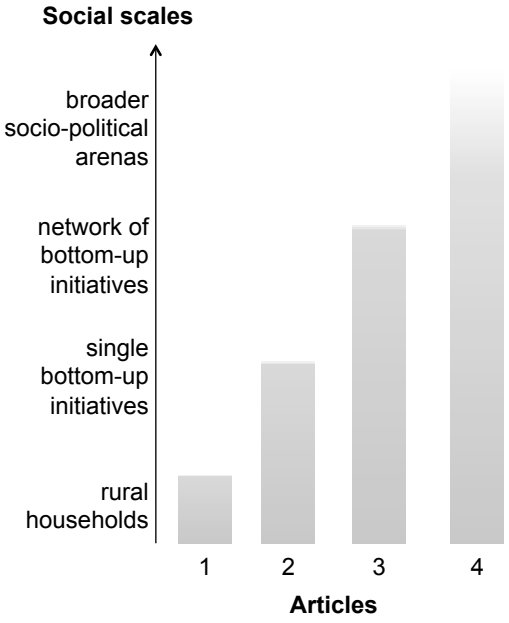

Figure 3 Schematic illustration of the expanding scope of social scales in which the notion of diffusion is explored along the four articles.

Furthermore, the comprehensiveness of the exploration increases along this iterative procedure. Comprehensiveness can be characterized through two dimensions: (i) the amount of concepts or conceptual aspects that are considered to shape the specific subject of inquiry of each study, and (ii) the level of abstraction and/or generalisation contained in that subject of inquiry. This characteristic increase of comprehensiveness along the whole journey is illustrated in Figure 4, in which each stage of the journey is charted on the conceptual map developed in Chapter 4, by highlighting the concepts or conceptual aspects that are central to the subject of the corresponding study.

The research journey begins with a thorough analysis of the diffusion programs of domestic biodigesters to rural households in countries of the global south. The focus is on the process by which this specific technical innovation are integrated (or not) into the daily realities of single rural households, in other words, the adoption process. As schematically illustrated in Figure 4, in this stage the focus is solely on exploring the interrelation between innovation and social change. Particular aspects or questions about agency from the bottom-up are not part of the enquiry, nor are questions about the role of research and researchers. In the second study the

attention does not fall on one technical innovation, but on energy supply models based on different decentralised renewable energy technologies. Central to those models is the building of new (or strengthening of existing) local socioeconomic structures that can assume and ensure the proper operation and supply of energy services. The interest in this study is on the strategies that organisations implementing community-based energy projects apply to support the realisation of such local structures. Unlike the previous stage, in the second stage the intervention of actors from the bottom-up in shaping the relationship between innovation and social change is the study's focus. However, in this stage there is still no inquiry about the research itself.

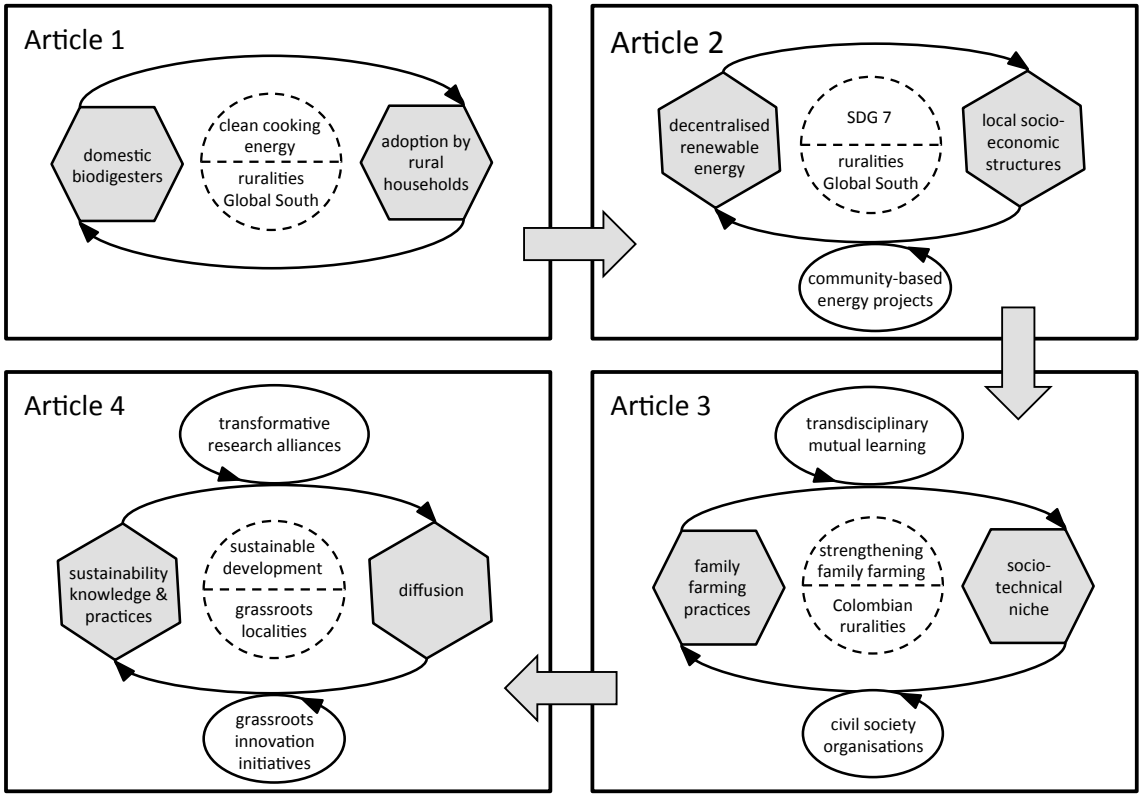

Figure 4 Schematic illustration of the concepts and/or conceptual aspects that are intensively explored in each of the four articles that form part of this cumulative doctoral dissertation.

The third stage entails a particularly significant increase in the comprehensiveness of the research journey. On the one hand, the role of the research itself is explicitly addressed. The study focused on a network of civil society initiatives advancing sustainable family farming in Colombia. The methodological approach allowed for both the study of that network and for supporting that network's internal processes. On the other hand, the study's subject comprises more general and abstract notions than those in the previous studies. Innovation in that study comprises the practices of family farmers associations, which can be categorised into different types, such as technical, organisational, financial, and commercialisation schemes. Additionally, the network of initiatives studied was conceptualised as a sociotechnical niche, which advances sustainable family farming innovations. The fourth and last study is a conceptual disquisition, which features the highest level of abstraction and generalisation among the four studies. Unlike the previous stages, the conceptual elaborations developed in this study are not directly related to empirical work. The study develops a conceptual framework that (a) provides better accounts for the particularities of endeavours aimed at the diffusion of knowledge and practices from the bottom-up across local contexts and social scales, and (b) advances first conceptual steps towards an explicit account for the role that innovation research (and innovation researchers) can assume for the actual realisation of diffusion.

6 Adoption and diffusion of domestic biodigesters by/to rural households

6.1 Charting article 1 in the research

This study takes a deep look into the innovation diffusion process at the level of the adopters. The focus is on rural households adopting domestic biodigesters. This is an energy technology innovation that has been promoted in several countries in the global south, mainly as an appropriate alternative for supplying clean cooking energy to rural households. The study applies a system perspective on the diffusion of domestic energy innovations. It builds on conceptual advances by scholars researching the diffusion processes of innovations in different rural areas in the global south (Agarwal, 1983; Altieri and Masera, 1993; Ruiz-Mercado et al., 2011), and develops a conceptual model of the dynamic processes triggered by the introduction of a domestic biodigester into an individual household. Qualitative content analysis of scientific literature is undertaken, in order to examine the empirically observed manifestations of the components and interactions of the conceptualised adoption model. In the broader context of the research journey, this study represents an in-depth exploration of the sociotechnical configurations that enable and constrain the abilities of single rural households to adopt, that is to integrate, the novel technology into their daily life. It provides empirical evidence of the specific transformative challenges involved in any attempt for the diffusion of that innovation, and of how initiatives/programs that promote diffusion mobilise crucial resources for supporting single households in that transformation.

6.2 Article 1

The present section comprises the full preprint version of the article with the title "Understanding the diffusion of domestic biogas technologies. Systematic conceptualisation of existing evidence from developing and emerging countries", that has been published in the journal Renewable and Sustainable Energy Reviews and is available online under http://dx.doi.org/10.1016/j.rser.2016.11.090.

Understanding the diffusion of domestic biogas technologies: Systematic conceptualisation of existing evidence from developing and emerging countries

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Abstract

Accelerating the diffusion of domestic biogas is considered to be a promising option for reaching the goal of universal access to energy by 2030, particularly for the provision of cooking energy for rural populations in developing countries. While interest in accelerating the diffusion of the technology has grown over the last decade, systematic understanding of the particular factors and specific circumstances which result in successful programmes is still lacking. The aim of this study is, therefore, to develop a systematic description of the factors that influence the diffusion of domestic biogas technologies. To achieve this, we reviewed empirical observations reported by 23 studies analysing dissemination programmes in 12 countries. These observations were organised by applying a system perspective to domestic energy transitions. The resulting model comprises the interactions between the user, the domestic biogas plant and six subsystems of a household's livelihood which are often directly affected by the introduction of the new technology. These subsystems are cooking, animal husbandry, crop production, promotion and education, financing and technology supply. Successful adoption (achieving sustained use) and diffusion (reaching the largest number of potential users) is determined by the level of compatibility between the domestic biogas functionality and the mentioned subsystems. Based on the evidence reviewed, factors and mechanisms regulating the interaction between the subsystems and the newly-introduced domestic biogas technology are described in detail. Once systematically organised, the evidence indicates the need to reconsider domestic biogas from two angles: i) by abandoning the common emphasis on the energy issue (i.e. cooking) of dissemination programmes and instead recognising the technology as a tool for strengthening the capacities of family farms and ii) by recognising the socio-technical structuration of domestic biogas, which determines users' ability to effectively integrate the technology within their family farms.

Keywords: domestic biogas, biodigester, developing countries, cooking energy, socio-technical transitions

6.2.1 Introduction

Biogas is considered to be a clean cooking alternative for the rural poor in developing countries. Accordingly, accelerating the diffusion of domestic biogas plants is expected to significantly contribute to achieving the ambitious goal of ensuring universal access to modern energy services by 2030 (IEA, 2011). Domestic biogas is not, however, a new idea and first initiatives developing practical designs appropriate for single households or farmers can be traced back to the first half of the 20th century[5] and there has been mass dissemination of the technology in some Asian countries for decades. For example, more than 26 million domestic biogas systems had been installed in China by 2006 (Chen et al., 2010); in India around 4.75 million plants were reported to have been installed by 2014 (MNRE, 2015); and from 1992 to 2013 over 260,000

[5] Some examples of early designs and applications include the patented design and its commercialisation by Mr Lo Guo-Rui in the 1930s in China (Chen, 1987), first installations of early designs under real conditions in Indian rural households during the 1950s (Gustavsson, 2000) and the demonstration of the technology at a school in 1955 in Kathmandu, Nepal (Bajgain and Shakya, 2005).

plants were installed in Nepal (van Nes, 2013). These programmes have been dependent on the continuous and long-term political support from central governments and have led to the emergence of nationwide institutional structures. In contrast, installation rates for domestic biogas plants (the main parameter for measuring the diffusion process) are somewhat marginal in countries where such programmes have not been established. However, global interest in broadening the diffusion of domestic biogas has been growing and during the last decade national biogas programmes have been launched in some Asian, African and Latin American countries.

Critical assessments of the suitability of the technology to improve the livelihood of the rural poor, as well as of the effectiveness of mass dissemination programmes, have been emerging. One notable strand of criticism contests the general assumption that biogas technologies are appropriate for addressing the developmental needs of the poorest. Indeed, the applicability of biogas technologies is constrained by access to specific resources such as water, manure, land and financial capital. Insufficient levels of these resources are more likely to be found in poor households. (A. Barnett, 1978; Gustavsson, 2000; Zohova, 2011) Another area of controversy is related to the adequacy and effectiveness of programmes fostering the mass dissemination of the technology. One central concern is the lack of individual motivation in the diffusion process; the high rate of diffusion achieved by successful programmes has been driven by concrete plant installation targets and corresponding subsidy schemes, whereas user commitment and motivation to adopt the technology remains low (Bhat et al., 2001; Daxiong et al., 1990; Lichtman, 1987). Related to this, poor user management practices and a lack of follow-up services (e.g. maintenance) are often reported, which leads to malfunction or, in the worst case scenarios, abandonment of the systems (Aschaber, 2010; Bhat et al., 2001; Cheng et al., 2014; Huanyun et al., 2013; Kossmann et al., 1999). The actual number of functional plants (behind the impressive total installation figures) is often unclear. Chen et al. estimate that, "of the 26.5 million biogas digesters in China's rural areas, only 60% … were operating normally" (Chen et al., 2010). In India, the rate of "acceptance" of installed plants varies between 40% and 70%, according to Bhat et al. (Bhat et al., 2001).

Although interest in broadening the global diffusion of domestic biogas has been growing, systematic understanding of the particular factors and specific circumstances which result in successful programmes is still lacking. This is relevant because domestic biogas programmes are expected to disseminate the technology under different environmental, social, economic and political conditions. Therefore, the main aim of the study is to develop a systematic description of the factors that influence the diffusion of domestic biogas technologies. The research approach comprises two components: i) a review of empirical observations reported by studies analysing dissemination initiatives/programmes in different geographical contexts and ii) the organisation of those empirical observations by applying analytical concepts derived from a system perspective on domestic energy transitions.

6.2.2 Conceptual Framework – a system perspective on the diffusion of domestic energy innovations

The process by which households in developing countries change their pattern of domestic energy consumption has long been the object of research by scholars from different disciplines. The simplest conceptualisation is the so-called 'energy ladder' hypothesis (Davis, 1998; Hosier and Dowd, 1987). While the energy ladder was extensively applied by studies on domestic energy transitions in the 1990s and 2000s, evidence highlighting deficiencies of the model accumulated and some scholars started to emphasise the need to abandon the idea of 'fuel switching' (which derives from the straightforward application of the energy ladder hypothesis), as well as other oversimplifications of adopters' behaviour (Brouwer and Falcão, 2004; Campbell et al., 2003; Hiemstra-van der Horst and Hovorka, 2008; Masera et al., 2000).

Accordingly, Ruiz-Mercado and her colleagues developed more comprehensive models of the process by which new energy devices and practices are adopted by members of a given social

system (Ruiz-Mercado et al., 2011). Their analysis focused on the adoption and diffusion of so-called improved cook stoves (ICS), i.e. stoves that allow the use of traditional biomass fuels, like firewood and charcoal, but whose designs reduce the negative impacts linked to cooking with open fires or traditional stoves, particularly indoor pollution, poor health, deforestation and climate change. The basic assumption of their model is that the adoption of a new cooking device is a process which "takes place in a dynamic system with strong interactions between the user, the technology, the fuels and the larger socio-economic and ecological contexts". The introduction of the new stove in a household initially disrupts the existing dynamic system and the adoption is the process by which a new state of equilibrium is achieved. The outcome is a modified set of cooking practices, in which each fuel-stove option available is applied where it performs best as perceived by the user. For instance, the preferred fuel-stove option for boiling might differ to that frying or grilling.

The system perspective proposed by Ruiz-Mercado and her colleagues shifts the focus from the fuels or the stoves to the user's cooking system. The cooking system comprises material components (fuels, stoves, kitchen etc.) and non-material elements (practices, traditions etc.). The goal of preparing cooked meals is achieved through the interaction between these two elements. This model is able to reproduce the coexistence of multiple stove-fuel options – evident from several studies in different countries – and moves the emphasis from the initial adoption of the new device to its actual use over time. In order to apply this system perspective to the case of domestic biogas innovations we propose to broaden the model in two ways; the first relates to the socio-technical differences of the innovations considered and the second aims to generate a more differentiated conceptualisation of 'the larger socio-economic context'.

Socio-technical differences between ICS and domestic biogas

While the anticipated impacts of the adoption and sustained use of ICSs are diverse, the direct effects on the 'dynamic system' that frames a household's daily life are mostly limited to the domain of cooking practices. The effects of introducing domestic biogas technology into a household are more diverse. Firstly, its application involves not only a new stove in the kitchen, but also the installation and operation of the biodigester that produces the fuel (the biogas), as well as auxiliary devices for feeding it and handling the effluent, and the pipes for transporting the gas to the kitchen. In other words, as well as becoming the user of a new stove, the user of a domestic biogas system also becomes an energy producer; i.e. the operator of the biochemical process that produces the biogas as well as the 'by products' (liquid effluent and sludge) of the anaerobic digestion. Secondly, domestic biogas is often promoted as a technical solution with a variety of benefits for a household in addition to energy for cooking. The most notable benefits are the provision of biological fertiliser, the adequate treatment of waste water and improvements to sanitation. Therefore, applying the system perspective to the case of domestic biogas requires a more differentiated conceptualisation of the 'dynamic system' in which the user is embedded and in which the new technology is expected to be integrated. Adopting a domestic biogas plant does not only entail adjustments to a household's cooking subsystem. During the process, adjustments between and within the household's other subsystems[6] may be necessary; particularly those related to animal husbandry (which provides the inputs for the anaerobic digester) and crop production (where the use of effluents should generate additional benefits). Therefore, as a minimum, our model should also consider the household subsystems relating to animal husbandry, crop production and sanitation.

[6] We opt to use the term 'subsystem' to refer to a set of interacting components which fulfils comprehensible single functions, which in turn contribute to constructing and/or sustaining a household's livelihood. Subsystems can be part of a household's own configuration (e.g. those providing cooked meals or crops) or can be external (e.g. those providing knowledge, training or loans).

Elaborating on 'the larger socio-economic context'

Several studies have emphasised the importance of the socio-economic context in the diffusion of domestic energy innovations, i.e. factors that lie beyond the configuration of individual households. For instance, when analysing their results on domestic energy transitions in Maun, Botswana (Hiemstra-van der Horst and Hovorka, 2008), Hiemstra-van der Horst and Hovorka noted that "structural factors such as policies and market trends at national, regional or even international scales can be critical influences on [households'] energy-use decisions". Useful insights on the influence of structural factors can also be found in Agarwal's work on the diffusion of innovations in rural contexts (Agarwal, 1983). Her analysis emphasises how user's ability to gain access to 'external' resources, such as knowledge, credit or inputs, is a strong determinant of the user's ability to adopt new technology. In order to improve the understanding of the diffusion process of biogas plants, consideration should be given to the institutional settings which determine how resources are allocated and exchanged amongst users and other actors involved in the process. Consequently, we propose studying subsystems which exist beyond the individual household configuration. Particularly those subsystems that provide the knowledge, financial capital and technical input required to ensure that a user can learn about, invest in, operate and draw benefit from a domestic biogas plant.

Figure 5 provides a schematic view of the conceptualisation proposed to understand the diffusion of domestic biogas. The basic assumption is that the installation of a domestic biogas plant changes the current conditions of household's subsystems; subsystems that fulfil important livelihood functions such as cooking, crop production, animal husbandry and sanitation. The reciprocal interaction between the user, the newly-installed biogas plant, the household configuration and the socio-economic context determine the actual usage of the new technology and, ultimately, its impact on the user's livelihood. Within the socio-economic context, particular attention is paid to subsystems which determine the ability of users to access (i) knowledge about domestic biogas technology; (ii) finance for the investment required and (iii) the necessary supply of technical inputs (skills and materials) for designing, constructing and installing the domestic biogas plants. Successful diffusion implies that adjustments within the subsystems are achieved in such a way that the functionality of the domestic biogas technology can be effectively performed and the expected benefits fulfilled.

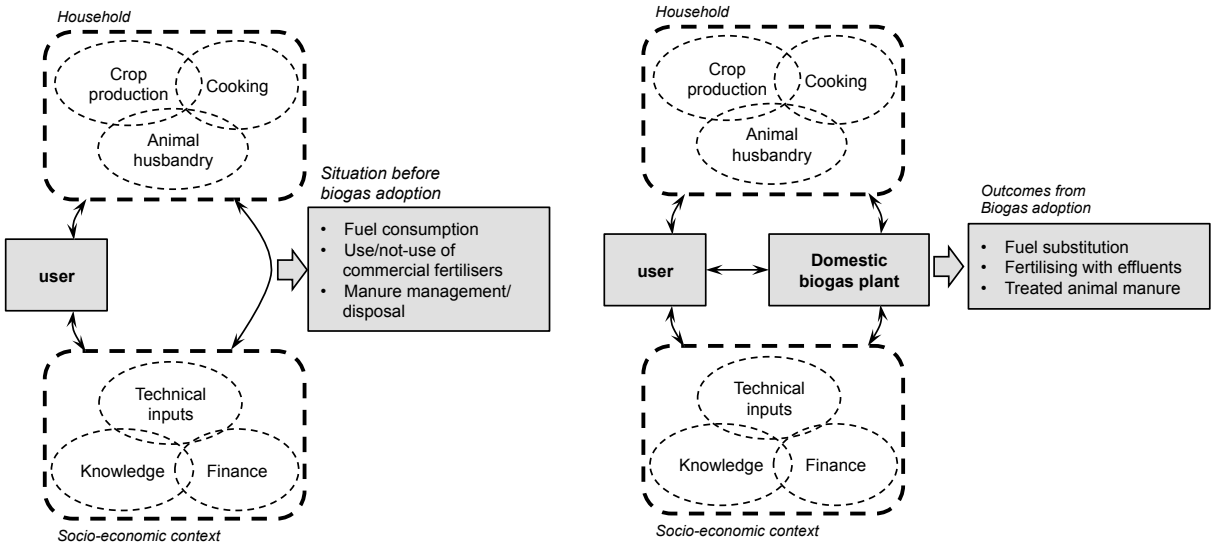

Figure 5 Schematic description of the dynamic system affected by the introduction of a domestic biogas plant.

6.2.3 Methods and materials

Qualitative content analysis of scientific literature is undertaken to examine empirically observed manifestations of the interactions between the domestic biogas plant, the user, the household and the socio-economic context. The aim of the analysis is to systematically organise the evidence of the factors that influence the diffusion of domestic biogas in developing or emerging countries. Influential factors are extracted and clustered by examining similarities and relationships between single observations from different case studies. The resultant systemised factors present the basis for the detailed descriptions of the components and interactions between the household configurations and socio-economic context that determine both the adoption process at household level and the overall technology diffusion.

Selection and description of the literature

Empirical findings on the factors influencing the diffusion of domestic biogas technology comprise the data for analysis. Accordingly, studies examining the conditions and results of single projects or complete programmes aimed at disseminating domestic biogas plants in developing or emerging countries were considered. Only studies that appeared in publications validated through a peer review process were included.

The selection process comprised several stages. The Scopus databank was used to screen the literature initially. The terms “biogas”, “digester” and “biodigester” were combined with the terms “domestic” and “household” to screen titles, abstracts and key words. This search uncovered more than 1000 titles. In order to refine the search, articles published in journals dedicated to research on biochemistry, engineering, mathematics, medicine and similar issues were excluded. At the time of the screening (August 2014) this refined search resulted in 509 titles. In a further step all the titles – and eventually the abstracts – were reviewed by the authors in order to further refine the list according to two criteria: geographical scope and object of study. Only studies that claimed to study field experiences from biogas dissemination initiatives in developing and emerging countries were considered. As a result, much of the literature, which focused on technological engineering, feasibility studies and projections of performance and potentials, was excluded. Ultimately, this resulted in a sample of 50 studies published between 1998 and 2014. The authors then examined the research objectives and methods applied by each study. The aim was to identify studies which considered (at least to some extent) the context in which users gain knowledge, make decisions, invest in, operate and/or use the products from domestic biogas plants. Finally, 23 studies were selected for in-depth analysis (listed in Table 2)

Regarding the scope of the analysis, the studies can be grouped into two categories: i) studies evaluating the implementation and/or impact of biogas dissemination through data collection at household level and ii) studies evaluating the lessons learned from nationwide dissemination programmes from an overarching perspective

The first group comprises 18 studies. Although the aims and methodologies vary, all are based on detailed surveys of single households. The sample sizes vary between 12 households in a small programme addressing rural Andean communities in Peru (Garfí et al., 2012) to 1227 households from four different provinces in China (Qu et al., 2013). Some of these studies comprise additional interviews with other stakeholders, such as government officials, technicians or NGO staff, to complement the information. Most of these studies aim to assess the effects of the technology on diverse dimensions of household livelihoods, but none provide data on the user situation prior to implementation (baseline data). Instead, a commonly-used approach is to compare data from users and non-users. This approach is applied by eleven of the reviewed studies. Three explicitly aim to assess problems and failures in the performance of the installed systems and another three focus on analysing factors affecting users’ decisions to adopt the technology.

Table 2 Studies selected for in-depth analysis.

Short citation	Country	Study area	Quantity households surveyed	Comparison users/non-users
Kabir et al., 2013	Bangladesh	4 Districts from Dhaka, Rajshahi and Rangpur	300	yes
San et al., 2012	Cambodia	50 villages in Kampong Chhnang province	767	no
Gosens et al., 2013	China	38 villages in Gansu, Guangxi, Hubei and Shandong provinces	1065	yes
He et al., 2013	China	12 villages from three 'cities' of Shandong Province	473	yes
Huanyun et al., 2013	China	41 villages from 8 towns in the Yuxi region, Yunnan province	797	no
Qu et al., 2013	China	32 villages in 8 counties in Gansu, Guangxi, Hubei and Shandong provinces	1227	yes
van Groenendaal and Gehua, 2010	China	3 villages in Gansu and Sichuan provinces	239	yes
Xiaohua et al., 2007	China	Lianshui in Jiangsu province and Guichi in Anhui province	696	yes
Bhat et al., 2001	India	25 villages in Sirsi, Karnataka state	187	no
Raha et al., 2014	India	8 villages in 2 districts of Assam	60	no
Mwirigi et al., 2009	Kenya	Nakuru and Nakuru North districts	200	yes
Cheng et al., 2014	Nepal	Nationwide field study	94	no
Katuwal and Bohara, 2009	Nepal	Nationwide biogas user survey 2007/2008	461	no
Garfí et al., 2012	Peru	Department of Cajamarca	12	no
Laramee and Davis, 2013	Tanzania	7 communities northwest of Arusha town	40	yes
Mwakaje, 2008	Tanzania	4 villages in the Rungwe district	200	yes
Walekhwa et al., 2009	Uganda	6 districts of central and eastern Uganda	220	yes
Thu et al., 2012	Vietnam	Quoc Oai district in Hanoi and Huong Tra district in Hue province	181	yes
Martí-Herrero et al., 2014	Bolivia	Nationwide programme	-	-
Buysman et al., 2013	Cambodia	Nationwide programme	-	-
Chen et al., 2010	China	Nationwide programme	-	-
Chen et al., 2012	China	Nationwide programme	-	-
Landi et al., 2013	Rwanda	Nationwide programme	-	-

Among the studies describing lessons learned from nationwide programmes, two explicitly indicate that interviews with different actors involved in the development of the programme were part of the data collection process (Buysman and Mol, 2013; Landi et al., 2013). The two papers reviewing the development of biogas technology in China are mainly based on a sample set of Chinese literature on the topic (Chen et al., 2012, 2010). Finally, one article documents the experiences from a nationwide biogas programme in Bolivia active between 2007 and 2012 (Martí-Herrero et al., 2014).

Coding and categorising

Our analysis combines both deductive and inductive category formation. The integration is achieved by applying 'axial coding': "the categories that are most relevant to the research question are selected from the [inductive] developed codes and the related code notes. Many different passages in the text[s] are then sought as evidence of these relevant codes in order to elaborate axial categor[ies]" (Flick, 2009). For our analysis the set of subsystems outlined in the conceptual framework (see section 2) serve as the deductive categories. Inductive category formation is applied to identify factors and mechanisms determining the interaction between the technology, the a priori formulated subsystems or other relevant domains framing households' decisions and actions. Thus, the relevance of statements and codes is evaluated by their ability to describe or explain interactions between the user and the domestic biogas technology.

Table 3 Resultant set of first and second-level codes clustered into the animal husbandry and crop production subsystems.

1st level code	2nd level code	Subsystem
Labour	Husbandry practices	Animal husbandry
Type of animals		
Use of stalls		
Wastewater regulation		
Number of animals	Number of animals	
Bought manure		
Use of water	Use of water	
Feeding preparation	Feeding preparation	
Awareness of effluent value	Cognitive factors	Crop production
Effect of effluent		
Effluent management		
Distance to fields	Physical constraints	
Farm size		
Manure as fertiliser	Existing fertilising practices	
Use of synthetic fertilisers		

In a first stage, the studies are reviewed in detail. The main focus is on observations about physical, practical and institutional components that influence the adoption process at household level, i.e. factors affecting the decision to adopt (or not) a biogas plant, the operation and maintenance of the installed plant, the actual use of the products (biogas and effluent) and the perception of the benefits. Reported observations are extracted as single statements with unambiguous meanings. Particular attention is given to the empirical source that backs up each statement. The first coding process assigns one 'keyword' to each statement. 'Keywords' are created from one or several words present in each statement which point to the aspect that is reported as relevant to the domestic biogas diffusion process. The keywords are firstly grouped into more general first-order codes with unified meanings. The aim here is to identify influential aspects that have been observed in several studies and to elaborate codes that best represent

those common observations. In a second stage, the analysis looks for relationships between first-level codes in order to create meaningful axial categories (second-level codes), which represent components or factors identified as influential to the diffusion of domestic biogas. Subsequently, an assessment is made as to whether the developed codes can be related to the functionality of one (or several) of the a priori formulated subsystems, or whether they might refer to subsystems that are not considered by the proposed conceptualisation of domestic biogas diffusion. The coding process is not linear. It implies a recursive procedure, where the suitability of codes and categories is challenged by re-evaluating their ability to incorporate observations from several studies. This recursive process forms the basis for building a detailed description of the dynamic system in which the adoption of domestic biogas takes place and, more specifically, for describing the household subsystems and their socio-economic contexts which are influential to the diffusion of the technology. Table 3 illustrates the results of this coding process by presenting the set of first and second-level codes clustered into two of the a priori formulated subsystems, i.e. animal husbandry and crop production.

Applied to the 23 selected studies, the analysis led to the extraction and classification of 382 sentences (Table 4). The vast majority of the extracted observations can be related to the functionality of at least one of the a priori formulated subsystems that configure users' households and their socio-economic context. However, only a few useful statements about the interaction between domestic biogas and the household sanitation situation were found. The information contained in those statements does not allow for generalisation about factors and mechanisms influencing the diffusion process of domestic biogas. Moreover, only a small group of statements (19) refers to aspects that cannot be related to the a priori formulated subsystems. These suggest possible interactions with four additional subsystems: research and development, water supply, heating, and lighting. However, once again the information in these statements is limited and does not allow for elaborated descriptions of the factors and mechanisms regulating their interaction with domestic biogas technology.

Table 4 Quantity of sentences coded and classified according to their affiliation to household subsystems or socio-economic context.

Subsystem	Coded statements
Cooking	83
Finance	64
Animal husbandry	58
Promotion & Education	53
Crop production	51
Technology supply	44
Sanitation	12
Research & Development	6
Water supply	4
Heating	4
Lighting	3
Total	382

6.2.4 Results

This section presents detailed descriptions of the factors and mechanisms observed to influence the integration of domestic biogas technology in six subsystems that configure users' households and their socio-economic context, i.e. cooking (the daily preparation of meals), animal husbandry, crop production, promotion and education (access to information and training), finance (improving financial capacity) and technology supply (supply of materials, equipment and technical services). Figure 6 summarises these findings in a schematic way. The situation

depicted by the graphic is one in which successful integration is achieved. This, in turn, is characterised by positive/beneficial outcomes from the household's point of view.

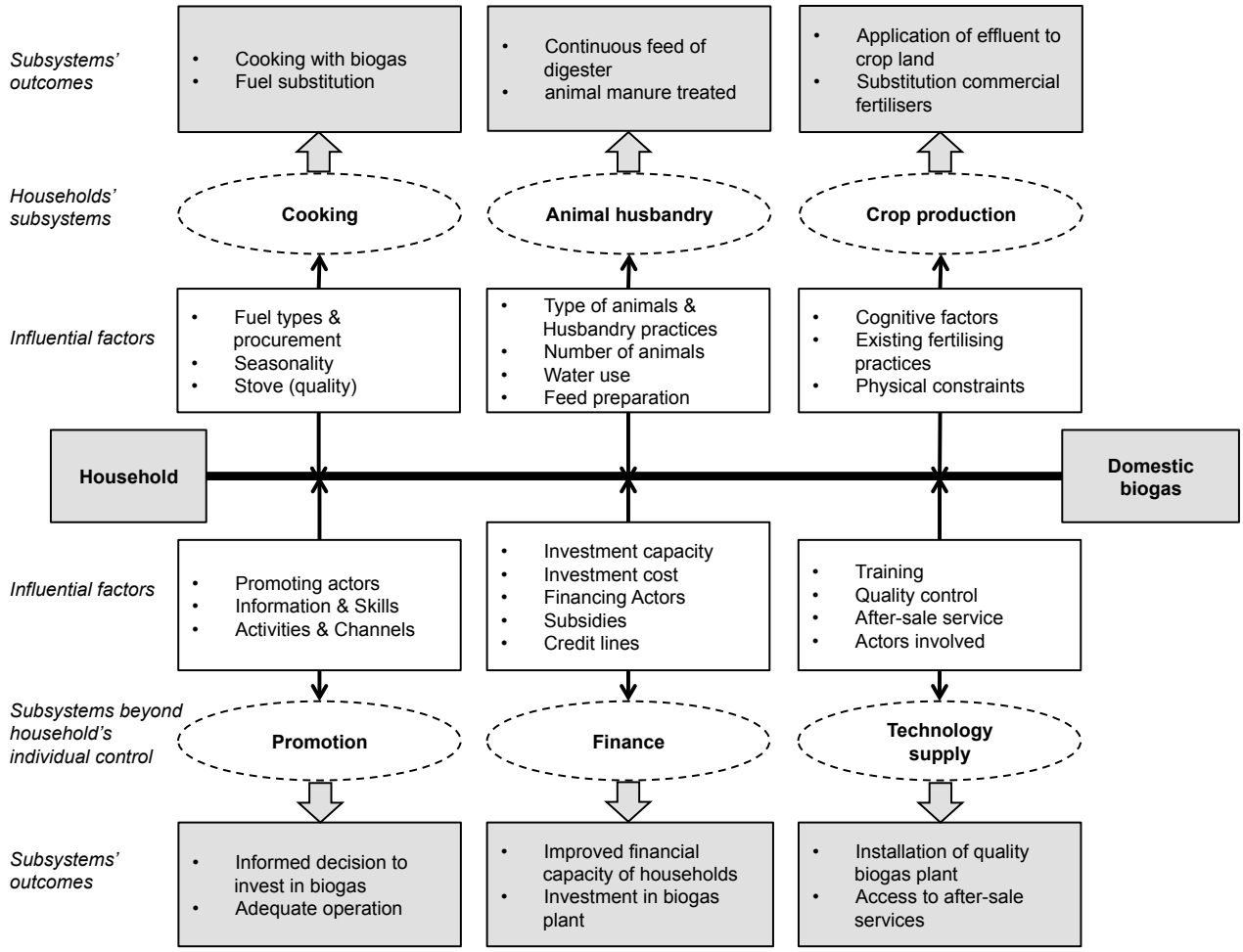

Figure 6 Schematic view of a system perspective of domestic biogas adoption and dissemination. The ability of a household to draw positive outcomes from domestic biogas technology is influenced by the extent to which the technology is integrated into (matches) the functionality of a household's livelihood subsystems, which in turn are affected by the presence of the technology. Factors influencing this integration process are listed (rectangles in white). The graphic presents a hypothetical situation of successful integration in all subsystems and the corresponding outcomes (shadowed rectangles).

Cooking

The use of biogas to replace the formerly used cooking fuel is the main anticipated outcome of the successful adoption of domestic biogas technology. However, rarely is the previously used fuel wholly replaced. One notable exception is given by Bath et al., who highlight that "85% of the [surveyed households] reported that all their normal daily cooking energy needs were met through biogas" (Bhat et al., 2001). Partial substitution, i.e. the adoption of biogas as an alternative fuel for cooking, is the most commonly reported outcome. The *type of fuels* used before (and after) the adoption of biogas and particularly the extent to which they can be *commercially procured* are the most prominent factors influencing this outcome. Additionally, the *seasonality* and the *quality of the biogas stoves* also influence the relationship between domestic biogas adoption and the user's cooking subsystem.

Types of fuels and fuel procurement

Non-commercial fuels are the primary source of domestic energy in all the studies. Firewood is prominent among the non-commercial fuels. It is part of the average energy mix for domestic use in all cases. The share of firewood in the energy mix, as well as the use of other non-commercial energy carriers, depends on local conditions and farm activities. For instance, total reliance on firewood is found by Garfi et al. in their case study in a Peruvian Andean village, where "in the previous scenario [without biogas plant] the families involved in the pilot project only used firewood" (Garfí et al., 2012). As well as firewood, agricultural residues such as straw and stalk are often part of the energy mix in rural Chinese households; however, the share of these energy carriers varies from province to province (Xiaohua et al., 2007) and even from village to village (van Groenendaal and Gehua, 2010).

In addition, a wide range of *commercial* fuels, mainly fossil fuels, are present in the energy mix in rural households, such as liquefied petroleum gases (LPG), kerosene, charcoal and coal. Once again, broad variations are found according to local conditions. Coal is particularly prominent in rural Chinese households, while in African countries charcoal and kerosene are the most used commercial fuels. Of all the commercial fuels LPG is the most universally present in the reviewed studies. The use of LPG is reported in China (Gosens et al., 2013; van Groenendaal and Gehua, 2010; Xiaohua et al., 2007), India (Raha et al., 2014), Kenya (Mwirigi et al., 2009), Nepal (Katuwal and Bohara, 2009) and Tanzania (Laramee and Davis, 2013). However, the actual consumption of LPG is often low and the extensive use of LPG to meet domestic energy needs is unusual. One noteworthy example is found in Guangxi, China, "where non-users of biogas used large quantities of LPG as well as commercially acquired fuel wood" (Gosens et al., 2013). This observation focuses attention on the fact that firewood (and other biomass-based fuels) may also be commercially available on the local market. However, few studies give explicit indications of the role that commercial firewood plays in the regions studied. The above-mentioned study by Gosens et al. (Gosens et al., 2013) is one of the few exceptions.

As well as variations in the share of commercial and non-commercial fuels, there are also variations in unpaid *labour* and monetary *expenses*. The consumption of non-commercial fuels does not necessarily involve monetary transactions, as in most cases access to biomass resources is free (e.g. biomass produced on the farm) and unpaid labour from family members is used for the required processes. Some exceptions are however evident; for instance, when the provision of non-commercial fuels necessitates hiring external labour and permission fees are payable for accessing communal resources (Laramee and Davis, 2013; San et al., 2012). However, in general, the procurement of non-commercial fuels has a low monetary cost and relies on financially uncompensated labour-intensive task.

The way in which these energy procurement tasks are assigned within a household plays a fundamental role in the adoption process. Regardless of the geographical context, in most of the studies women are reported to be the primary household members responsible for the provision of energy. Workload in terms of time is an often-used indicator to track changes resulting from biomass adoption. The reduction in time spent on fuel collection after installing the biogas plant varies from "not significant" in Dong Huan, China (van Groenendaal and Gehua, 2010) to a 50% decrease in the Peruvian case study (Garfí et al., 2012). Moreover, women play the main role in the whole cooking subsystem, which includes tasks such as fuel procurement, meal preparation and cleaning the cooking utensils. Therefore, some studies differentiate or include the labour related to these tasks in their analysis. While the reduction in time required for all cooking-related tasks is often documented and quantified, the additional labour required for the operation and maintenance of the biogas plant is not. An interesting exception is found in the survey carried out by He et al. in China. When asked for perceptions on reductions in housework load in general, less than 50% of the respondents gave positive assessments (He et al., 2013).

Seasonality and the biogas stove

In addition to fuel types and their procurement, *seasonality* and the *biogas stove* (or biogas stove quality) play a role in the adoption process. The biogas yield is directly related to the temperature of the substrate within the digester. In regions with pronounced winter seasons, users face significant reductions in biogas yields during wintertime, as reported in some regions in China (He et al., 2013; Xiaohua et al., 2007) and India (Raha et al., 2014). In order to use the biogas for cooking, the adoption of a biogas plant always comprises the provision of a new stove, or the adaptation of the existing one. This requires the user to adopt new practices in operation and maintenance. Only three studies report on observations related to the biogas stoves. All of these refer to difficulties, such as improper maintenance by the users (Cheng et al., 2014) and recurrent need for maintenance (Laramee and Davis, 2013; Thu et al., 2012) due to the rapid deterioration of stove components.

Animal husbandry

Animal manure is the primary source of substrate for domestic biogas plants. Consequently, the integration of the biogas technology with the user's animal husbandry is central to the adoption process. The desired outcome is to ensure that the digester is continuously fed with appropriate substrate mixture, which requires the redirection of the flow of animal manure (or a fraction of it) to the digester. The *type* and *number of animals* are the most basic influencing factors. However, the actual *configuration* of a household's animal husbandry has a strong influence on the adoption process; i.e. issues such as use of animal stalls, animal feeding practices and also water usage.

Animal type and husbandry practices

Among the cases described in the reviewed literature, manure from cattle and pigs is the main source of substrate for household biogas plants. A noteworthy difference was found between East Asian countries and other regions. Animal husbandry in China, Vietnam and Cambodia seems to be dominated by pig production, while in Africa, India, Nepal and Bangladesh cattle rearing was almost exclusively documented. This difference is relevant because animal type is directly related to different configurations in animal husbandry practices.

Pig husbandry is more likely to comprise stalls (i.e. pigpens). This makes the availability of manure for biogas production directly dependent on the number of animals. In China, this common feature of pig husbandry has even led to the development of standardised intervention packages, like the so called 'three-in-one' model, which "combines the biogas digester with a pigpen and toilet" (Chen et al., 2012). Consequently, "the investment in the bio-digester is combined with a major renovation of the farm (at least a new kitchen, pigpen, and toilet)" (van Groenendaal and Gehua, 2010).

On the other hand, the actual availability of manure from cattle is influenced by the existing husbandry practices. Most of the case studies from Africa highlight free-grazing as a common practice. Programmes promoting domestic biogas look for farmers who practice 'zero-grazing', like in Kenya (Mwirigi et al., 2009) and Tanzania (Laramee and Davis, 2013), or those who practice 'semi-stabled' husbandry, in which animals are stabled at least at night, like in Rwanda (Landi et al., 2013). As a result, dairy farmers, or those who produce milk on a daily basis for self-consumption, are more likely targets for biogas promotion programmes, as illustrated in Tanzania (Mwakaje, 2008) and India (Raha et al., 2014).

Numbers of animals

The size of the biodigester depends on the daily availability of manure. The biogas promotion programmes studied set minimum standards of between 20 kg per day in the case of Rwanda (Landi et al., 2013), and up to 50 kg manure per day in the case of India (Raha et al., 2014). Accordingly, a minimum number of animals is often a pre-condition for participation. For instance, in Rwanda "at least 4 pigs, 4 semi-intensive (stabled at night) or 2 stall-fed (zero-grazing) cattle … at farm" are the minimum requirements (Landi et al., 2013), while to apply for national funds in the Chinese programme, "3 pigs per household" is the minimum (Gosens et al., 2013).

Lack of manure is a major cause of failure. In their Nepal study, Cheng et al. found that 10 plants (from a sample of 69) were "underfed or irregularly fed, which is due to the fact that some farmers gave up livestock breeding or decreased the number of animals" (Cheng et al., 2014). Reduction in the number of animals on the farm and the consequent reduction (or abandonment) of biogas production has also been observed in China (Huanyun et al., 2013; van Groenendaal and Gehua, 2010). Migration dynamics can account for such changes, i.e. young people moving to the city for work, which reduces the labour force in the countryside and impacts on farming activities (Chen et al., 2012; Huanyun et al., 2013; Qu et al., 2013). However, insufficient animal manure from the farm does not necessarily hinder the adoption of biogas systems. In their study of villages in Shandong province, China, He et al. reported that 104 households (from a sample of 301) purchased manure for their biogas plants (He et al., 2013).

Water use and feed preparation

As well as the number of animals and the use (or not) of animal stalls, two additional animal husbandry practices which can affect the functionality and effects of biogas plants are worth mentioning: water use and animal feed preparation. Water may be used for the regular cleaning of animal sheds. This can reduce the need for additional water to form the appropriate substrate mixture. However, excess water will reduce the effectiveness of the biogas plant by reducing the decomposition rate of the organic matter and, in turn, the biogas production. This situation was noted by Thu et al. in the provinces of Hanoi and Hue in Vietnam (Thu et al., 2012). While the availability of manure was not a problem (the average number of pigs per farmer was 39 in Hanoi and 11 in Hue), the authors found ratios of manure to water from 1:8 to 1:16. These values significantly exceed recommended standards (which vary between 1:1 and 1:4, depending on the digester and manure type). In contrast, Laramee and Davis observed biogas plants integrated in dairy farms in Northern Tanzania where "cattle urine collected was a sufficient amount of liquid for mixing, and (…) water inputs were minimal" (Laramee and Davis, 2013).

Another common feature of husbandry practices in stables is that animal feed has to be transported to the stalls and it often requires some sort of preparation. Four of the reviewed studies explicitly recognise the use of biogas as fuel for these feed preparation tasks. For instance, the preparation of mash for pigs requires a cooking process. Such examples were found by San et al. in Kampong Chhnang province, Cambodia (San et al., 2012), by Xiaohua et al. in Lianshui and Guichi, China (Xiaohua et al., 2007) and by Thu et al. in Hanoi and Hue provinces, Vietnam (Thu et al., 2012). Interestingly, Laramee and Davis describe how biogas was used for heating drinking water for cattle during the cold season in Northern Tanzania (Laramee and Davis, 2013). These observations give clear indications about linkages between biogas technology and animal husbandry which go beyond mere substrate provision.

Crop production

Users of domestic biogas plants are generally assumed to be involved in some sort of agricultural activity. Consequently, it is generally expected that the effluent from the anaerobic digestion will provide additional benefit to users as bio-fertiliser, thus increasing crop productivity. The actual application of effluent to a user's crops is the main link between biogas

technology and the user's crop production. How this link develops during the adoption process depends on diverse factors that can be grouped into *cognitive* components (e.g. knowledge, awareness and perception of the value of the effluent as a fertiliser), *practice/routine* elements (e.g. use of synthetic fertilisers and effluent management practices) and *physical constraints* (e.g. distribution and distance to crop plots and the liquid nature of the effluent).

Cognitive factors

Although the production of bio-fertiliser is explicitly mentioned as one of the main benefits of domestic biogas in all the reviewed studies, only seven actually note high levels of awareness and/or the actual application of bio-fertiliser in their case study areas (Bhat et al., 2001; Gosens et al., 2013; He et al., 2013; Kabir et al., 2013; Katuwal and Bohara, 2009; Laramee and Davis, 2013; Martí-Herrero et al., 2014). In contrast, other studies identify low levels of awareness leading to low levels of application (Huanyun et al., 2013; Raha et al., 2014), ineffective application (van Groenendaal and Gehua, 2010) or improper management and discharge of effluents (Cheng et al., 2014; Thu et al., 2012). Garfi et al. and Martí-Herrero et al. note that a lack of validated knowledge on the fertilising value of effluents for the specific crops cultivated by users, as well as on appropriate application techniques, explains these low levels of application (Garfí et al., 2012; Martí-Herrero et al., 2014). There is little data about the effect of effluent use in terms of crop productivity. This may be partly explained by the methodological difficulty of linking crop productivity to the use of effluent in a sound way, as "too many confounding variables (…) influence this relationship" (Gosens et al., 2013). However, some studies take the user's own perceptions as an indication of the actual effects of effluent use. For instance, Katuwal and Bohara report that 68% of the surveyed households "noticed an increase in crop productivity in their kitchen garden" (Katuwal and Bohara, 2009) and Martí-Herrero et al. note that "farmers report a great capacity of the [effluent] to protect the crops from freezing". (Martí-Herrero et al., 2014)

Existing fertilising practices

Measuring reductions in money spent on fertilisers and pesticides is a proxy variable that is often used to track the use and effect of effluents. An underlying assumption is that the farmers commonly used commercial fertilisers and pesticides prior to the adoption of domestic biogas. However, this is not a general feature of domestic biogas users. For instance, the dominant farming system in Cambodia integrates rice cultivation and livestock, where "rice production relies on draught power and manure from cattle or buffalos" (Buysman and Mol, 2013); Thu et al. find that a considerable share of farmers (non-biogas users) in Hanoi and Hue (in Vietnam) use some of their pig manure to fertilise their own plots, often after composting treatment (Thu et al., 2012); and Mwakaje notes that the most common fertiliser in Tanzania is raw cattle dung (Mwakaje, 2008). However, for those farmers who spend significant amounts on commercial fertiliser, the adoption of biogas and particularly the use of effluents can lead to measurable financial savings, as illustrated by the analysis of Gosens et al. in four different provinces of China. They found that savings in "fertiliser and pesticide had a bigger contribution to household budget improvement" than the impact on commercial fuel expenditure for biogas users in three of the analysed provinces (Gosens et al., 2013). Nevertheless, it remains the case that cognitive factors can reduce the actual financial effect of effluent application. This is illustrated by another study in China where biogas users applied the effluent in addition to, instead of as a substitute for, commercial pesticides and fertilisers (van Groenendaal and Gehua, 2010).

Physical constraints

The availability and distribution of crop plots strongly influence the actual use of effluents. The development of 'eco-agricultural models' in China illustrates how the distribution of crop plots (and more generally the existence of characteristic production systems) can influence the whole conceptualisation of biogas technology. The popular 'three-in-one' model (previously described)

is often related to the production of fruit or vegetables (Chen et al., 2012; van Groenendaal and Gehua, 2010). Moreover, extensions to that model integrate investment in greenhouses for vegetable production into one single intervention (Chen et al., 2010). In contrast, three studies provide examples of crop production distributed between different plots and at varying distances from the farmers' home, animal stalls and the digesters, in Vietnam (Thu et al., 2012), Tanzania (Laramee and Davis, 2013) and Nepal (Katuwal and Bohara, 2009). In such situations the actual use of effluents is influenced by the means of storage, transportation and field application available to users. A common outcome in such situations is a low rate of effluent application, where only small plots near to the home and biodigester, such as kitchen gardens (Katuwal and Bohara, 2009) and vegetable patches (Thu et al., 2012), are fertilised using the effluent. Applying the effluent to plots located far from the digester requires additional equipment and labour, as illustrated by farmers in Vietnam who transport the effluent "in barrels on rudimentary vehicles such as hand-pulled carts or motorbikes" (Thu et al., 2012). Its liquid nature is a major difficulty for the transport of the effluent to distant plots. Drying the effluent can be an option, as reported by Raha et al. (Raha et al., 2014) The liquid nature and high dilution rate of the effluent are major disadvantages in comparison to synthetic fertilisers. This, in turn, further reduces the actual substitution potential of synthetic fertilisers at plots remote from the digester, as illustrated in the case in Northern Tanzania analysed by Laramme and Davis, where "[s]ynthetic fertiliser was more commonly used at secondary plots located at some distance away from the household" (Laramee and Davis, 2013). Thu et al. also found that farmers in Hue, Vietnam, "tended to use mineral fertiliser for rice and maize crops in fields far from their house" (Thu et al., 2012). However, the lack of personal crop land or surplus effluent might not necessarily lead to improper discharge. Raha et al. observed that in one scheme in Assam, India, the effluent is sold "to a local organisation which used it in the production and marketing of vermin-compost" (Raha et al., 2014).

Promotion and Education

Domestic biogas is still an unknown and novel technology for many rural households who could benefit from adopting and integrating it into their daily lives. Under the label 'promotion and education', we gathered a cluster of issues reported by the reviewed studies. On the one hand, these aim to raise awareness among potential users and create well-informed households that are able to decide whether or not to invest in the technology. On the other hand, 'promotion and education' includes efforts aiming to build knowledge and skills among users for the appropriate (and continuous) operation and maintenance of the domestic biogas system, in order to enable "informed, engaged user[s] to fully realize and utilize its array of intended benefits" (Landi et al., 2013). Promotion and education activities targeted at (potential) users are recognised in most of the reviewed studies as crucial for the diffusion of the technology. Factors reported as influential in this process can be divided into three categories: the *actors* involved in promotion, the *activities and channels* used for promotion and the actual *information and skills* transferred.

Promoting actors

Various state agencies are involved in the planning and implementation of nationwide biogas programmes, which rely on central government support. The role of state agencies is diverse. In general terms central government entities promulgate supportive policies, overarching goals, standards and financial support schemes, while local state entities implement practical measures and local-specific projects. Central government entities are often ministries or ministerial offices, for instance: Chen et al. mention "The Ministry of Finance, National Development and Reform Commission [NDRC], and Ministry of Agriculture [MOA]" as central actors in China (Chen et al., 2012); in India the Ministry of New and Renewable Energy (MNRE) assumes the central management of the National Biogas and Manure Management Programme (NBMMP) (Raha et al., 2014); the national biogas programme in Cambodia was set up by a partnership "between the Cambodian Ministry of Agriculture, Forestry and Fisheries (MAFF) and the Dutch Development Organisation SNV" (Buysman and Mol, 2013); and in Rwanda the

Ministry of Infrastructure is involved in the implementation of the national biogas programme (Landi et al., 2013).

There is evidence of diverse institutional arrangements to disseminate nationwide policies and goals to the field and to reach the targeted beneficiaries. In China, for instance, a 'five-level' hierarchical system of agencies is responsible for the management and promotion of rural energy projects, which includes agencies at national, provincial, city, county and township level (Chen et al., 2012). Proposals for building single plants are aggregated upwards along the system. Initially proposals are collected at village level by village committees; proposals from several villages are then grouped by township rural energy agency and the aggregation process continues at county, city and provincial level. The provincial rural agencies submit feasibility studies to MOA and NDRC, which formulate annual construction plans and budgets, among other provisions. Plans and budgets are then subdivided into different regions, level by level, and finally local township rural energy agencies are responsible for organising and supervising the construction and operation of biogas plants (He et al., 2013). In India, in addition to the Ministry of New and Renewable Energy, there are three levels at which the National Biogas and Manure Management Programme is implemented: a) The 'State Nodal Agencies' where targets and subsidy funds are allocated from central government; b) private companies[7], which are contracted by the state nodal agency in order to undertake biogas plant installation and post-installation maintenance; c) households who adopt the technology (Raha et al., 2014). In Bangladesh, the National Domestic Biogas and Manure Programme is coordinated by the state-owned Infrastructure Development Company Limited (IDCOL). Technical specifications, as well as other regulations for subsidy allocation, are set by IDCOL and donor organisations (SNV and KfW). The actual implementation of biogas plants is assumed by more than 30 partner organisations, which include NGOs and private companies active in rural areas (Kabir et al., 2013).
While the above-mentioned institutional arrangements provide the broad framework for the diffusion of the technology, promotion in the sense of user awareness and capacity-building depends on the involvement of organisations active at local levels with more direct links to potential users. Locally active organisations include official entities, non-governmental organisations, farmers' associations and private companies. Official entities should provide extension services that are well-suited for promotion to rural households. Thu et al. report that 52% of their respondents in the Hue region recognised extension services as an information source and, in the more densely populated region of Hanoi, 26% responded similarly (Thu et al., 2012). In Tanzania, the Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) has been continuously involved in the development and dissemination of biogas technologies since 1982 (Laramee and Davis, 2013).

Non-governmental organisations are often involved in the promotion of domestic biogas among their rural beneficiaries. In Bangladesh "[a]bout 90% of biogas users were motivated for adopting the biogas technology by NGOs" (Kabir et al., 2013). Similarly, church organisations have been active in biogas promotion in Tanzania (Mwakaje, 2008) and Uganda (Walekhwa et al., 2009) since the mid-1980s. The pilot project analysed by Garfi et al. in the Peruvian Andes was the combined work of three NGOs active in the region (Garfí et al., 2012).

Farmers' associations can play a central role in the promotion of domestic biogas. Bhat et al. state that the promotional activities and additional credit options provided by "growers' societies" were key factors in creating demand and effective supply structures in Sirsi, Karnataka state in southern India (Bhat et al., 2001). In Bolivia, farmers' associations were key in the implementation of the biogas programme analysed by Martí-Herrero et al. These

[7] As well as private contractors, the participation of other types of agencies in the implementation of the NBMMP is foreseen, such as cooperatives, community action groups, NGOs, financial institutions, etc. However, Raha et al. found "very few examples of these agencies playing an active role in the villages (…) visited in Assam"(Raha et al., 2014)

associations operated as executive organisations that "received governmental funds and implemented the project on their own" and/or cooperated directly with the programme implementing agency (the German society for international cooperation, GIZ)(Martí-Herrero et al., 2014).

In countries with established national programmes and financial subsidies, private companies are involved in the diffusion of domestic biogas. Currently, incentivising the participation of the private sector is a common objective of those programmes. In China, once approval and resource allocation from the government agencies is secured, village projects "should be implemented by a qualified construction company" (He et al., 2013). As previously described, the biogas programmes in India and Bangladesh promote the participation of private contractors for the implementation of specific projects. The 'development of a private biogas sector' is an explicit aim of the programmes in Cambodia and Rwanda (Buysman and Mol, 2013; Landi et al., 2013).

Information and skills

Information about the benefits of the technology is undoubtedly central for raising the awareness and motivation levels of potential users. The range of motivational issues is broad. The provision of adequate responses to pressing environmental concerns at local level can be important, as illustrated by farmers in Vietnam who cited the ability of biogas technology to tackle problems caused by inappropriate manure management as one motivation to adopt the technology (Thu et al., 2012). Similarly, the study from Bangladesh reports that, "about 62% of the respondents mentioned to be motivated toward biogas adoption for its forestation advantages" (Kabir et al., 2013). Expectations linked to improvements in household livelihoods are also important divers. Laramee and Davis found that 40% of their respondents acknowledged the increased scarcity of fuel wood as a motivation for investing in domestic biogas in Tanzania (Laramee and Davis, 2013). Based on their observations in China, Van Groenendaal and Gehua claim "that the households regard the renovations and the improved indoor living conditions as the major benefits, and not the financial benefits" (van Groenendaal and Gehua, 2010). Anticipated economic gain can also play a role. In their sample of biogas users in four different provinces of China, Qu et al. found that the expected "economic gains can stimulate the building of biogas digesters" (Qu et al., 2013). In this case, economic gains were linked to both reductions in energy costs and the awarding of government subsidies. Similar results were reported by Kabir et al. in their study of four districts in Bangladesh. Here too, the availability of financial support mechanisms (i.e. subsidies and credits) were important motivational factors (Kabir et al., 2013).

In addition to the need to increase user motivation, some studies provide clear indications of the need to build users' knowledge and skills in the operation and maintenance requirements of the technology. Lack of knowledge about the periodical operation and maintenance tasks often causes failure. For instance, from a sample of 94 digesters in Nepal, Cheng et al. identify lack of knowledge about the technology and maintenance as the main cause of low biogas production, failures in the pipeline systems and - more prominently - unsuitable management of effluents (Cheng et al., 2014). Similarly, Huanyun et al. found that over 60% of the digesters from their sample of 797 in Yunnan province in China were dysfunctional and point to "poor management" by adopters as "the biggest reason" leading to that outcome (Huanyun et al., 2013). When describing the national biogas programme in Cambodia, Buysman and Mol highlight the "pre and post construction training of users on operating and maintaining the digester" as one of the strategies aiming "to maximise user benefits of and satisfaction with the technology" (Buysman and Mol, 2013). The link to promotional activities, in the sense of building technological knowledge and skills and the integration of other subsystems (as previously discussed), is worth mentioning here. An example is the role of cognitive and practical factors in the proper integration of biogas technology into the crop production and animal husbandry subsystems. In this regard, Martí-Herrero et al. also point to the need to consider the workload linked to the adoption of the technology as an integral part of the promotional activities and recommend

"giving equal emphasis to benefits, weakness and the workload involved in operation and maintenance" (Martí-Herrero et al., 2014).

Activities and channels

Promotional activities can be divided roughly into two groups. On the one hand, mass promotional campaigns aimed at reaching wide audiences using TV, radio and other forms of electronic and printed media are explicitly reported in Bangladesh (Kabir et al., 2013), Cambodia (Buysman and Mol, 2013), China (Qu et al., 2013), Kenya (Mwirigi et al., 2009), Rwanda (Landi et al., 2013) and Vietnam (Thu et al., 2012). On the other hand, more targeted activities such as workshops at village and provincial level, visits to demonstration sites or seminars with locally-active NGOs and associations are reported (Buysman and Mol, 2013; Landi et al., 2013; Martí-Herrero et al., 2014). As well as these promotional activities driven by organisations coordinating biogas initiatives, some studies highlight the role of informal channels for disseminating information and increasing motivation. For instance, Thu et al. found that most of their respondents learned about biogas from neighbours rather than from media such as television or newspapers (Thu et al., 2012). Kabir et al. also reported that "48% of the respondents were inspired from neighbors' advice to take the decision to adopt biogas plant" (Kabir et al., 2013) and Landi et al. state that the "overall strategy [of Rwanda's national biogas programme], while utilizing TV, radio, and other forms of media, relied heavily on word-of-mouth promotion" (Landi et al., 2013). Moreover, Buysman and Mol cite an attempt to institutionalise this type of promotional activity by implementing projects with "peer to peer user networks" as a mean of promoting and marketing biodigesters in Cambodia (Buysman and Mol, 2013).

Finance

From a simple economic perspective the introduction of a biogas plant is an investment in new capital, which is expected to improve a household's general economic performance and yield a financial return in the form of increased income or savings. A common observation in all the reviewed studies is that the initial *investment cost* of domestic biogas plants exceeds the *investment capacity* of most potential users. Within the finance subsystem, we collated the issues that influence the ability of potential users to make the required financial investment. In addition to the investment cost itself, three additional factors appear to influence whether or not a potential user will invest in a biogas plant. These factors are the availability of *subsidies*, access to *credit sources* and the *actors* providing financial assistance.

Investment costs

Figures relating to initial investment costs are presented in Table 5. The reported costs vary between USD 200 in Vietnam to USD 1155 in Rwanda. Caution should be exercised when making comparisons based on these values. Firstly, most of the studies do not describe what costs are included in the estimation when a household decides to invest in a biogas plant. While it can be assumed that material costs are always considered, only two studies explicitly mention that labour costs for installation are actually included (Laramee and Davis, 2013; San et al., 2012). Moreover, costs relating to programme management are probably excluded in all the estimations. The lowest costs are found in Vietnam, Bangladesh and Bolivia. However, these case studies also indicate that initial investment costs are a main barrier for adoption and that "the most common reason associated with not installing biogas plants is lack of money". (Thu et al., 2012)

Table 5 Selection of investment costs and subsidy levels reported by the studies reviewed.

Country	Short citation	Reference year (a)	Investment cost [USD]	Subsidy [USD]	Subsidy-cost ratio	Plant size [m^3]
Vietnam	Thu et al., 2012	2012	200	60	0.30	6-8
Bolivia	Martí-Herrero et al., 2014	2014	220	55	0.25	11.3
Bangladesh (b)	Kabir et al., 2013	2013	385	115	0.30	1.4 - 8
China (c)	He et al., 2013	2013	456	249	0.55	8
Cambodia	San et al., 2012	2012	500	150	0.30	6
India (d)	Raha et al., 2014	2009	722	206	0.29	4
Tanzania	Laramee and Davis, 2013	2011	750	200	0.27	6
Rwanda	Landi et al., 2013	2013	1155	300	0.26	6

(a) Reference year is the year of publication of the corresponding study, except in the case of India and Tanzania where the studies explicitly mention other reference years. (b) Figures for investment cost and subsidy originally given in BDT (30,000 and 9000 respectively); exchange rate 1 USD = 78 BDT is used. (c) Figures for investment cost and subsidy originally given in Yuan (2800 and 1530 respectively); exchange rate 1 USD = 6.14 Yuans is used. (d) Figures for investment cost and subsidy originally given in Rupies (35,025 and 10,000 respectively); exchange rate 1 USD = 48.5 Rs. is used.

Subsidies

All the programmes and initiatives in the studies provided subsidies to cover part of the investment costs. The preferred scheme is that of a 'flat rate', i.e. the provision of a fixed subsidy regardless of the size (and therefore the actual cost) of the selected biodigester. However, different levels of financial assistance in different geographic regions can be applied. For instance, the Chinese and Indian programs differentiate between five geograghical regions (Gosens et al., 2013; MNRE, 2015). Interestingly, the majority of the subsidy schemes presented in Table 5 tend to cover 30% of the investment costs for biodigesters of 6m^3. The case in China is noteworthy as the subsidy rate is significantly higher (more than 50%) in comparison to the other national programmes considered.

The only exception to the 'flat rate' scheme is reported in India, where the national biogas programme stipulates different subsidy levels depending (also) on the size of the biodigester. The most recent version of the programme includes only two size ranges for domestic biodigesters (1-2m^3 and 2-4m^3 (Raha et al., 2014)), although the former version (as noted by Bath et al.) included a wider range of digester sizes. Bath et al. claim that this type of graded scheme may incentivise the installation of oversized biogas plants, as the cost to be covered by the household (after deducting the subsidy) does not vary much between some size ranges. This theory seems to have been borne out in Sirsi, Karnataka state, where "the biogas plants actually built are larger by an extra capacity of nearly 4 m^3 than the required size". (Bhat et al., 2001)

Sources of credit

Another frequent claim in the studies is that potential users find it difficult to meet the remaining investment cost, even after subtracting the available subsidies. Consequently, in addition to subsidies, rural households often require loans to cover the initial investment. Most of the national biogas programmes considered include specific credit mechanisms to meet this need. In general terms, financial resources for biogas credit lines are part of a programme's budget, although the individual loans are ultimately provided by specified third party organisations. For instance, in Nepal, "167 micro finance institutes are engaged in biogas and mobilizing loans from AEPC's Biogas Credit Fund" (Katuwal and Bohara, 2009); in Cambodia, farmers "[t]he biodigester credit scheme, financed by FMO (a Dutch development bank) [is]

implemented by two local banks, AMRET and Prasac" (Buysman and Mol, 2013); and in Rwanda the national programme "partnered with the Banque Populaire du Rwanda (BPR) to establish a microfinancing scheme" (Landi et al., 2013).

China seems to be an exception. In the six studies in China, there is no mention of loan schemes for domestic biogas investment. There may be two reasons for this. Firstly, rural households participating in the biogas programme seem to have the ability to cover the remaining costs (around half the total investment). As observed by He et al. in their sample, "no household built its bio-digester through a loan from a bank" (He et al., 2013). Secondly, commercial loans in rural China are somewhat limited, which may be excluding the poorest households from the programme (Qu et al., 2013).

Financing actors

In a similar way to the promotion subsystem, the interplay between different organisations is central to ensuring the financial capacity of potential domestic biogas users. These organisations can be divided into six classes: state entities, international development agencies, local banks and microfinance institutions, locally-active non-governmental organisations, farmers' associations and private companies. The allocation of the overall financial resources for subsidies and credit is often assumed by central state entities, as in the case of the biogas programmes in India and China, or by a partnership between state entities (e.g. ministries) and international development agencies, as in the numerous biogas programmes where the involvement of SNV is reported (Bangladesh, Cambodia, Nepal, Rwanda and Vietnam). The actual delivery of financial support to single households is undertaken by organisations local to the rural population, such as local banks and NGOs. Consequently, the implementation of financial mechanisms (subsidies and credit) relies on institutional arrangements to funnel financial resources from central coordination agencies to more localised organisations. This may comprise several stages, in a similar way to the organisation of promotional and educational tasks as described before. Moreover, in some cases financial support comes from other entities beyond the centrally-coordinated national programmes. Farmers' associations can also play a role in ensuring the financial capacity of users. The presence of "growers' societies" actively involved in financing and promoting the technology was a positive factor that "led to creating sustained demand and meeting such demand effectively" in Karnataka state in India (Bhat et al., 2001). Likewise in Bolivia, the "regional or local farmers' association asks for a commercial credit, and re-issues it in small amounts to associated farmers at commercial rates" (Martí-Herrero et al., 2014).

Technology supply

The adoption of domestic biogas necessitates the installation of all the physical components that make up the system (e.g. the biodigester, pipes and biogas stove). Under the label 'technology supply' we include empirical observations about how to ensure that all the required material components and skills are available to provide the technology to interested households. Factors influencing the effective supply of the technology can be divided into four categories: *training of suppliers*, *quality control*, *after-sales service* and the *actors* involved.

Training suppliers

Qualification programmes aimed at building technical skills for the construction and maintenance of domestic biogas plants are in place in most of the countries covered by the reviewed studies. Often those programmes are also linked to the certification of technicians. For instance, Chen et al. report that "more than 292,400 technical workers have access to the national vocational qualification certificate that qualifies them as 'biogas production workers'" in China (Chen et al., 2012), and Landi et al. note that "303 masons and 121 supervisors have received certification in biogas digester design and construction" under the national biogas

programme framework in Rwanda (Landi et al., 2013). Different observations provide evidence of the importance of training suppliers. For instance, in their detailed study of failures of domestic biogas plants in Nepal, Cheng et al. identify "low-quality workmanship" as one main cause of several of the failures (Cheng et al., 2014). Landi et al. point to "the training and development of a workforce equipped with the necessary skills to construct biogas plants" as one of the main challenges faced by the biogas programme in Rwanda (Landi et al., 2013). Probably the clearest explanation is given by Buysman and Mol, who assert that "training and certifying masons" is one of the measures applied by the Cambodian biogas programme in order to "build trust in biogas technology among potential clients" (Buysman and Mol, 2013).

Quality control

Strategies for ensuring the quality of the plants rely on three main components.

i) Setting technical standards, which are also related to the allocation of subsidies, as illustrated by the Bangladeshi programme where the assignation of the investment subsidy to the biogas user is dependent on the fulfilment of "the specifications and standards set by IDCOL/SNV/KfW", the organisations involved in the financial coordination of the programme (Kabir et al., 2013).
ii) Establishment of a supervision mechanism, which includes the physical inspection of installed plants by third parties (i.e. unrelated to the supplier and the user). This could even include "frequent random inspections of biogas plants under construction", as in the Cambodian case (Buysman and Mol, 2013).
iii) Establishment of a certification system for technicians. This component is directly related to the training of suppliers, as described above.

After-sales service

The provision of post-installation technical support to users seems to be crucial to ensure the sustained use of the technology. Some national programmes include compulsory guarantees and technical support from the suppliers. For instance, in Cambodia, "a compulsory 2-year guarantee" is in place (Buysman and Mol, 2013) and Martí-Herrero et al. recommend that technicians monitor installed digesters "until the user understands the system and its maintenance (usually 6 months)", based on the experience of the Bolivian case (Martí-Herrero et al., 2014). While setting provisions for guarantees could be a step towards ensuring sustained use, Raha et al. provide an illustration showing that the enforcement of the provisions might not take place. They found that, "although it was evident that the units had four-year guarantees, neither the village contact, nor the private contractor had visited the household post-installation to assess or monitor the plant." (Raha et al., 2014)

Actors involved

Different terms are used to refer to those who ultimately provide the products and services to households interested in installing or already using domestic biogas plants: 'technicians' (Huanyun et al., 2013; Martí-Herrero et al., 2014), 'builders' (Bhat et al., 2001), 'skilled masons' (Kabir et al., 2013; Landi et al., 2013) and biogas 'companies' (Buysman and Mol, 2013; He et al., 2013; Landi et al., 2013). The roles of suppliers are diverse; they may look for and assess potential households, construct and install digesters and provide after-sales service and guarantees. A common expectation evident in most of the studies is that the supply and installation is undertaken by private actors who offer their products and services on a regulated market, in order to ensure the quality of the equipment and the enforcement of guarantees.

The central task of a national biogas programme is, therefore, the establishment of training and certification systems in order to create (or induce the formation) of a private sector with capacities and skills in domestic biogas technology. This also implies regulatory functions (e.g. setting standards and establishing supervision and certification mechanisms) which are

assumed by the central coordination agencies, for instance IDCOL in Bangladesh, the MNRE in India and the national biogas programme offices in Cambodia and Rwanda. Putting the regulations into operation can require complex structures to transmit responsibilities from central governmental agencies to local offices. In China, this process starts in a division of the Ministry of Agriculture and ends up at local Rural Energy Offices (Chen et al., 2012). Of particular interest is the monitoring included in the Indian programme, which entails physical inspections from three different entities at state level, each of them reporting to the MNRE "separately for triangulation of information from the field" (Raha et al., 2014). In less populated countries, such as Rwanda and Bolivia, partnerships with existing capacities (i.e. technical colleges and universities) have been sought for the quality control operation (Landi et al., 2013; Martí-Herrero et al., 2014).

Similar patterns can be seen for the qualification of technicians. In China, this role also comes under the institutional structures of the Ministry of Agriculture (Chen et al., 2012). In India, "training and education is delivered by the Biogas Development and Training Centres". (Raha et al., 2014) Ten such centres were in place by 2011 (IBP, 2009). In Rwanda, once again a partnership was sought which involved integrating biogas qualifications into the curriculums of existing educational institutions (Landi et al., 2013).

6.2.5 Discussion

The results of our analysis illustrate the variety of ways in which domestic biogas interacts with and can potentially reshape the user's livelihood subsystems. The proposed system perspective implies that a household's ability to draw benefits from domestic biogas technology depends on the extent to which the technology is integrated into the functionality of those subsystems. This perspective highlights the many impacts that the introduction of domestic biogas technology can make. The provision of energy for cooking is by no means the only function met by the technology. Our review points to important benefits that can be achieved in a user's crop production and animal husbandry practices, as well as sanitation aspects. Moreover, a household might not perceive the impacts of biogas installation on its energy situation as the most important. The fertilising and plant protection effects of effluents might address more pressing needs of rural households, as illustrated by the study in Bolivia (Martí-Herrero et al., 2014). The effective reduction of environmental burdens derived from animal husbandry might be a stronger motivation for users, as in the case in Vietnam (Thu et al., 2012). The installation of a biogas plant might be linked to broader improvements to a user's house (kitchen, toilet) and farm (pigpen, orchard) and appreciated for these reasons, as observed in China (van Groenendaal and Gehua, 2010). Additionally, from a techno-economic perspective the reviewed literature highlights the fact that the financial effects deriving from fuel substitution (the main outcome related to energy issues) are negligible if most of the energy for cooking was previously generated by non-commercial fuels, as is often the case for households targeted by domestic biogas programmes.

Acknowledging the multi-functionality of domestic biogas

Our findings suggest that the common perception of biogas as an intervention to address domestic energy needs (specifically energy for cooking) should be, at the very least, reconsidered. In examining the selected literature, it is interesting to note that only one study was published in a journal without the word 'energy' in its name, i.e. the study by Thu et al., which focuses on the impact of domestic biogas on manure management practices of farmers in Vietnam (Thu et al., 2012). This might point to a particular bias from our end. Indeed, understanding domestic biogas plants in terms of energy intervention is an underlying initial assumption of the present study. This bias towards energy does, however, seem to be a generalised perception. First, the term 'energy' was not used as a search criterion at any stage of the literature selection. Second, the two most central criteria for the selection process were: i) the geographical scope of the studies (case studies in developing countries) and ii) the object of

the research (analyses of real experiences in the promotion and dissemination of the technology).

The emerging issue is that accelerating the diffusion of domestic biogas has been firmly linked to global discussions/discourses on energy poverty and visions of universal access to 'modern', 'clean' or 'sustainable' energy. In the standard literature on energy access, biogas is regarded as a type of 'modern' energy (IEA, 2011; *Progress Toward Sustainable Energy - Global Tracking Framework 2015 - Summary Report*, 2015). It is considered in the same set of options for modern cooking energy as LPG and electricity. While the potential benefits of effluents are recognised by all the national biogas programmes in the reviewed studies, information on the actual application of the effluent by biogas users is lacking in the majority of the studies. In some cases the effluents are not being used at all and some of the studies highlighted a lack of knowledge about their potential use for the particular crops and practices of the targeted households. The issue of sanitation is even more marginal. Moreover, information on technical options or strategies for the integration of the technology into households' farms is scarce. The only noteworthy exceptions are the standardised packages popular in China, such as the so-called 'three-in-one' model which explicitly addresses the linkages of the technology to other subsystems beyond cooking.

Linking domestic biogas technology to the broader aim of recognising the role of family farms and strengthening their capacities would probably better fit the multi-functional nature of the technology. The essential characteristic of family farms is their reliance on family labour in managing the farm operation. The concept unifies the 'domestic' practices (at home, non-productive, non-tradable) and the 'farming' activities (on the farm, productive, tradable). "The family and the farm are linked, coevolve and combine economic, environmental, reproductive, social and cultural functions". (Garner and de la O Campos, 2014) Framing domestic biogas as an option for reshaping family farms recognises the multiple ways in which the technology can influence a household's livelihood. Cooking meals is still one domain that might experience changes due to the adoption of the technology. However, it should not necessarily represent the central aim of programmes promoting the diffusion of domestic biogas, nor be considered as the strongest motivation for users to adopt the technology.

Some precautionary reflections should be added to this call for broadening the understanding of domestic biogas technologies. Recognising the multiplicity of benefits that can derive from the introduction of domestic biogas in family farms does not imply that the technology will provide a 'silver bullet solution' to the multiple challenges they face, nor that any single intervention can address all aspects of a household's livelihood. More accurately, the broader understanding of the technology suggests the need for programme designs that are more sensitive to the conditions and expectations of those family farmers targeted. In addition, the potential of domestic biogas might, in some cases, be better realised if its diffusion is considered as a tool instead of the central goal of a programme, as observed by Martí-Herrero et al. when reflecting on their experiences coordinating domestic biogas dissemination in Bolivia: "[Domestic biogas] transforms into a tool that can be integrated into many different projects such as waste and watershed management, ecology, energy, organic food sovereignty, health, climate change mitigation and adaptation, etc."(Martí-Herrero et al., 2014)

The socio-technical structuration of domestic biogas

Organising the evidence according to the system perspective allows for a more in-depth explanation of the socio-technical structuration of the adoption and diffusion processes of domestic biogas. Adoption can be understood as the process in which adjustments or changes are undertaken, validated and – in the best case scenarios – routinised by the user to achieve the integration of the technology into the family farm. Diffusion comprises similar stages (i.e. change, validation and routinisation), but includes a number of agents in the process, i.e. other households and organisations. Both processes (adoption and diffusion) are closely related and it

is difficult to consider one without the other, but there is an important distinction. This distinction points to *agency* and *power*, i.e. to the capability to 'act otherwise' and to mobilise resources in order to cope with the transformational challenge of integrating the new technology into the individual family farm (adoption) and into the population of family farmers in a geographical or administrative area (diffusion).

The introduction of a biogas plant into a household challenges the daily routine of the family farm operation. Once the biogas plant is installed, rules that were previously applied in a range of contexts, providing meaningful procedures for specific situations, could result in unsatisfactory outcomes. Material, normative and cognitive elements involved in routine actions or procedures could become incompatible with the actions/procedures required for domestic biogas operation. This transformative challenge at household level can be illustrated by considering the animal husbandry domain. Previous animal husbandry practices and corresponding manure management could hinder the proper feeding of the digester. These previous practices were made possible by material components (e.g. number of animals, configuration of stables and availability of water) and normative elements (e.g. rules for the allocation of labour within the household, value ascribed to manure and regulations on manure management). In order to reap the benefit from the biogas plant, the user has to adjust the animal husbandry practices accordingly. This might involve, for instance, the construction of new animal stalls or the modification of existing ones, as well as changes in the daily routine and labour allocation for husbandry practices and manure management. The grade of difficulty of the necessary transformative tasks depends on (i) how compatible the structures that framed the previous practices are with the new configuration required for the domestic biogas plant and (ii) the ability of the user to access resources needed for the transformation; for instance financial capital (e.g. for modifying stables), knowledge (e.g. about adequate water use and cleaning practices) and technical skills (e.g. for design and installation of auxiliary devices adapted to the specific farm configuration to facilitate the feeding of the biodigester). This transformative capacity of the individual household highlights the linkages between individual adoption and wider diffusion of the technology.

The transformative capacity of domestic biogas users is likely to be low, given the novelty of the technology, the users' lack of finance and the general marginalisation of family farmers (Garner and de la O Campos, 2014). Crucial resources for achieving the integration of the new technology at household level are beyond the control of individual users. Facilitating access to those resources is the central task of programmes aimed at disseminating domestic biogas. This role involves the deployment of power in the sense proposed by Giddens in his description of structuration theory. He distinguishes two sorts of resources in the structuration of power: "authoritative resources, which derive from the co-ordination of the activity of human agents, and allocative resources, which stem from control of material products or of aspects of the material world."(Giddens, 1984) Sections 4.5 to 4.7 illustrate how allocative and authoritative resources are deployed by national biogas programmes in an attempt to complement individual farmers' lack of resources. Different institutional configurations have been established in order to increase the transformative capacity of households and ultimately empower family farmers. Common features of these programmes are a predominantly 'top-down' flow of resources, as well as a hierarchical organisational structure stemming from a central coordinating agency (commonly a state organisation) towards organisations whose range of action are closer to the local farmers. Programme funding is provided from national budgets as well as from international development agencies or banks. Standards and procedures are established in order to organise the further allocation of funds. At this stage not only are subsidy schemes defined, but other relevant nationwide issues such as promotional strategies, training programmes, quality standards and monitoring procedures are established.

The scope of national biogas programmes covers – as the name suggests – rural populations in different geographical and administrative regions. The aggregated volume of resources requiring allocation and the coordination effort needed to ensure their effective distribution and

application would be difficult to organise in a 'bottom-up' or 'horizontal' structure. However, the reviewed literature offers interesting indications about the contribution that more decentralised or localised capacities and 'horizontal' flows could bring to the diffusion process, even when it is framed within a large national geographical scope. Locally-active NGOs have been working on domestic biogas application and accumulating context-specific knowledge for decades, as shown in the studies in Bangladesh, Tanzania and Uganda (Kabir et al., 2013; Mwakaje, 2008; Walekhwa et al., 2009). Local farmers' associations can be involved in the diffusion of the technology by providing information and financial resources to users, as illustrated by the studies in India and Bolivia (Bhat et al., 2001; Martí-Herrero et al., 2014). The flow of information between farmers has been identified as a significant factor for motivating new users, as reported in studies in Bangladesh, Cambodia, Rwanda and Vietnam (Buysman and Mol, 2013; Kabir et al., 2013; Landi et al., 2013; Thu et al., 2012). It is becoming clear that significant transformative capacities can be found at more localised levels. While these local organisations are unlikely to be able to drive national diffusion processes, their resources (knowledge, coordination abilities, communication channels with the local population, financial instruments etc.) could be suitable for adaptation to the local context and circumstances of the family farmers with whom they commonly interact. Ensuring the integration of existing local capacities into national biogas programmes could increase the sustainable adoption of domestic biogas technology by family farms and increase the range of benefits gained.

6.2.6 Conclusions

The present study systematically organised available evidence of the factors that influence the adoption and diffusion of domestic biogas in developing and emerging countries. To achieve this aim, adoption and diffusion were conceptualised as the processes by which the dynamic systems that frame the livelihoods of potential users adjust once the new technology is introduced. Organised in this fashion, the evidence reported by scientific studies indicates that:

i) the adoption of domestic biogas creates a particular challenge for the functionality of three subsystems configuring households' farms: cooking, animal husbandry and crop production;
ii) the adoption and diffusion processes are both determined by the ability of users to access resources beyond their own households, in particular knowledge (about the technology and its potential benefits), financial capital (for the required investments) and skilled suppliers (providing the corresponding products and services); and
iii) the successful diffusion of domestic biogas in a given social system (i.e. achieving a situation where the greatest number of potential adopters are using the technology in a sustained way) is determined by the compatibility between the functionality of the new technology and the mentioned subsystems.

The factors that regulate the interactions between domestic biogas and the outlined subsystems are summarised and schematically displayed in Figure 6. The analysis suggests that in practice domestic biogas technology is mainly considered as a tool for addressing domestic energy needs, in particular energy for cooking. However, our results also underline the multi-functionality of domestic biogas. We therefore recommend linking domestic biogas technology to broader attempts to recognise and strengthen family farms. We argue that in this way the potential benefits deriving from the technology's multi-functionality will be better appreciated by family farmers and the benefits will, consequently, meet their actual needs.

In addition, our analysis advances the understanding of the socio-technical structuration of the adoption and diffusion of domestic biogas technologies. In this regard the analysis emphasises that crucial resources (e.g. knowledge, finance and skills) for achieving the broad diffusion and sustained use of domestic biogas are beyond the control of individual households. The results show that the common response to this fact is the establishment of programmes organised in a 'top-down' structure. However, we also found evidence of the availability of resources and

significant capacities at more localised levels, such as locally-active NGOs, experienced practitioners and farmers' associations. Their resources and capacities could be particularly suitable for adaptation to the local context and circumstances of the family farmers they serve. Ensuring the integration of these local capacities into national programmes could improve the outlook for the successful and sustainable diffusion of domestic biogas.

7 Diffusion of decentralized energy solutions for rural communities

7.1 Charting article 2 in the research

In this study, different types of decentralised renewable technologies are considered, which offer promising alternatives for meeting the energy-related needs of rural populations that lack appropriate access to energy services. The attention is on solutions that deploy such technologies through community-based projects. The particular focus of the analysis is on the practical strategies that implementing organisations apply in order to induce socioeconomic changes at a local level, in a way that ensures the proper and continuous provision of the energy services, i.e. the sustainable operation and maintenance of the applied energy solutions. To that end, an analytical framework is built that combines the conceptual insights from two streams of existing research: transition management (Loorbach, 2007; Rotmans et al., 2001), and participative approaches to development (Bond and Hulme, 1999; Hickey and Mohan, 2004). A sample of four community-based energy projects is used as empirical case studies. Project documentation and interviews with staff of the implementing organisations are reviewed and analysed. In the framework of my doctoral research, this article demonstrates how bottom-up initiatives help to create and maintain spaces for experimentation, in which new socioeconomic configurations are negotiated, introduced, evaluated, and adjusted in cooperation with local and external actors.

7.2 Article 2

The present section comprises the full accepted version of the manuscript with the title "Introducing Modern Energy Services into Developing Countries: The Role of Local Community Socio-Economic Structures", as accepted and published by the journal Sustainability and which has the digital identification number: doi:10.3390/su4030341.

Introducing Modern Energy Services into Developing Countries: The Role of Local Community Socio-Economic Structures

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Abstract

Sustainable energy technologies are widely sought-after as essential elements in facing global challenges such as energy security, global warming and poverty reduction. However, in spite of their promising advantages, sustainable energy technologies make only a marginal contribution to meeting energy related needs in both industrialised and developing countries, in comparison to the widespread use of unsustainable technologies. One of the most significant constraints to their adoption and broad diffusion is the socio-economic context in which sustainable energy technologies are supposed to operate. The same holds true for community-based energy projects in developing countries supported by the WISIONS initiative. Practical strategies dealing with these socio-economic challenges are crucial elements for project design and, particularly, for the implementation of project activities. In this paper experiences from implementing community-based projects are reviewed in order to identify the practical elements that are relevant to overcome socio-economic challenges. In order to systematise the findings, an analytical framework is proposed, which combines analytical tools from the socio-technical transition framework and insights from participative approaches to development.

Keywords: sustainable energy technologies; community-based projects; socio-technical transitions; WISIONS initiative

7.2.1 Introduction

The provision of modern energy services using renewable energy technologies offers multiple development opportunities to off-grid communities in emerging economies and developing countries. Several technical alternatives using renewable energy sources exist, which have proven to be adequate for responding to diverse sustainability challenges. Therefore, the promotion of these technologies is being widely sought as an essential part of the strategy aiming to alleviate poverty in developing countries (UNCTD, 2010; Practical Action, 2010; AGECC, 2010). However, although the deployment of renewable energy technologies has significantly increased in recent years, in terms of meeting the energy needs of individuals, communities and nations, the share of renewables remains rather low in comparison to conventional and fossil fuel based technologies. As a result, more ambition and decisive efforts are necessary to truly unlock their potential contribution to more sustainable development paths (Edenhofer et al., 2011).

The transition to sustainable energy provision requires significant efforts in developing, testing and further improving technical innovations as well as in identifying and applying effective implementation strategies for those new technologies. It is not only technological issues that pose the greatest challenge; social and economical barriers are often even more difficult to overcome. There is no one-size-fits-all solution for the successful implementation of climate friendly technologies, but each initiative, project or programme gives rise to new findings and know-how that can help accelerate the transition process. The present study aims to build a framework for guiding the analysis and evaluation of the implementation strategies of community-based projects. The study is part of the on-going process of organising the findings of the WISIONS initiative. WISIONS was launched in 2004 and is supported by the Swiss-based foundation ProEvolution (WISIONS, 2019). The aim of WISIONS is to improve the South-South and North-South knowledge transfer on good-practice implementation models for sustainable

energy supply. The initiative provides financial support for the implementation of innovative energy projects and models via its scheme SEPS, Sustainable Energy Project Support. Over the last six years more than 50 projects have been selected for support—based on a framework of well-chosen sustainability criteria. In particular, community-based solutions have been supported, where residents are the beneficiaries as well as the agents of change.

Based on the experiences and findings from the WISIONS initiative, which is run by the Wuppertal Institute, this study starts with an overview of the relevance of socio-economic issues from both practical experiences and an analytical perspective in the process of innovation development adoption and diffusion. Subsequently, the explorative approach applied to review the design, and particularly the implementation, of community-based projects is described. The selected case studies from the WISIONS initiative are introduced in the fourth section. Results are organised and discussed in the fifth section. Based on the reviewed analytical perspectives, an analytical framework is outlined where the empirical observations are regarded as strategic elements for inducing socio-economic transformation during project implementation.

7.2.2 Towards a Framework for Understanding Community-Based Energy Projects

Lessons Learned—Experiences from Project Implementation

In the development of community-based energy projects local residents are not only the expected beneficiaries but also (and importantly) the agents of change.
Likewise, the socio-economic realities of the communities need to be considered as both "object" and "subject" in the design and implementation of project activities: (a) on the one hand, the underlying project goal is to improve the opportunities for social and economic development within a community; (b) on the other hand, achieving this goal requires the emergence of new social and economic structures, or the adaption of existing ones, which are able to overcome case-specific socio- economic obstacles.

(a) Socio-economic realities as "object": The implementation of sustainable energy solutions can contribute to improving the ability of individuals and communities to protect their livelihood and to unlock additional development options. The potential social and economic impacts are manifold and depend on the kind of energy needs that are addressed. Better conditions for education (e.g., lighting and access to modern communication and information systems), improved health conditions (e.g., running of cooling devices for storing vaccines and powering of medical equipment), and opening new or improving business opportunities (e.g., by providing the option to mechanise tasks) are some potential impacts that can derive from the reliable provision of electricity (Dienst et al., 2010). Innovations that improve the energy supply used for cooking may improve health conditions (by reducing indoor air pollution), free up time and/or reduce the cost associated with the provision of energy for cooking, or even contribute to improved sanitation (as in the case of some biogas options) (Dienst et al., 2011).

(b) Socio-economic structures as "subject": Conditions that may hinder achieving the expected improvements are also diverse, as are the challenges of finding appropriate structures to drive the necessary changes. In the case of electrification initiatives, some notable aspects are: the need for broad consensus among different actors (e.g., users, future providers of operation and maintenance, administrative/governmental entities, suppliers of technology, donors, etc.) to ensure long-term success. Alternative finance mechanisms (probably involving a variety of actors) may be necessary to overcome the obstacle of financing the capital costs, which in most cases exceed the investment capacity of communities that do not have access to electricity. Adequate technical and managerial skills, as well as clear and widely accepted contracting practices and rules, are crucial in ensuring the proper and sustained operation, maintenance and management of power generation and distribution systems. In the case of technical

interventions to improve cooking practices, some notable issues are: adopting new cooking technologies involving changes for users in their daily practices, of which the latter are most likely based on traditional methods and customs. Existing supply structures for appliances and fuels have evolved together with traditional cooking practices; diffusion of improved technologies will therefore require the adaption of those existing structures or the establishment of new structures. The exchange of products and services related to traditional cooking technologies does not always take place as a commercial transaction. The lowest income population, in particular, may depend on non-commercial structures for the provision of appliances or even fuel for cooking.

Two Analytical Perspectives of Socio-Economic Structures and Adoption of Innovations

Socio-technical transitions approach: The difficulty in overcoming the inertia to making the change from conventional energy systems is a substantial element of the political and academic agenda in industrialised nations. Important analytical efforts to understand the underlying mechanisms and forces that hinder the more rapid diffusion of sustainable energy technologies have (re)focused attention on the social construction of technology. From this perspective, socio-technical regimes can be understood as "relatively stable configurations of institutions, techniques and artefacts, as well as rules, practices and networks that determine the "normal" development and use of technologies" (Rip and Kemp, 1998). Regime shifts comprise multiple adaptations of skills and infrastructure at company level, but wider changes in terms of institutional issues (e.g., values, regulations, norms, etc.) that go beyond company structures are also needed (Kemp, 1994; Schot et al., 1994). The dynamics that can result in the transformation of the technological regime are better described in a "multi-level" perspective, as proposed by Geels (Geels, 2002). In this context the regime may experience pressure to adapt from broader changes of economic, ecological or cultural trends (landscape level), from internal misalignment amongst regime actors (regime level) or from the growing relevance of new technological solutions that have been supported by a (generally small) network of actors outside the regime (niche level) (Smith et al., 2005). Socio-technical niches play a crucial role in the development of innovations and, eventually, in influencing regime shifts. They are protected spaces for "societal experiments", networks of actors sharing expectations of new concepts for dealing with (also shared conceptions of) persistent problems (Raven, 2005; Smith, 2006).

The dynamics that lead to the emergence, structuration and growth of socio-technical niches are of special interest when it comes to induce purposive socio-technical transformations. This application oriented strand of research organizes the tasks for socio-technical transition management within a cyclical framework containing four governance activities (Loorbach, 2007; Rotmans et al., 2001; Rotmans and Loorbach, 2010):

(1) Problem structuring and establishment of a transition arena: Activities in order to build both: shared understanding of problems and guiding principles for the envisaged solutions, as well as networks and partnerships that can provide "resources" (e.g., knowledge, legitimacy, capital, etc.) during the process.
(2) Developing visions and pathways: These are tactical activities where specific objectives as well as concrete concepts for technologies, managerial concepts, or even policies are conceived.
(3) Execution of transition-experiments: Based on the developed visions, pathways and concepts, practical measures are carried out (experiments). These operational activities generate new experiences, which will form the basis for further evaluations and adjustments.
(4) Monitoring and evaluating: These reflexive activities involve both monitoring the impacts (i.e., whether expected changes are actually happening) as well as evaluating whether adjustment to the guiding visions and/or principles might be required.

Participative approach to development: The highly significant relevance of socio-economic structures in driving or hindering the adoption and diffusion of innovations has also been recognised by scholars and practitioners dealing with development cooperation projects (Agarwal, 1983; A. Barnett, 1978). As a response to the often disappointing experiences of top-down approaches to development in the early 1980s, interest grew for more participative and learning-based approaches to development (Bond and Hulme, 1999; Korten, 1980; Uphoff et al., 1998). The central idea is that the project beneficiaries are not simply passive recipients of assistance but the key actors in the process of shaping social and economic development in their own local context. In this approach, understanding local realities is regarded as a key component of project design and implementation; this entails considerations such as recognising the "actual" needs of the population involved, the existing capabilities (e.g., organisational, technical, managerial, etc.) and the potential inputs from the local population. In this context, implementation tends to be a rather gradual process, where progress is uncertain and requires a flexible managerial approach and strong capacities for on-going problem-solving.

Community-Based Projects in the Light of Both Analytical Perspectives

Both analytical perspectives, the socio-technical transformation and the participative approach to development, offer valuable insights into the structural challenges faced by projects aiming to introduce innovative energy solutions to the socio-economic reality of communities. From both perspectives the process takes on a rather evolutionary character, where designs, user practices and perspectives as well as local socio-economic structures coevolve, so that innovations become part of people's daily routine. In the context of socio-technical change, community-based energy projects offer experimental spaces where innovation is nurtured, i.e., artefacts as well as institutional structures and practices can be tested and adapted in order to give an appropriate response to the specific energy related needs of individuals and/or the community. Building alliances between actors, articulating expectations, securing "protection" for and learning from experimentation are all key functions to facilitate the process (Romijn et al., 2010).

The participative approach to development offers detailed insights into organisational and managerial practices that facilitate the bottom-up building of local capacities. The implementing organisations become facilitators, which ensures the reshaping of socio-economic structures and the transformation of existing development practices (Hickey and Mohan, 2004). In this way, project activities may lead to the (re)configuration of networks of local and external actors that are able to supply services and goods related to the provision of modern energy services.

Although both analytical frameworks offer valuable insights, they provide little indication about more concrete elements regarding the design and, particularly, implementation of community-based energy projects. Although many socio-economic challenges faced during the implementation of energy projects are common (e.g., social acceptance, motivation and consensus, shaping new supply structures, establishing adequate finance mechanisms, etc.), strategies to deal with these challenges should be adapted to each project's particular circumstances. This know-how is a crucial "asset" of implementing organisations with considerable experience in the field. The following analysis aims to identify the practical components that play a relevant role in dealing with socio-economic challenges during the implementation of community-based projects supported by WISIONS. Subsequently, we will attempt to organise these empirical observations using tools and insights provided by the analytical approaches described.

Applied Methodology

An explorative empirical approach was adopted in order to identify components that contribute to overcoming socio-economic constraints faced by projects aiming to improving energy access in rural communities in developing countries. Therefore, the experiences from community-

based energy projects that were implemented with WISIONS support have been analysed. Standardised documentation, which is part of the communication between the implementing organisations and the WISIONS team, was used as base data.

The first step describes the main objectives and core activities of the different projects, followed by a detailed analysis of activities, measures and strategies taken to meet the socio-economic challenges faced. The relevance of different strategies in the creation of more favourable socio-economic conditions for the adoption and the long-term use of energy technologies is then discussed. As a result of these previous steps a general framework is established which organises project components in terms of their relevance for the implementation of community-based energy projects. The proposed framework is an attempt to combine central elements of the socio-technical transition approach and the participative approach to development with experiences made during technology applications.

7.2.3 Case Studies

In the following chapter four projects, which have been successfully implemented under the WISIONS supporting scheme "SEPS-Sustainable Energy Project Support", are presented as case studies. All four project models have a participative implementation approach. The projects are located on different continents, apply different renewable energy technologies and represent different kinds of (participative) implementation models. Table 6 gives an overview of the four case studies and the strategies adopted to meet the socio-economic challenges. For more detailed information regarding the four case studies please visit the project website (WISIONS, 2019).

Project A: Small Scale Biogas Digesters in Rural India

This project was implemented by the Asian branch of the International Energy Initiative (IEI). The aim was to establish small enterprises in rural areas in Karnataka, India, to provide biogas as clean cooking fuel. This enterprise consists of a dairy for income generation and associated household biogas supply systems, replacing the existing traditional biomass stoves. The biogas requirement per family was estimated on the basis of the present biomass use. To meet the needs of all the village families, eight biogas plants were planned (six of 8 m3 and two of 10m3 capacity). To deliver biogas to every household, a mini-grid piping system was installed between each digester and the group of households it serves. Each kitchen is provided with a double-burner stainless steel stove. Based on suggestions from the users regarding their cooking timings, gas is provided for three hours every morning and one and a half hours every evening.

Integration of participative strategies and socio-economic aspects: The project site was selected based on interaction with local organisations and a survey of ten villages in a neighbouring district. The focus was on economically disadvantaged areas, indicated by the level of possessions and the dependence on daily wage labour. To ensure the involvement of all families a village assembly, grama vikas sabha (GVS), in which each household is represented by one member, was formed under the guidance of the project implementing organisation. This was followed by a formal agreement between the GVS and IEI, the implementing organisation, regarding the proposed energy enterprise. The dairy is operated in a labour-intensive manner, in order to provide employment and income to the unemployed villagers who were trained to carry out the required tasks such as collecting and transporting substrates, feeding and maintaining the biogas plant. A competent supervisor was appointed (from a neighbouring village) to oversee the activities and to keep records and accounts, with an assistant from within the village. The accounting system consists of the daily recording of inflows and outflows and weekly verification and electronic recording of the relevant details by the implementing organisation (IEI). (All information is based on the "Final project report", submitted to WISIONS by IEI)

Table 6 Overview of analysed case studies.

	Project A Karnataka, India	Project B Cajamarca, Peru	Project C Xiengkhuang, Laos	Project D Kagera, Tanzania
Energy Need	Cooking	Electrification	Cooking	Lighting & low power electric services
Technology	Biodigesters & small biogas distribution network	Stand-alone wind energy systems	Improved biomass stove	Solar PV & LED lamps
Assessment of user requirements	Baseline assessment of cooking needs & socio-economic aspects	Socio-economic baseline survey of all households	Suitability assessment of new stove designs with direct involvement of households	No baseline assessment, resulting in adjustment during implementation
Awareness raising & motivation	Continuous interaction with local committee & integration of income generation opportunities	Information activities according to actors: users, potential entrepreneurs, local authorities	Integrated information/training activities addressing different actors: organisations, users, manufacturers, retailers	Integrated information/training activities addressing manufacturers/entrepreneurs
Support structures	Establishment of local committee based on well known & accepted practices	Establishment of local committee based on well known & accepted practices	Close cooperation with well-established provincial organisations	Cooperation with an organisation working in the region & involvement of local micro-finance groups
Management system	Cooperative enterprise for dairy business & biogas distribution	Communal implementation; operation & management by local entrepreneurs	Fostering the establishment of a regional supply chain	Local manufacturing "micro-factories", maintenance and marketing of low cost lamps.
Capacity building	Training in operation/ management tasks, support & adjustments during start of operation	Training activities, according to future roles of actors, support & adjustments during start of operation	Learning by doing and learning by using. Support to provincial organisations	Intensive training of local entrepreneurs

Project B: Small Wind Power Systems in an Andean Village in Peru

The project was designed to electrify a rural community, including a school and a medical centre in a village in Peru. The selection of the village was based on the wind potential and the willingness of the authorities and the population to contribute to the project. The project, which was carried out by ITDG Peru, started with a detailed socio-economic survey on energy demand within the community and the current expenditure on energy. Based on the results it was

decided to provide independent power for each building. As a result, 22 stand-alone wind power generation systems were installed in 2007 and 13 additional systems were set up in 2008. The implementation of the projects was based on the active and effective participation of the community in almost every aspect. The District Municipality took over the legal ownership of the electrical systems and, to ensure the future sustainability of the project, a local management model was established.

Integration of participative strategies and socio-economic aspects: Baseline information about the community was collected during the first phase of the project. It included two main aspects: (1) basic data on potential users, such as the average income of households, current energy use and cost, and (2) information about the community organisation, such as the number and kind of local associations, as well as a qualitative assessment of the perception of individuals towards those organisations. In general, both aspects were shown to be favourable. To facilitate communication and coordinate activities with the community, a local "electrification committee" was established. Their main tasks were awareness raising and organising local logistic and labour contributions. ITDG Peru further applied an interaction model, which takes into account social and political structures and relationships. It consists of four actors (owner, private entrepreneur, control unit and users), whose responsibilities and interactions are ruled by written contracts and/or customary norms. The basic features of the model are: the owner of the system hires a (local) private entrepreneur who takes over the operation and maintenance of the systems and the collection of fees from the users. The entrepreneur, on the other hand, closes individual contracts with the end users. A "control unit" is established with representatives of the owner entity and the users. The control unit supervises the services provided by the entrepreneur and acts as the conciliation and decision entity for the whole system. Furthermore, several information and training activities were carried out. These included technical basics and the maintenance of small wind power systems, electro-technical basics for household installations and managerial instruments for small energy entrepreneurships. Once the training was completed the responsibility for the system was transferred to one of the trained technicians. During the initial months, the entrepreneur received intensive support (guidance) from the team of ITDG. At the time of the last visit scheduled within the implementation strategy, in May 2009, the management model was functioning and the perception of the users towards the system was very positive. Some families were already using electricity to set up and run small businesses such as a radio broadcasting station, a sweater-making business and a cheese factory. (All information is based on the "Final project report", submitted to WISIONS by Soluciones Practicas)

Project C: Promoting the Diffusion of Improved Wood Stoves in Laos PDR

The aim was to introduce more efficient wood stoves to an area suffering from fuel wood shortage in Laos. The project consisted of three phases: (1) Within the first phase, two stove types were tested by locals with the intention of collecting information on the suitability of the stove models for the local conditions and of measuring and comparing fuel wood consumption. The improved cook stove design chosen for the project was not the most efficient stove design but the most suitable for the local conditions. (2) In the second phase, local artisans were trained in the manufacture of the improved stoves. At the same time a promotion campaign was started to target potential users. (3) In the final stage of the project the results were published and disseminated among provincial and national authorities. By the end of the implementation period a final survey on the end users' perception was carried out. More than 90% of surveyed users perceived a significant reduction in both smoke and firewood consumption.

Integration of participative strategies and socio-economic aspects: The project was proposed and coordinated by the Technology Research Institute (TRI), an organisation that is part of the Prime Ministers Office of Lao PDR. It provided the technical and managerial skills for the realisation of the project. The cooperation with two provincial organisations was crucial, as they provided local staff and access to local networks. The active involvement of end users, particularly

women, was a crucial requisite for determining baselines and evaluating the performance of new stove designs. Transferring know-how to local manufactures was part of the activities designed to trigger commercial supply structures for the improved stoves. As well as training, special tools to manufacture the new designs were also provided. Furthermore, a promotional campaign was launched in order to trigger the demand for the improved stoves. For this activity the women's union took the leading role by making use of its network and the regular activities of its village branches. Three public events attracted over 600 people and the first 127 stoves from local manufactures were sold. Although retailers became interested in offering the new stoves, many of them were not willing to take on the risk of investing in a first trial. To overcome this barrier the project team decided to fund an initial market trial. During the whole project the staff of the TRI provided assistance to the manufacturers and the women's union in order to solve different technical problems. (All information is based on the "Final project report", submitted to WISIONS by TRI)

Project D: Village Micro-Factories in Tanzania for LED-Based Household Lighting Systems

This project, implemented by CAMCO, sought to improve access to low cost LED lighting systems by establishing local micro-factories at village level in Tanzania. Two types of lighting systems, designed for use in developing countries by a US based company (Green Energies LLC) were selected. The systems combine local low-cost materials, such as empty water bottles and imported components (manufacturing toolkits including PV solar cells). At the beginning the project team identified existing local groups as suitable local entrepreneurs. These entrepreneurs were trained to produce and maintain the lights. During the project 7 micro-factories were established, which have sold 270 LED lighting systems to rural farmers to date.

Integration of participative strategies and socio-economic aspects: Several aspects affected the acceptance and success of the project. First of all, existing local groups were convinced of the benefit to take part in the project and to build up the micro-factory groups. This meant that there was no need to establish new groups, which would have required time and often entails potential conflict. Also favourable for the project was the fact that due to the former political system, many community groups exist in Tanzania and the people are used to working in collective groups. Secondly the project has benefited greatly from an ongoing programme carried out by SCC-Vi Agro-forestry. The SCC-Vi Agro-forestry local project worker was the contact person for the communities and collected the funds for the purchase of the new components from the United States. The financial management system was another important aspect in the implementation. The manufacturing tool kits for the first installations were loaned to the micro-factories with payment only being made once all the systems had been assembled, installed and sold. The groups were trained in management issues and made their own decisions about the price of the single lighting system and their profit margin. On one hand, the responsibility for the marketing success fully rested in the hands of the local groups while, on the other hand, the burden of the financial responsibility was lowered by the loan. In parallel the future acquisition for new lighting systems was assured. All project steps together led to the identification of the local groups with their new business. The local groups actively solved any problems that surfaced during the project. (All information is based on documentation submitted to WISIONS by Camco, Kenya)

7.2.4 Results—Strategies for Dealing with Socio-Economic Challenges

The four case studies represent exemplary project models that aim to implement modern energy services in communities with poor energy supply. In all examples it becomes apparent that various aspects affect the performance of the projects and influence their success, regardless of technical feasibility, suitability or geographical conditions.

The most striking and common socio-economic components are highlighted below. They are arranged in five categories following the chronological course of the implementation process:

- User requirements and acceptance
- Raising awareness, motivation and identification with the project
- Support structures for implementation
- Configuration of management and financial system(s)/business and financial management
- Capacity building to ensure project provision and sustainability after implementation period

User Requirements and Acceptance

Clearly, it is essential to target the specific (energy) requirements of the users and try to meet their needs. To ensure that these needs are met, it has proven to be helpful to analyse the users' needs before choosing an implementation strategy. The experience with the four sample projects showed that it is important to continue gathering feedback during the whole implementation process.

In the Indian biogas project the detailed survey of the specific user requirements was important for the acceptance and success of the biogas system that was introduced. The dairy and biogas plants were constructed based on the average daily household need for cooking. This level was doubled to ensure supply for future increases in demand. In addition, the delivery of gas was based on user suggestions regarding their cooking times. This meant that gas was not being provided all day, but at times when it was needed most. The miscalculation of these needs could have led to the failure of the whole project. In the Tanzanian LED-lighting project the requirements of the users were not totally covered by the new technology. The need for energy to charge mobile phones was not considered. In addition, the brightness of the lights was not sufficient for all rooms and potential users did not appreciate the unattractive design of the lights. In general, technologies that are used in urban areas or industrialised countries often have a better reputation compared to low-cost appliances made for poor rural populations. In the Peruvian wind project, a socio-economic survey was the first stage and this ensured that energy needs and the potential financial contribution of each household could be estimated on a realistic basis. Furthermore, the information gained about the community structure and organisations helped to design the appropriate form of management. To evaluate the performance of the new stove design in Laos, participating "test-households" were involved through questionnaire surveys and direct interviews. During the market introduction of the stove, additional user surveys found quality defects in the manufacture. After some analysis and tests with different clay mixtures, an appropriate ratio was found that better matched the mineral characteristics of soils in the region.

Raising Awareness, Motivation and Identification with the Project

All four projects presented in this study depended on the active participation of the community members and technology users. To engage the communities in the project areas it was important to raise awareness and encourage users to identify with the projects. This step contributed significantly to the successful implementation of the four projects.
In Laos the user workshop and promotion campaign were important for raising awareness about the advantages of new efficient stoves. The local manufacturers, who were supposed to include the new stove in their product portfolio, and the local stove retailers, were not easily convinced. This meant that the initial financial risk for the new stove had to be covered by the project organisations. In the Tanzanian lighting project, the entrepreneurs had to be motivated during the training workshops at the start of the project, because after the training the implementing organisation left and the manufacturers were responsible for the production, quality, marketing and installation of the lighting systems. Only the financial burden of the initial investment for the materials was covered by the project grant. As a consequence, the

entrepreneurs were responsible for the success or failure of the project and they accepted this responsibility. The information on how to use the wind electricity system in Peru was presented in an illustrated brochure that could be understood by all villagers, including children and illiterates. In combination with an information workshop at the beginning of the project, these measures helped to prevent the misuse and overcharging of batteries and also helped to lower the users' expectations. The fact that the local radio station runs on the new electricity system and that new small businesses were established also increased the acceptance. Likewise the new dairy and biogas plants in the Indian village changed the life of the community. To ensure the equal participation of the villagers, a grama vikas sabha, a common form of Indian community group, was founded with one member representing each household. All households receive equal levels of biogas and have had to adapt their cooking to the use of biogas stoves. In addition, fresh milk became available from the dairy and several villagers secured work there, which also increased the acceptance of the project.

Support Structures for Implementation

Experiences show that communication between the implementing organisations and the local population is not always easy. To facilitate and improve the communication process it has proven to be helpful to work with local committees or similar associations. In the regions where the sample projects were implemented, different kinds of community associations already existed. Our analysis confirmed that working together with these organisations was a key step to facilitate implementations of the four projects. These structures also supported the coordination of activities that involved active participation of the local population. The participation in certain activities (e.g., transporting materials or carrying out civil works) had further positive effects in the communities, e.g., strengthening their identification with the project, building practical skills and reducing cost.

In Peru the windmills were set up collectively by all villagers, which helped them to identify with the new technology. For the development of an adequate management system the existing committee structure and perception of the villagers were analysed and later adopted. In Laos the cooperation with existing local women's groups and other local and provincial organisations was crucial, particularly for the testing and marketing phases. Also in Tanzania, the involvement of existing local microfinance groups and the connection of the project with a regional long-term programme for local farmers significantly contributed to the project's successful completion. In the case of the Indian village, the support structure can be seen in the selected community itself. All villagers belong to the same low-income group, which minimises the inequalities. The implementing agency had learned lessons from observations from other projects that had failed because of perceived inequalities (e.g., only those owning cattle had to supply dung), or those that were restricted to private endeavour (e.g., those households who could afford the costs had their own plants). It was also helpful to use the local tradition of establishing a grama vikas sabha as a democratic committee/decision group. The people were used to this kind of group and therefore accepted the concept.

To sum up, for the projects outlined above, it would have been very time consuming and also risky to establish new or different group structures in the relevant communities. Using existing and known group structures is a significant success factor for community-based energy projects.

Configuration of Financial Management and Business System(s)/Business and Financial Management

For long-term success, beyond the initial implementation phase and after the outside project team has left, it has become apparent that it is important to set up a sound and well-structured management system. To form such a management system, the local situation and community structures have to be taken into consideration. Empirical research has shown that weak management systems with no clear responsibilities have a high risk of failure, including the risk of corruption or favouritism. Particularly in cases where external control or supervision is not

possible, these aspects have to be taken into account. Some common aspects considered in the four case studies include: defining ownership of the equipment; defining the responsibilities for operation and management; setting a scheme of tariffs or prices; and establishing entities responsible for supervising, conflict solution and decision-making. Particular attention was given to cultural particularities and power structures that facilitate the configuration of appropriate management systems. These settings of "rules of the game" helped to assure the provision of e.g., electric power and other related services.

On the financial side, the high initial costs are often a barrier for the users/buyers, who normally belong to low-income population groups. This barrier can often be overcome by either supporting the initial investment or bridging the investment through loans or revolving funds. The latter is also helpful for ensuring funding for expenses such as maintenance or to fund further project extensions.

In the Indian biogas system a new enterprise was established, meaning that the management system had to be developed with great care. Both the dairy and the biogas plant are sensitive systems that need to be well organised to run efficiently, so the sound management of the technical processes also had to be ensured. The implementing organisation stated that, in particular, feeding the biogas plant had to be regulated. Consequently the management system included clear and fixed tasks and responsibilities: daily accounting and a transparent and fair payment system. For the recording, an external supervisor from a neighbouring village was recruited.

Capacity Building to Ensure Project Provision and Sustainability after Implementation Period

Based on the analysis it can be stated that technical and managerial skills are a key asset to ensure the continued operation of the implemented energy systems. Local technicians have to be trained to be able to tackle failures of installed systems. Additionally, electrification measures can include components that promote the productive use of electricity in order to enable income generation activities and improve the overall financial sustainability of projects. The promotion of the productive use of electricity can for example include training in entrepreneurship and support in accessing new markets.

All four projects considered this aspect and technical training was always one of the first implementation steps. Even in the case of this technical training, the particular conditions of the location must be taken into account; e.g., for the dairy activities in India, it took longer than expected to train the employees in the daily routine required as they did not have regular employment before the enterprise was established. This fact had not been considered in the planning process.

7.2.5 Discussion. Outlining an Analytical Framework for Community-Based Projects

The common aim of community-based energy projects is to ensure the long-term adoption of innovations, which have evolved to a point where they provide an appropriate response to people's energy related needs. As discussed before, the fulfilment of this objective requires a socio-economic transformation. This means that community-based energy projects can be understood as interventions aimed at triggering and accompanying transformative processes within socio-economic structures. The chosen field of intervention commonly coincides with small geographical and/or administrative areas. Within the context of the participative development approach, implementing organisations are understood as facilitators of transformation. Therefore, emphasis should be put on the wording: "triggering and accompanying". This recognition of the need of endogenous transformative dynamics is consistent with observations from complex system theory, which indicate that external entities

may have some influence in the processes. However, ultimately, the actual system's reshaping is the result of negotiations within the system itself (Willke, 2001).

The transformative task appears to be clearly recognised by the organisations implementing the case studies. Establishing local structures that are capable of delivering the services and products related to the new energy solution is a clear objective of the implementation strategies. Already available capacities constitute the basis for establishing those new structures; e.g., available models of community organisations like the case of grama vikas sabha in India and community committees in Peru; organisations with long track records in the region such as the women's groups in Laos and the agro-forestry program in Tanzania; existing entrepreneurial activities, like traditional stove manufacturers in Lao and local micro-finance institutions in Tanzania. Transferring know-how and developing skills are the central means of upgrading or building the required capacities within the local structures.

The project implementation period can be seen as a transition phase from the current state (use of traditional practices, energy needs that are not fulfilled and/or linked to detrimental social, economic and environmental effects) to a target scenario where innovative (more) sustainable technologies are a real option for individuals, specific sectors or the community in general. The implicit assumption of each community-based project is that by implementing the planned activities a socio-economic transformation would take place where the target scenario can emerge. In this way, the implementation period represents the experimental setting to test the validity of that implicit assumption. As an experiment, the possibility of adjusting/modifying certain variables is central. In the case of energy projects these variables can be elements such as features of devices, practices (of users, suppliers or other actors) or institutional arrangements. The experiment also requires a "feedback loop", i.e., a monitoring function to identify possible failures and unexpected or undesired effects.

Examples for on-going problem solution and adjustment can be found in the analysed case studies: modifications of technical features according to feedback from users (finding an adequate clay mixture for the stoves in Laos or offering additional services to users of PV LED solutions in Tanzania) and adjusting implementation plans (the decision to support the first trial of stoves for commercial distribution in Laos or the decision to hire a person from a neighbouring village in order to bring expertise and neutrality to the dairy cooperative in India). Because undesired or unexpected effects may appear during any stage of implementation, assuring effective communication between actors involved in the projects emerges as a central issue. This monitoring function can also cover planned activities, like the interim surveys of users' perceptions in the case study in Laos.

The transformative and experimental character of community-based projects stresses the contradictory field in which project management takes place: On the one side, achieving motivation and identification of local actors with the project may require some sort of certainty of the expected positive outcomes. On the other hand, the transformative task of community-based projects implies a certain level of novelty, which actually increases uncertainty. Novelty can be found in different components of the project concept. Some notable examples are: new devices (wind turbines); new technical features of known devices (improved stoves); new procedures for operation (collection transport, mixture of substrates in order to feed biodigesters); new interactions among actors (setting a system of feeds for electrification services and the required rules and contracts).

Analytical tools for understanding and bringing into operation this complex challenge of influencing societal change towards a vision of sustainability can be found in the literature on socio-technical transition. One central assumption is that societal change is a result of the interaction between relevant actors at different levels. And although it recognises that the inherent complexity of societal systems implies a low level of control, it suggests that "there are generic patterns and dynamics that could allow for intelligent forms of planning based on

learning" (Loorbach, 2007). In this context the process of influencing socio-technical (purposive) change entails four basic governance activities: strategic, tactical, operational and reflexive activities (Loorbach, 2010, 2007). This approach to socio-technical transition management has been mainly applied in the context of industrialised societies. However, the concept of influencing societal change can also describe the implementation process of community-based projects in developing countries, such as in case studies presented here. The implementation strategy of such projects can be understood as an interrelated group of activities providing the means to meet four fundamental functions:

(1) Developing a shared vision of innovative solutions for specific energy needs. This may include assessment of actual needs, awareness about the potentials and limits of a new technology, creating motivation amongst the target population and/or strategic actors, etc.
(2) Building local alliances that support the transformation process. Some common elements of this function are concluding cooperation agreements with existing organisations, setting up training activities to improve or build technical, managerial or other capacities.
(3) Participative implementation of activities: Active participation of the local population and/or organisations can take different forms, such as the direct contribution of resources (e.g., labour, capital or land) or assuming the coordination of specific activities.
(4) Continuous learning and problem solving: This is the recognition of the experimental character of community-based projects, where progress is uncertain and requires on-going interaction. The central elements of this function are the establishment of mechanisms for gathering feedback from all relevant actors; some practical examples are the scheduling of surveys of user perceptions and building clear communication channels between involved organisations.

These functions do not necessarily take place in a successive manner but influence each other interactively. They are the means to create and maintain the experimental and transformative space needed to move towards socio-economic structures, where (more) sustainable energy practices are applied and further developed. The proposed framework is schematically described in Figure 7.

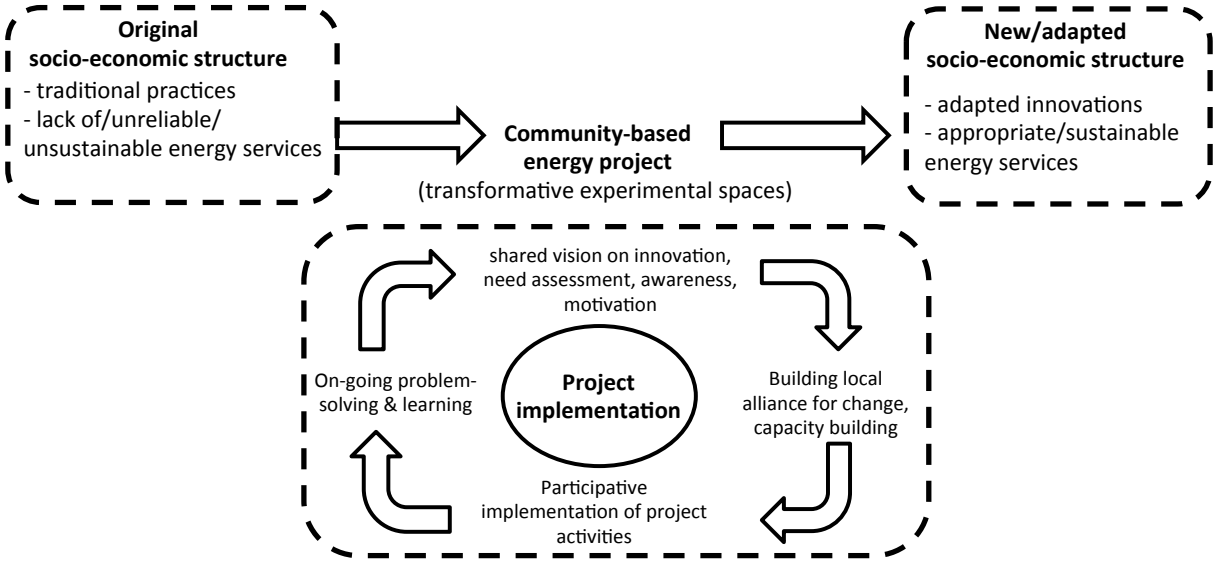

Figure 7 Community-based energy projects as "transformative experimental spaces" and the implementation activities as an iterative process.

7.2.6 Conclusions and Outlook

The real significance of socio-economic structures in driving or hindering the adoption and diffusion of sustainable energy technologies has been recognised in both contexts, promoting sustainable consumption and production structures in industrialised nations as well as shaping opportunities for sustainable development in developing countries. Correspondingly, local socio-economic conditions often turn out to be the most challenging obstacles to overcome for community-based energy projects.

All the case studies reviewed in this article already included strategies that addressed specific aspects of the socio-economic conditions of the communities involved. Such strategies are not only found at a single stage of the implementation, they are present along the different phases of the whole intervention process; from the initial assessment of actual needs, through setting up support structures for the implementation, to establishing appropriate business/management models to ensure long-term operation and necessary capacity building amongst local/regional actors.

The analytical framework outlined is based on the four central functions for enabling socio-technical transition, which do not necessary take place in a successive manner, but rather influence each other interactively:

(1) Developing a shared vision of innovative solutions for specific energy needs
(2) Building local alliances supporting the transformation process
(3) Participative implementation of project activities
(4) On-going learning and problem-solving

The practical strategies applied in the analysed case studies can be well organized as activities for fulfilling these four central functions. The framework offers an analytical basis to compare the implementation strategies of different types of community-based energy projects. This kind of "ex-post" analysis, combined with an assessment of the long-term impacts of projects, may bring additional insights into the inherent mechanisms that determine the success of community-based projects in triggering socio-technical transformations at a very local (micro) level.

The framework outlined implies a rather unconventional approach to community-based projects. It presents the project implementation period as an "experimental space". In this kind of space, the actors involved can test but also adjust the new practices. Additionally, an underlying aim of the experiment is to induce a purposive transformation of the socio-economic structure. Under the new socio-economic configuration the use of superior (more sustainable) energy solutions becomes common practice. The experimental character of project implementation opens up questions regarding the way supporting programmes are designed and how to evaluate the progress of single projects. Fixed terms of reference or other forms of requirements could prevent the introduction of changes in- progress that might improve the outcome of a project. Framing the requirements of a programme in a way that reflects the experimental nature of community-based projects may help to improve the impact of both supporting programmes and single projects.

8 Diffusion of sustainability family farming practices in Colombia

8.1 Charting article 3 in the research

This is the study of a network of bottom-up initiatives that have been advancing alternative approaches to family farming in Colombia. The network comprises mainly farmers associations, other organisations from civil society, and researchers (from academia and from institutions for applied research). These actors have been collaborating and experimenting with innovations in different fields, such as technical (e.g. agroforestry schemes, agroecological practices, biodigesters), organisational (e.g. peasant agroecology schools, autonomous staff of technical advisers), financial (e.g. self managed funds), environmental (e.g. plans for protection and management of local water basins), and commercial fields (e.g. peasant markets, communitarian processing facilities). The study aims to provide insights into the challenges and difficulties faced by those actors in broadening the diffusion of the innovations they have been advancing. Conceptualisations of sociotechnical niches are applied in order to analyse the case study. A methodological strategy is applied that combines a transdisciplinary mutual learning format with qualitative content analysis techniques. In the context of the research journey, this article provides additional empirical evidence about how bottom-up initiatives act and interact in order to develop, test, and promote the diffusion of innovations. It is also a first attempt at operationalising research alliances, in which the academic research of innovation diffusion is a constitutive part of a transdisciplinary endeavour that promotes the diffusion of innovations.

8.2 Article 3

The present section comprises the full accepted version of the manuscript with the title “The diffusion of sustainable family farming practices in Colombia: an emerging sociotechnical niche?”. It was accepted and published by the journal Sustainability Science and is available online under https://doi.org/10.1007/s11625-017-0493-6.

The diffusion of sustainable family farming practices in Colombia – An emerging sociotechnical niche?

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Abstract

There is significant potential for family farming to contribute to several dimensions of the Sustainable Development Goals (SDGs) adopted by the United Nations General Assembly in 2015. Our research aims to provide insights to help strengthen sustainable family farming. We focus on initiatives that have advanced sustainable family farming innovations in Colombia and analyse the factors and dynamics that have led to the limited penetration of those innovations across the country. To that aim, a transformative methodology is applied involving representatives of farmers' associations, supporting organisations and researchers from various disciplinary fields. We analyse the network of initiatives against the conceptual background of sociotechnical niches and identify a stable niche where generic lessons are being systematically identified and used to establish replication projects. However, this niche is still limited in its breadth, which results in a low capacity for expansion and a strong dependency on international donors for reproducing experiences. Specific recommendations are outlined for broadening the type of actors involved in the interpretation and dissemination of lessons from the niche. Moreover, we outline suggestions for further research and conceptualisation in two directions: for exploring effective ways of broadening the niche and translating niche lessons to state policies and for deepening the understanding of interactions between the niche and other levels.

Key words: family farming, agroecology, sustainability transition, sociotechnical niches, case-based mutual learning, Colombia

8.2.1 Introduction

Smallholder agriculture has a major role to play in any attempt to move towards sustainable development pathways. Transitions to sustainable agriculture can make direct contributions to several dimensions of the Sustainable Development Goals (SDGs) adopted by the United Nations General Assembly in 2015. (FAO, 2015) On the one hand "[t]he majority of the world's poorest and hungry live in rural settings and depend directly on agriculture" (IAASTD, 2009) and most of these populations rely on small-scale farms, i.e. plots of less than two hectares of land, which account for about 60% of arable land worldwide (ibid). These farming systems rely mainly (or entirely) on family labour for their operation and management. Thus, strengthening family farmers will be key for tackling poverty and hunger, which are the global challenges addressed by the first two SDGs. On the other hand, there are growing indications that the striking growth in productivity in industrial capitalist agriculture during the last half century is associated with the externalisation of environmental burden and social inequalities (Weis, 2010). Agriculture is, therefore, both a driver of detrimental environmental impacts, such as climate change, deforestation and increasing water scarcity, and is also negatively affected by those changes (Gordon et al., 2010; Hosonuma et al., 2012; Smith and Olesen, 2010). Though, innovative approaches have been emerging that allow smallholders to improve food production while enhancing the functional biodiversity of agroecosystems as well as the energy and resource efficiency of their farming systems (Altieri and Toledo, 2011; Kremen et al., 2012; Pretty et al., 2003).

The overall objective of our research is to provide insights to help strengthen sustainable family farming. We focus on initiatives that have advanced alternative approaches to family farming in Colombia and explore whether the network of farmers' associations and supporting institutions driving those initiatives can be considered as an emerging sociotechnical niche. Our specific aim is twofold: firstly, we investigate how farmers' associations can best contribute to strengthening sustainable family farming. To achieve this, we apply a transformative methodology that allows

for mutual learning based on the joint investigation of cases involving representatives from the supporting organisations, farmers and researchers from various disciplinary fields. This allows for societal learning and the transformation towards sustainability through collaborative research (a transformative objective). Secondly, we analyse to what extent the network of farmers' associations and supporting institutions can be considered an emerging sociotechnical niche (a conceptual objective). Based on conceptualisations of sociotechnical niches and the mechanism of their emergence, development and growth, the analysis aims to provide insights into the challenges and difficulties faced in broadening the diffusion of sustainable family farming practices in Colombia, as well as to offer suggestions about how to overcome these obstacles.

In this article, we elaborate on a network of initiatives that have advanced sustainable family farming practices in Colombia. The main focus is on the ability of the initiatives to diffuse innovative practices that have been developed and tested – in some cases over a period of more than two decades. The research is based on a broad understanding of innovation that includes ideas, practices and objects that are perceived as new by potential adopters (Rogers, 1983). Thus, innovations are not restricted to technical aspects (e.g. new ways of organising and operating in physical domains, such as soil, crops, animals and forests), but also cover new ideas and practices in the social and cultural domains of family farming, such as cooperatives, policies and markets. In our research, we apply a quasi-evolutionary perspective to technological change in which technology and society co-evolve in the same process (Rip and Kemp, 1998). From this perspective, diffusion can be conceptualised as learning processes within and between different sociotechnical structuration levels (i.e. niches and regimes), which cover not only lessons about technology but also about preferences and rules (see 'Conceptual framework – sociotechnical niches' section). Likewise, our research methodology is organised as a mutual learning process within and between different levels and combines different qualitative content analysis techniques (see 'Methodology' section).

This article is structured as follows: the second section provides an overview of the development and current state of the initiatives that aim to strengthen the family farming sector in Colombia. The third section offers a review of the conceptualisation of sociotechnical niches, which is proposed as the conceptual framework for assessing the potential of the network of initiatives studied to induce the broader diffusion of the innovations in Colombia. The fourth section presents the methodology applied to advance both the transformative and conceptual objectives of the study. In section five, the network of initiatives is analysed against the conceptual background of sociotechnical niches and in section six we explore the implications of our analysis from two perspectives. We derive recommendations concerning the possible dynamics of the wider diffusion of the analysed sustainable family farming practices in Colombia. We reflect on the suitability of the conceptualisation of sociotechnical niches for grasping the complexity of the environment in which the analysed network of initiatives operates, and derive suggestions for further theoretical considerations concerning sociotechnical niches. The final section summarises the main findings of the study and offers an overview of areas for further research.

8.2.2 Family farming in the Colombian agrarian context

The family farming concept in Colombia

The term family farming is used to refer to farming system types that vary across different countries. Heavy reliance on family labour, the role of the family in the management of farm operations and the size of the farm are the most common characteristics of the different notions of family farming (Garner and de la O Campos, 2014). The term is, however, often linked to other ideas that go beyond the economic (productive) functions. The concept of family farming also encompasses a social and cultural dimension and refers to a particular relationship between

farming families and the environment (Schneider and Niederle, 2008). This makes the concept of family farming particularly suitable for exploring transitions towards sustainable agriculture.

In Colombia, the term family farming is not widely used. The concept of family farming (*agricultura familiar*) that responds to the contextual particularities in Colombia has only been recently recognised and is still in the early stages of development. Some examples of this process are the characterisation of family farming systems through academic studies (Acevedo-Osorio, 2016a; Forero-Álvarez, 2013), as well as the definition of a category for policymaking (MADR, 2014). Consequently, there is still very little literature in which the term is explicitly used. However, the core productive notions of family farming – i.e. the predominance of family labour and the farm size – match the characterisation of peasant farms or the peasant economy (*economía campesina*), which is a term commonly used by academics analysing Colombian agrarian and rural development (Reinhardt, 1988; Salgado Araméndez, 2002; Zamosc, 2006). Moreover, the productive notion of family farming is also evident in the categorisation of small farmers or small producers (*pequeños productores*), which is a concept commonly used in policy formulation, such as in the national development plans (DNP, 2015a).

In this study, we use the term family farming to encompass the conceptualisations that have been commonly used to date, while – additionally – recognising the other non-productive functions of the farming systems it refers to. The cultural meanings and environmental dimensions of family farming are particularly relevant in the Colombian case. Farming units and practices are components of the identity-building of social groups with ethnic links, such as the indigenous (Cano et al., n.d.; Corrales Roa, 2011a; Hristov, 2005) and Afro-Colombian populations. Agricultural cooperatives bringing family farming units together have also been prominent in creating the notion of social groups (Gutiérrez, 2014). In the environmental dimension, family farms exhibit greater reliance on inputs and services from the ecosystem in which they operate, and use fewer commercial inputs (e.g. fertilisers, seeds and fuel) than large agricultural organisations (Forero-Álvarez et al., 2002). Moreover, environmentally-friendly practices, such as the sustainable management of soil, agroforestry and multi-cropping, are critical for maintaining and improving livelihoods on the areas of land, which are often extremely small, managed by family farmers (Corrales Roa, 2011b; Nicholls et al., 2016).

Current state and role of family farming in Colombia

Family farming remains an important socio-economic arrangement in the rural context, even though the rate of urbanisation in Colombia has been increasing steadily over the last 60 years. Three-quarters of Colombian municipalities display rural socio-economic structures where social and productive relationships are organised around land tenure and use (DNP, 2015b; UNDP, 2011). Around 30% of the country's population (or 14.5 million inhabitants) lives in those predominantly rural municipalities. The last country-wide agrarian census (2014) showed a particularly high concentration of land tenure: 64.8% of the total agricultural area is owned by 2.8% of landowners, with landholdings larger than 100 hectares, while 70% of the landholdings dedicated to agricultural production are smaller than 5 hectares in area and cover only 4.8% of the total agricultural area (DANE, 2016). In contrast to this marginal share of family farmers in terms of total agricultural area, family farmers remain significant actors for national food production: family smallholdings account for 47% of the total area cultivated with transitory crops and 56% of the area with permanent crops – i.e. the area dedicated to the production of food (Garay et al., 2010).

Although significant advances in human development parameters have been achieved in Colombia over the last two decades, poverty and marginalisation remain higher in rural areas. Around 46% of the rural population and 18.5% of the urban population lives in poverty (DNP, 2015b). These disparities persist despite the rural development policies and programmes addressing the livelihood conditions of the rural population – and family farmers in particular – which have been implemented over the last two to three decades (Borras, 2003; Castro Murillo,

1995; World Bank, 2014). Different dynamics have exacerbated the marginalisation of family farmers: the violent domestic conflict, the surge of illicit crop cultivation, the increasingly drastic consequences of climate change and the weak institutional presence of the state (Garay, 2013; Gómez et al., 2015). However, several commentators also consider that rural development policies and government programmes have been ineffective in reducing poverty and marginalisation: the focus over the last two decades has been on integrating the national agricultural sector and rural economic activities into international commodity markets (i.e. food and raw materials) and on financial capital through technical modernisation and diverse incentives to invest in agro-business and other large developments (e.g. mining and large hydroelectric projects). This policy direction has not only intensified the concentration of land tenure (Garay, 2013; UNDP, 2011), it has also failed to recognise the productive particularities of family farming, such as diseconomies of scale (Forero-Álvarez, 2013; Reinhardt, 1988) or the multi-functionality of farming practices for the livelihood of the family unit (Acevedo-Osorio, 2016b). Ultimately, the pauperisation of the rural population has been reinforced by government policy (Salgado Araméndez, 2002; Tobasura Acuña, 2011).

The current peace process between the Colombian government and the Revolutionary Armed Forces of Colombia – People's Army (FARC–EP) has produced expectations of the establishment of national policies for strengthening family farming in the country (Machado et al., 2013). Indeed, the first part of the agreement establishes the guidelines for "integral rural reform", which includes, among other promising aspects, measures for tackling the land tenure inequality, allowing and supporting displaced families to return to their farms, as well as improving support for family farmers in general (the last version of the peace agreement, signed on 24.11.2016, can be consulted online at http://www.altocomisionadoparalapaz.gov.co)

Initiatives for alternative family farming innovations

Numerous initiatives have applied alternative approaches to the livelihood conditions and needs of Colombian farming families. In contrast to the orientation of government programmes and large farmers' unions, which focus on the market competitiveness of farmers in single market segments, alternative approaches take into consideration the social, ecological, cultural and spiritual dimensions of family farming systems. A prominent surge in these types of alternative approaches can be traced back to the 1980s. This change came about as part of a dynamic in several Latin American countries, where numerous agroecology-based projects were promoted by NGOs incorporating elements of both indigenous knowledge and modern agricultural science (Altieri and Toledo, 2011). Since then, the drive towards the integration of science-based agroecology techniques and indigenous farming technologies in Colombia has manifested itself in different ways. One notable example is the establishment of '*escuelas campesinas de agroecología*', which can be translated as 'peasant agroecology schools'. The concept has been influenced by the work of rural activists in Central America (Bunch, 1985; Rodríguez and Hesse-Rodríguez, 2000) and in other Latin American countries (Pumisacho and Sharwood, 2005). Although the term encompasses a rather heterogeneous set of initiatives, the initiatives do share certain key characteristics. The concept refers to groups of farmers who are committed to meeting regularly to undertake training with the aim of mutual learning. The training is directly linked to the practical application of principles and techniques on a pilot farm or, preferably, on the participants' farms; the topics are chosen according to the specific conditions of the participants' farms and emphasis is given to promoting the exchange of knowledge and experiences between participant farmers. There are no precise statistics for peasant agroecology schools in Colombia. However, Mejía-Gutierrez (2006) reported more than 50 schools in the south-west region of the country and Acevedo-Osorio (2013) estimated that more than 100 could be operating across the whole country. Different types of farmers' associations have also been advancing the development and promotion of alternative solutions for their members. These associations share a broad focus, i.e. they generally adopt a holistic perspective on the livelihoods of their associates instead of focusing on productive competitiveness in particular market segments (e.g. coffee, sugar, fruits or milk). The majority are officially registered as legal

entities and operate in very limited geographical scopes, covering small administrative units – from one or several villages up to a couple of neighbouring municipalities (Acevedo-Osorio and Martínez-Collazos, 2016).

Research initiatives applying participative approaches were already key during the surge of alternative approaches to family farming in Colombia in the 1980s and 1990s. Notable is the case of the research centre on sustainable agricultural systems (Centro para la investigación en sistemas sostenibles de producción agropecuaria,CIPAV), a non-academic institution which, since its foundation in 1986, has conducted applied research projects for the development of sustainable agricultural systems, integrating peasants and entrepreneurial farmers in the research process (Murgueitio, 2002). The seminal work of Mejia-Gutierrez has also been particularly influential. It describes the diversity and suitability of existing indigenous agricultural systems in the country and highlights their social, cultural and spiritual value (Mejía Gutierrez, 1997). Initially, there was little interest from academic institutions in adopting and advancing agroecology (not to mention integrating indigenous knowledge). However, this picture has been changing in the last decades. Agroecology programmes have been emerging in academic institutions and there has been growing interest from academic researchers in integrated family farming systems.

Despite their diversity in terms of their foundations and institutional settings, these initiatives share a reliance on firm concepts of sustainability. They take into consideration the social, economic, ecological and cultural dimensions of sustainability in family farming. However, these approaches to family farming are still the exception in the overall Colombian family farming sector. Some indications of this marginality are reflected in the figures related to poverty measures revealed by the last agrarian census (as already outlined). Moreover, the absence of alternative approaches to the livelihood requirements of family farmers in the most recent central policies addressing rural development issues in Colombia raises questions about the potential for the country-wide diffusion of sustainable family farming practices.

Some efforts aimed at improving the connections between the initiatives are evident. Examples include networks such as the Colombian chapter of the agro-ecological movement of Latin America and the Caribbean (Movimiento Agroecológico de América Latina y el Caribe, MAELA) and the Colombian association of natural reserves of civil society (Asociación Red Colombiana de Reservas Naturales de la Sociedad Civil, RESNATUR). Recent initiatives have also fostered the systematisation of existing experiences, increasing advocacy and facilitating the broader diffusion of sustainable family farming practices. Two notable examples are the Colombian network for energy from biomass (Red Colombiana de Energía de la Biomasa, RedBioCol) and the national committee for the promotion of family agriculture (Comité de Impulso Nacional de la Agricultura Familiar en Colombia, CIN-AF). The former was launched in 2012 and focuses on facilitating networking and continuous knowledge exchange among local actors (Rodríguez Jiménez, 2016). The latter emerged in 2014 and places strong emphasis in its mission statement on increasing influence at national political level (CIN-AF, 2015).

Against this background, the transformative objective of our research is to advance the understanding of how farmers' associations can effectively contribute to the sustainability of Colombian family farms and, in this way, support networking initiatives such as RedBioCOL and the CIN-AF in their attempt to achieve the broader diffusion of sustainable family farming practices.

8.2.3 Conceptual framework – Sociotechnical niches

In the literature on sustainability transitions, niches are conceived as "protected spaces that allow the experimentation with the co-evolution of technology, user practices, and regulatory structures" (Schot and Geels, 2008). In such protected spaces, alternative technical solutions to persistent sustainability problems can be tested and improved. Sociotechnical niches are conceptualised in contrast to regimes, which are the incumbent sociotechnical systems where

mainstream technologies for the provision of societal functions – such as the provision of energy, food and water – are operated, maintained and reproduced (Smith et al., 2010). Regimes are conceived as strongly structured systems which cover a high share of the corresponding markets and rely on stable sets of understanding, values, norms and practices. They restrict the search for innovation in technical designs that conform to the existing regime's configuration and rules (Geels, 2002). In contrast, niches are less structured configurations, where understanding, values, norms and practices are still in the process of definition. They are, therefore, spaces for developing more radically different designs. However, the novelty of those designs commonly implies inferior qualities when compared to well-established commercial/mainstream solutions, e.g. in terms of convenience, price or comfort. In this sense, niches are regarded as societal configurations where promising innovations can be nurtured, i.e. continuously tested and improved.

Given the functional role of niches in the generation of sustainable innovations, considerable research has been undertaken to understand how they emerge, operate and grow. The conceptualisation of emerging sociotechnical niches can be described around four central concepts: protection, co-evolution, internal niche-building processes and the twofold level of niche development. Protection is fundamental to allow for the testing and further development of inventions which are still immature and which should be nurtured to the point where they can compete and survive in mainstream markets. There are a variety of means of protection, provided by different kinds of actors. The state is often involved through the mobilisation of public resources in the form of research and development (R&D) programmes or subsides, or through direct involvement in innovation projects that are of particular societal relevance, such as in the field of military technology (Schot and Geels, 2007). Important protective resources can also be found in cultural milieus by means of cognitive and normative settings, which put forward alternative lifestyles and question the suitability of mainstream technology configurations to respond to sustainability issues, such as in the case of the environmentalist milieu that supported the consolidation of an organic farming niche in the UK (Smith, 2007). The protective space offered by sociotechnical niches allows for more than the testing and improvement of the novel technology: the experiences gained from the innovation also generate insights into issues such as user preferences, routines, assumptions and regulations. In this way, the novel technology – as well as the social environment in which it is embedded – co-evolve in the same process (Schot and Geels, 2007). This co-evolution of the social and technical dimension is conceptualised as taking place by means of three internal niche-building processes, which are described by Geels (2011) as follow (words in italics from the original):

- The articulation (and adjustment) of *expectations* or *visions*, which provide guidance to the innovation activities, and aim to attract attention and funding from external actors.
- The building of social *networks* and the enrolment of more actors, which expand the resource base of niche-innovations.
- *Learning and articulation processes* on various dimensions, e.g. technical design, market demand and user preferences, infrastructure requirements, organisational issues and business models, policy instruments, symbolic meanings.

These processes are expected to lead to the aggregation of generic lessons and the emergence of a "community that shares cognitive, formal and normative rules" (Schot and Geels, 2008) to stabilise the social practices and technical designs that co-evolve in the protected spaces. The development of such a community – or the stabilisation of the sociotechnical niche – is conceptualised by Geels and Deuten (2006) as progressing on two levels and through four phases: interested actors engage in the design, use and re-design of innovations by setting local projects of an experimental character. In the initial stages those are rather isolated projects, where expectations, designs and rules might exhibit local characteristics (the local phase). Through the reiterative exchange between actors within local projects, knowledge and experiences can be compared and aggregated and generic lessons and rules begin to be articulated at a more global level (the inter-local phase). Intermediaries and relatively stable

networks of actors emerge, which systematically gather the knowledge from local projects required to constitute and stabilise the global level (the trans-local phase). Finally, the rules, resources and the community stabilise to the point where local projects are framed and coordinated by the global niche level (the global phase). According to Geels and Deuten, the aggregated knowledge "is sufficiently general, abstracted and packaged, so that it is no longer tied to specific contexts" (ibid) at this level and can diffuse more broadly. The extent to which niche innovations can challenge and substitute mainstream (i.e. regime conforming) practices does not solely depend on the niche's own expansion dynamic. Rather, regime change is a process of co-evolution and mutual interaction within and between the levels (Schot and Geels, 2008). Moreover, co-evolution patterns do not necessarily imply full substitution of the old (regime) by the novel (niche). Other possible patterns imply processes in which niches "branch, pile up, and contribute to changes in the behaviour, practices and routines of existing regime actors" (ibid).

Starting from the conceptualisation of sociotechnical niches, the conceptual objective of this research lies in exploring how far the network of farmers' associations and supporting institutions that advance sustainable family farming innovations in Colombia can be considered as an emerging sociotechnical niche.

8.2.4 Methodology

Our research applies a transformative methodology which combines a transdisciplinary research methodology with qualitative content analysis. We built a network of farmers' associations, scientists and supporting institutions in Colombia and realised a *case-based* Mutual Learning Session (*cb*MLS), as described by Vilsmaier et al. (2015). The *cb*MLS was conceived to advance the transformative objective within a transdisciplinary research setting. Concerning the conceptual objective of the research, qualitative content analysis techniques were applied to textual materials generated during the *cb*MLS to validate the hypothesis of a sociotechnical niche building process around sustainable family farming practices in Colombia. Figure 8 shows a schematic description of the applied methodology.

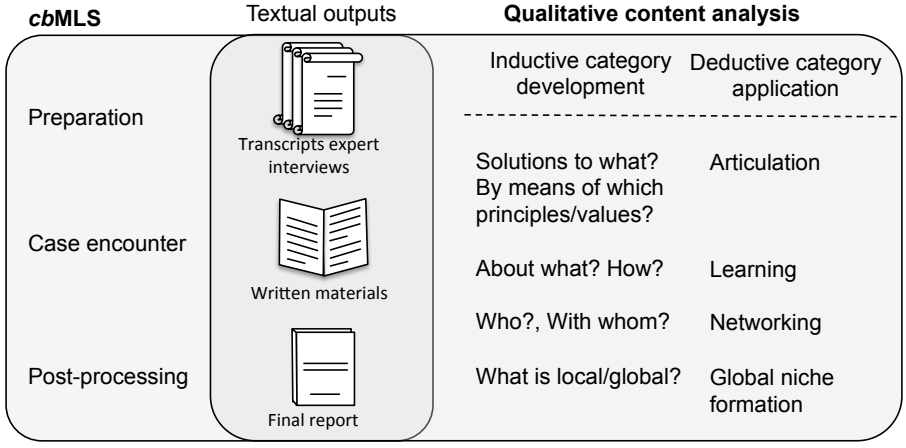

Figure 8 Schematic description of the applied methodology.

Case-based Mutual Learning Sessions (*cb*MLS)

Mutual learning sessions are group-based methods for transformative sustainability research that aim for both knowledge production and societal transformation by enabling knowledge integration and transfer. Mutual learning sessions can be considered temporary transdisciplinary research spaces. They serve two central aims. On the one hand, they are created to allow people from different cultures of knowledge, cognition, sociocultural or political contexts, or everyday practices, to express and jointly process their individual perceptions and conceptualisations of a specific sustainability challenge (Vilsmaier et al., 2015). This should ensure the plurality of perspectives and the consideration of different knowledge bases, all

considered equally important. On the other hand, *cb*MLS support knowledge transfer between different cases that deal with similar sustainability issues and between different scales; i.e. they support the up and down-scaling of experiences and learning between different scales, such as administrative units (ibid.). *cb*MLS provide a general procedure and principles that ensure a certain degree of traceability of the learning process, knowledge production and transfer, and enhance the robustness of the obtained results by framing and structuring highly dynamic, vivid transdisciplinary research situations.

In *cb*MLS, a case or a set of cases serve as boundary objects (Star and Griesemer, 1989) through which different perceptions and conceptualisations of the phenomenon the case stands for are analysed and negotiated (Vilsmaier et al., 2015). The organisation of a *cb*MLS comprises three phases: (i) a preparation phase, (ii) a case encounter and (iii) a post-processing phase. During the preparation phase (i) the goal and specific objectives of the session are defined. A representative case (or a set of cases) is selected and perspectives and knowledge about the case(s) are gathered and systematised; moreover, relevant actors are connected in order to build a team of participants. The composition of the team is crucial. To ensure the robustness of the results a balanced team is recommended in terms of representatives of the relevant knowledge fields, cases or policy institutions, diversity aspects and — according to the issue of concern —sociocultural backgrounds. During the case encounter (ii) the participants engage directly with the case by interacting with case agents and, if possible, by visiting the case site. They work on the objectives defined during the preparation phase for the session. The detailed structure of the encounter can vary in type, size and duration. However, the general aim is "to construct a shared view on what components/aspects of the case are crucial for sustainable transition and to document alternate/contrasting views" (Vilsmaier et al., 2015). The post-processing phase (iii) allows for the consolidation of the results mutually agreed by all the actors involved, the illustration of divergences and contradicting viewpoints, the documentation of what is considered to lead to more sustainable pathways and/or requirements for further knowledge. Results are prepared for the different societal spheres that are challenged by the issue of concern. Accordingly, they are elaborated in different publication formats and (technical) languages to serve decision making on different levels and in different societal fields.

*cb*MLS on sustainable family farming in Colombia

For the aim of the research presented here, a *cb*MLS was organised to provide a temporary transdisciplinary space in which interactions between the network of initiatives, scientists and supporting institutions could take place, which could result in stabilising a global niche for family farming innovations in Colombia. The *cb*MLS was realised between December 2015 and June 2016. Representatives from five farmers' associations and seven supporting institutions, as well as eight researchers from different research institutions and academic fields (i.e. sociology, agroecology, ecology, sustainability, geography, anthropology and cultural studies), were involved. The participating organisations are listed and briefly described in Table 7. The association of indigenous and peasant producers (Asociación de Productores Indígenas y Campesions, ASPROINCA) was selected as the case study for the *cb*MLS. It was founded in 1995 and currently has more than 200 members. ASPROINCA promotes sustainable agricultural practices and encourages the re-establishment of native varieties of beans, maize, sugar cane and fodder plants to increase household food sovereignty. It also trains farmers in sustainable agroecological practices, promotes the use of biogas from animal waste and coordinates efforts to recover and protect micro-watersheds - among other initiatives aimed at improving the livelihoods of peasant communities in Riosucio and other neighbouring municipalities (UNDP, 2012).

Table 7 List of the organizations participating to the case encounter. The descriptions focus on aims and/or activities relevant to the central guiding question of the cbMLS.

Type of actor	Organisation	Quantity of representatives participating	Description
Farmers' Associations	Asociación de Cabildos Indígenas del Norte del Cauca (ACIN)	1	ACIN brings together 20 indigenous *cabildos* (local government councils) from the Cauca region. It was established in 1994. The association coordinates diverse programmes aimed at strengthening the political capacity and the living conditions of indigenous communities.
	Asociación de ganaderos y agricultores medioambientalistas de Ubalá (ASOGAMU)	1	ASOGAMU brings together 15 farming families living in the rural area of Ubalá, a municipality in the department of Cundinamarca. It was established in 2010. The focus of the organisation is on improving the production systems of their associates by applying agroecological techniques.
	Asociación de Organizaciones Campesinas y Populares de Colombia (El Común)	1	El Común brings together 25 farmers' organisations active in the department of Santander. It was officially established in 1986. Its main focus has been the promotion and strengthening of organisational processes aimed at improving their members' living conditions.
	Asociación de Productores de Puente Abadía (APPA)	1	APPA gathers together 24 farming families living in Puente Abadía, a small village (*vereda*) near Villavicencio, the capital of the department of Meta. It was established in 2010. It has particularly focused on establishing processing facilities and commercial channels. It owns two companies and manages its own coffee label.
	Asociación de Productores Indígenas y Campesinos de Riosucio Caldas (ASPROINCA)	2	ASPROINCA gathers together more than 300 farming families in the north-eastern region of the department of Caldas. It was officially established in 1995. It trains farmers in sustainable agroecological practices, promotes the use of biogas from animal waste and coordinates efforts to recover and protect micro-watersheds.
Science / Academia	Antioquia University - Research group culture, politics and social development (GICPDS)	3	One research focus of the group is on community forms of organisation - both in rural and urban contexts - and the ways in which they influence/participate in the formulation and implementation of development interventions.
	El Bosque University - Bioengineering department	1	One focus area is the design and optimisation of farming systems with a focus on food security and environmental sustainability.

	Javeriana University - Institute for Rural Studies	1	One central aim of the research is to provide scientific-based information on the economic, social and environmental performance of agricultural systems with roots in traditional knowledge and practices, i.e. those applied by peasant, indigenous and Afro-Colombian communities.
	Minuto de Dios University - Research group on agro-ecology and environmental management	1	One focus area of the group is the characterisation of family farming in Colombia and the development of tools for the design, implementation and monitoring of sustainable family farming systems.
	Leuphana University - Institute for Ethics and Transdisciplinary Sustainability Research	1	One focus of research is on epistemological and methodological foundations, and methods for inter and transdisciplinary research.
	Wuppertal Institute - Research Group Future Energy and Mobility Structures	1	One research area of the group is on the transition towards sustainable energy systems based on renewable energy technologies in the rural context of non-industrialised regions.
Supportive Organisations	Centro para la Investigación en sistemas sostenibles de producción agropecuaria (CIPAV)	2	CIPAV provides applied research, capacity-building and dissemination of technical innovations for sustainable systems of agricultural and animal production.
	Grupo Semillas	1	The organisation provides conceptual and technical tools to farmers' associations to promote the protection of their territories, conservation of biodiversity and food sovereignty.
	La Cosmopolitana Foundation	1	The foundation provides capacity building on agroecological tools and techniques as a mean of empowering rural families and communities, while helping to achieving food security, natural resource conservation and environmental protection.
	Movimiento Rios Vivos	1	Rios Vivos brings together organisations of people affected by the construction of large dams. It works for the defence of the rights of the affected communities.
	Podion Foundation	1	One of the areas of action of the foundation is rural development, which aims to contribute to achieving food sustainability while applying sustainable soil management practices. To that end, the foundation supports community associations in different regions of the country.
	Proyecto Trueke	1	Proyecto Trueke is an initiative that promotes spaces for the exchange of goods and services without the use of money. It has also experimented in the use of

		complementary currencies. The initiative has been active for around 20 years, mainly in the metropolitan area of Medellín.
Red Colombiana de Energía de la Biomasa (RedBioCol)	1	RedBioCol is a network of individuals and organisations committed to contributing to the sustainable development of Colombian society by promoting the use of organic residues for energy generation.

The central guiding question of the *cb*MLS was: "By means of which instruments and strategies can farmers' associations effectively contribute to strengthening the Colombian family farming sector regarding economic, social, environmental and cultural domains?" This guiding question depicts the transformative aim of our research and was developed jointly with representatives of ASPROINCA and of the RedBioCol network. The tools and strategies applied by ASPROINCA to support its members were set as the case study around which the mutual learning session was structured. During the preparation phase, expert interviews were undertaken with 15 participants via Skype™. The interviews were designed with two aims: (i) to make explicit the perspectives of the invited participants on the topic and collect their inputs in order to break down the central guiding question into more specific issues; and (ii) to provide qualitative data about the interactions between the participants and other actors involved in initiatives promoting sustainable family farming in Colombia.

The case encounter took place between 30th March and 1st April 2016 in Riosucio, Caldas, Colombia. The encounter comprised three stages: (i) visits to farms, (ii) sharing of experiences and (iii) group work units. The visits (i) provided the participants with first-hand experience of the type of family farming systems promoted by ASPROINCA and enabled them to interact with individual farmers and the staff of the association. The individual experiences from the field (ii) were systematically shared and collected through written and spoken statements. Finally, three units of group work (iii) were designed to induce mutual learning. The first two units aimed to stimulate knowledge transfer between similar cases and to generate recommendations for ASPROINCA and for other farmers' associations. The third unit promoted the extrapolation of lessons to extract recommendations for the consolidation of the RedBioCol network. The results from the entire mutual learning session were synthesised and consolidated in the form of specific recommendations. A final document, which was created and approved by the participants, comprises a detailed description of the process, the results and the consolidated recommendations (the comprehensive Spanish *cb*MLS report can be consulted online at https://goo.gl/6x0lys).

Qualitative content analysis

Qualitative content analysis techniques were applied to the textual materials generated from the *cb*MLS to validate the hypothesis of a sociotechnical niche building process around sustainable family farming practices in Colombia. The materials analysed comprise the transcripts of the 15 expert interviews, written material produced by the different group work units during the case encounter and the *cb*MLS final report. The analysis combines procedures for inductive category development and deductive category application as described by Mayring (2000). The concepts of internal niche building processes (learning, articulation of expectations and networking) and the formation of the global niche level are applied as deductive categories for the analysis. The inductive strand of the analysis aims to characterise how those deductive categories were expressed in the interactions between the community of organisations and initiatives represented in the *cb*MLS. Consequently, questions guiding this work ask about the specific qualities of the presumed niche development in Colombia:

- Learning about what and how?
- Innovations to which sustainability problems/challenges?
- Based on what principles/values?
- Who is involved? Through which interactions?
- What are the local projects?
- How is the formation of a global niche level being promoted?

The analytical process combines techniques for summarising and structuring content in an iterative way. The main aim of the summarising technique is to reduce the text to obtain the essential content relevant for advancing the conceptual aim of the research (Mayring, 2008). The structuring technique in our case involves filtering and organising aspects evidenced in the texts according to the deductive categories, i.e. according to the conceptualisation of sociotechnical niche development. The resulting set of categories (the code system) is shown in Table 8. The code system is organised into three orders. The first order of categories refers to aspects described and/or highlighted by single text passages. The number of passages containing relevant information about the corresponding aspect is indicated. First order categories were clustered into second order codes, as a first step in the aggregation of inductive categories within the structure provided by the key concepts of the sociotechnical niche. The criteria applied for this aggregation task vary. Categories relating to the articulation of expectations of the presumed niche community were grouped into two types of aspects: (i) those that provide common ground for what can be regarded as the shared vision of the niche community and (ii) those that refer to the most pressing problems or challenges faced by family farming, for which the innovations being nurtured should offer alternatives. Information about the learning process taking place within the presumed niche was clustered into five second order categories. The first four clusters gather the learning topics into groups of lessons according to their scope of application; i.e. lessons for individual farms, for the structure and operation of farmers' associations, for tackling commercialisation issues, and lessons with larger scope, which we refer to as the socio-ecological level. The fifth cluster gathers information about how the learning about those topics is being organised. During the coding process, the decision was taken to consider the deductive categories of 'networking' and 'building of global niche level' together. Both concepts point to the set of actors involved in the niche development, their role and interactions. While the concept of networking is focused on the structure and growth of that set of actors, the building of a global niche emphasises how those actors engage in the sequential aggregation and application of general lessons. However, trying to differentiate single statements in terms of their information value about structure or role was problematic during the coding process. Therefore, first order categories relating to these two concepts were grouped according to the type of actors about which the considered text passages provide information.

8.2.5 Results - the niche of sustainable family farming practices in Colombia

In this section, the composition and the dynamic interactions between the community of actors promoting sustainable family farming practices in Colombia is described. This descriptive exercise is based on the code system resulting from the qualitative analysis displayed in Table 8. This section is structured according to the four key concepts of sociotechnical niches applied as deductive categories. Each subsection collates and summarises the information extracted from the analysed materials, corresponding to each deductive category. Therefore, the whole section can be understood as an attempt to reconstruct the community of initiatives promoting sustainable family farming in Colombia by applying conceptualisations of sociotechnical niches.

Table 8 Code system obtained through the qualitative content analysis of written materials generated by the cbMLS.

Code System	Text passages
Articulation of expectations	
Key problems/challenges	
Out-migration to urban centres	13
Lack of recognition of socio-economic significance	11
Unsuitable or harmful policies	10
Intermediaries and unfair prices	9
Components of shared vision	
Food sovereignty	10
Organisational autonomy	10
Fair commercial channels	9
Ecologically sound production	9
Learning processes	
Lessons at individual farms	
Agroecological techniques	13
Biodigesters	8
Integrating/valuing all family members	7
Lessons at association level	
Revolving fund	12
Building staff for technical advice (promoters)	8
Methodologies for promoting/following up farm transformation	7
Monitoring and documentation	6
Lessons at socio-ecological level	
Recovery of local species	8
Territorial planning perspective	5
Lessons on commercial issues	
Community processing facilities	4
'Peasant markets'	4
Community shops	4
Institutional procurement	3
Learning formats	
'Peasant to peasant' approach	8
Events for knowledge exchange	5
Training in the field	4
Written materials	3
Training at agroecological farms/schools	2
Networking & building of global level	
Interaction and roles of farmers' associations	
Participation in projects coordinated by NGOs	15
Beneficiaries of international donors	7
Outreach operations	5
Weakness in leading replication projects	3
Interaction and roles of NGOs	
Advice and training to associations	11
Design and realisation of rural development projects	6
Systematisation of experiences	5
Continuous support of international donors	4
Interaction and roles of academia	
Systematisation of experiences	7
Technical advice	2
Interaction and roles of state entities	
Support to individual projects	6

Articulation of expectations

Common expectations and visions provide coherence to niche development by guiding the search for alternative solutions in different locations (Geels and Raven, 2006). They are conceptualised as "a special set of cognitive rules that are oriented to the future and related to action" (ibid). Two types of aspects were analysed to capture the common cognitive rules guiding the work of the initiatives considered in the present study, i.e. aspects of common problems and challenges and components of the shared vision of the niche.

The central challenge is the conventional perception that equates peasant or rural with poor and backwards. A critical manifestation of this perception is that small farming systems are assumed to be unproductive and economically unfeasible by nature, which seems to be the background against which rural development policies have been designed over the last two to three decades. This underestimation of family farming (and of the rural environment in general) is also reflected in the extremely weak physical and social infrastructure in rural areas of the country, which became evident in the most recent agrarian census (see previous section 'Current state and role of family farming in Colombia'). Accordingly, national policies are regarded as unsuitable (or even detrimental) for supporting the sustainable livelihoods of family farmers. This applies not only to policies concerning agricultural issues, but also to those with direct effects on land distribution and use, such as the definition of areas for mining developments and large hydroelectric projects. An additional challenge is evident in the conventional commercial channels, which involve several intermediary stages and result in low prices being paid to farmers, not to mention the high risks involved in the primary production stages and the uncertainty of the market. This general situation and the ongoing armed conflict have been the main drivers of the continuous migration of the rural population to urban centres, particularly amongst the youth. This has resulted in difficulties in ensuring the availability of labour to sustain family farms. As one of the interviewees commented, "the land is now full of elders".
The most prominent component of a shared vision is more often referred to as food sovereignty. The concept comprises different notions. The most basic is the idea of producing crops for self-sufficiency. Background to this common expectation is the fact that a significant proportion of small farmers has adopted an entrepreneurial approach to farming, which implies specialisation in a single (or few) commercial crop(s). One side-effect of this approach is that self-sufficiency (in terms of food consumption) has considerably decreased and farming families now rely heavily on supplies from the national (and increasingly international) markets. More broader meanings of food sovereignty entail notions such as the recovery of native seeds, the application of indigenous knowledge, and practices in crop production as well as the concept of responsible consumers (beyond the rural context) who look for regionally produced crops. Linked to autonomy in the production of food for self-consumption is the search for farming practices that are better integrated in the features and functions of the ecosystem in which the farm is located. In this respect, agroecological principles are also seen as options for improving the autonomy of individual farmers by diminishing (or avoiding) the need for external inputs. In addition to expectations about specific features of individual family farming units, there are recurrent indications about expectations relating to the role of farmers' organisations. One prominent aspect is the search for organisational autonomy, which refers to the growth of the own resource basis of farmers' associations (e.g. in terms of human, financial and political capital) to provide appropriate services to their members in a continuous way. Another prominent component of a shared vision is the configuration of commercial channels that ensure fair prices. This is often linked to the development of processing steps that add value to the produce and to the reduction of intermediary steps between farmers and end consumers.

Learning processes

The development and stabilisation of sociotechnical niches imply learning processes on multiple dimensions (Schot and Geels, 2008). The topics that are the subject of learning processes within the community studied can be organised into four categories. These categories reflect the scope

of application for which the lessons are most relevant; i.e. on individual farms, at organisational level, in terms of commercial channels and at socio-ecological level.

Learning about technical innovations, such as agroecology techniques, bio-digesters, improved biomass stoves or biological soil recovery and protection practices, is particularly relevant at individual farm level. This includes the training of farmers on techniques that are applicable to the specific conditions of their farms and are compatible with their own planning and expectations. Learning processes at this level can take place in different formats. They often involve a trainer or facilitator working with a group of farmers to foster the exchange of knowledge and experiences between farmers. Moreover, emphasis is put on the practical implementation of the innovations by the participating farmers on their own farms, which in turn fosters the process of learning by doing and the development of variations or adaptions that respond to the specifics of the individual farms, the family farmers and the local ecosystem. Other relevant lessons at individual farm level deal with options to counteract generational and gender imbalances; these are perceived to be very common among farming families. This kind of learning is less prominent than technical farming innovations. However, there are indications that some actors are interested in greater consideration and exchange on innovative and effective ways of integrating the younger generations into the family farming processes and of improving the status of the role of women among all family members (including the women themselves).

At organisational level, the niche community was most interested in how to effectively improve and maintain the autonomy of farmers' associations. Some notable examples of topics of interest are: a) the establishment of revolving funds managed by the associations which open up the possibility of providing micro-credits to their members to support the transformation of their farms; b) building and maintaining a staff of 'promoters', i.e. trained farmers with the technical knowledge and methodological skills to provide training and technical advice to associated farmers and follow up the transformation of their farms; c) the development of tools and methodologies for diagnosis, planning and monitoring the farms, which are adapted to the particularities of the family farmers served by the associations; and d) the continual maintenance of documentation about the progress of individual farms and/or programmes implemented by the associations. Learning about these issues largely relies on the direct exchange of experiences between farmers' organisations, rather than on the circulation of information through printed or digital materials. Moreover, these types of issues are rarely covered in publications, booklets or guidelines produced within the niche community. Direct exchanges between associations are commonly facilitated by NGOs. Such exchanges often form part of single (short-term) projects or (long-term) programmes initiated and coordinated by supportive NGOs. Programmes led by NGOs usually include the advisory services of external professionals who provide training and/or guidance to farmers' associations in organisational issues, which complement the case-specific knowledge exchange between associations.

Another type of lesson being shared comprises innovative practices to address issues related to the socio-ecological systems in which family farming and farmers' associations are embedded. One prominent example is the establishment of seed banks that facilitate the recovery of native species and the dissemination of crops, weeds and trees that are required to build the farming systems promoted by the studied initiatives. There are also indications of initiatives for the recovery of local animal breeds (cattle, poultry and swine). Another example is the carrying out of territorial planning exercises with broad geographical scope, such as landscapes, micro watersheds or biotopes. The developed plans help to align measures at farm level with broader aims; e.g. the protection of a watershed. The plans can also contain measures beyond the scope of individual farms, such as the establishment of forest reserves.

In addition, there is considerable interest in finding effective ways to establish commercial channels that better respond to family farming. The specific experiences that are currently feeding learning processes in this field cover diverse initiatives led by farmers' associations and

range from establishing processing capacities, registering and managing own brands, establishing community shops to coordinating regular markets dedicated exclusively to the sale of produce from family farmers. Learning in this field largely relies on direct exchanges between associations in the form of project site visits and participation at events with links to the commercial issues faced by family farmers, such as markets, fairs or festivals. The systematisation of experiences and knowledge consolidation in this field are scarce.

Networking

Networking in the conceptualisation of sociotechnical niches refers to processes that "facilitate interactions between relevant stakeholders, and provide the necessary resources (money, people, expertise)" (Schot and Geels, 2008). To characterise the networking processes that build the niche community of sustainable family farming in Colombia, we propose a typology of actors and describe the main patterns of interaction.

The actors involved in the niche community can be divided into six categories: (i) individual farm families, (ii) farmers' associations, (iii) supportive NGOs, (iv) international donors, (v) researchers and (vi) state entities. The family is the main analytical unit around which the concept of family farming is organised. For our study, the individual families (i) represent the 'end users' of the technical innovations being nurtured in the sociotechnical niche. Their role in the innovation process is manifold. They are involved in the processes of learning by doing, by adapting and applying the alternative sustainable farming practices on their own farms, as well as in the dissemination of knowledge through learning formats that facilitate exchanges between farmers. Their agency is also central in the establishment and operation of farmers' associations. The farmers' associations (ii) involved in the analysed niche community are organised groups of different kinds of family farmers. Important support for the establishment and operation of farmers' associations is provided by a variety of non-governmental organisations (supportive NGOs) (iii), which have rural development issues as part of their field of action. Support is commonly linked to the implementation of single (short-term) projects or (long-term) programmes coordinated by supportive NGOs and can comprise diverse activities, such as professional advice and follow-up, training campaigns, facilitation of knowledge exchange among farmers and associations and direct investment in inputs and equipment. Financial resources for the realisation of those projects and programmes is often secured through grants from international donors (iv). Some donors have been supporting the niche community more or less continuously for decades. As well as projects and programmes led by supportive NGOs, financial support from international donors has been key for the realisation of research studies and the systematisation and documentation of knowledge within the niche community. To achieve this aim, the participation of researchers (v) committed to alternative approaches to agriculture has been key since the early stages in the 1980s and 1990s. Finally, various state entities of regional or local character (vi) have supported projects undertaken by farmers' associations, supportive NGOs or researchers within the niche community.

The formation of a global niche level

The formation of a global niche encompasses the aggregation and circulation of generic lessons, and – in the case of niches at an advanced phase of development – the application of those generic lessons for the design of replication projects (Geels and Deuten, 2006). To capture the presumed formation of a global niche in the case study, the typology of actors introduced in the previous section is extended by focusing on the role of those actors in aggregating, circulating and applying generic lessons.

The work of supportive NGOs appears relevant for the formation of a global niche. They play an important role in the aggregation of lessons from several local projects and the consolidation of generic rules, for instance in the sense of generic procedures and know-how about the design, formulation, fundraising and implementation of programmes that entail the initiation of new projects and/or the strengthening of existing local projects. The publication of printed and

digital materials is also a common task of supportive NGOs, which contributes to the consolidation and circulation of generic lessons among the niche community. For instance, booklets or books on agroecological principles; handbooks for the construction and operation of bio-digesters, solar driers and other devices; or practical guidelines for the transformation process of individual farms. Research and academic institutions within the niche community also contribute to this aim through research studies evaluating local projects and their impacts. However, knowledge circulation to and at the local level seems to take place predominantly through direct exchange, which is in line with the preferred training formats that emphasise the direct practical application of knowledge on the farms. In this context, the professional staff of supportive NGOs play a significant role in the aggregation and circulation of knowledge.

International donors have been crucial in the development of the niche of sustainable family farming practices in Colombia. Supportive NGOs with long track records in the field of sustainable family farming practices (such as La Cosmopolitana, CIPAV and Podion) have counted on regular financial support from international donors (e.g. Misereor, Swissaid and Oxfam). Their support has facilitated the establishment of farmers' associations, such as ASPROINCA, which relied on support from Swissaid in the initial stage of its development. International donors have been key for the systematisation and dissemination of lessons by supporting studies and publications in the field of sustainable family farming in Colombia. International donors have also supported certain recent initiatives carried out by supportive NGOs (particularly church organisations) and universities, which have fed the current debate on rural development issues in a post-conflict scenario through studies presenting insights into the current state of sustainable family farming and future alternatives. Moreover, international donors appear crucial when considering processes in which generic rules are used to achieve replication, i.e. to frame and initiate new local projects and to expand the niche. Here too, the mobilisation of required resources often depends on support from international donors.

This rather simple analytical pattern, linking the activities of farmers' associations with a local niche level and the agency of NGOs and researchers supported by international donors with the formation of a global level, reflects the distribution of roles that are found in most of the interactions and concrete activities of the community. However, there are notable exceptions to this common pattern that point at other alternative processes of global niche level formation, where farmers' associations and local government entities play significant roles. It is not uncommon to find references to activities undertaken by individual farmers' associations or projects coordinated by supportive NGOs that have been supported by government entities, such as local municipalities, regional environmental agencies or state-owned utilities (e.g. water and energy utilities). However, these examples of public support tend to be sporadic contributions emerging from local circumstances, rather than expressions of a national or regional long-term programme or policy. Moreover, there are hardly any examples of long-lasting public support of local projects within the niche community. This demonstrates that the flow and translation of knowledge, lessons and rules into policymaking at government level does not seem to happen.

Another interesting process of niche formation that does not fit the common pattern described above is found in a handful of replication initiatives autonomously formulated and implemented by farmers' associations. Partnering with well-established farmers' associations for the initiation and implementation of new programmes is a common strategy followed by supportive NGOs. The experiences and capacities of mature farmers' associations provide important resources (e.g. knowledge, skills and demonstration sites) for projects that aim to replicate good practices in other communities. However, tasks such as project formulation, fundraising, project management and reporting are commonly assumed by supportive NGOs. ASPROINCA offers a couple of examples in which the association was the initiator and coordinator of projects aiming to use its own consolidated knowledge to support the establishment of new local projects. Interestingly, financial support for these unusual replication activities was secured mainly through public resources from government entities: a regional environmental agency and the

state organisation managing national parks and natural reserves. To date, these projects have not led to further replication or variations and remain an exception in the development of ASPROINCA.

8.2.6 Discussion

In this section, the results of the study are discussed from two different perspectives. The first perspective seeks to characterise the current state of the analysed community of initiatives as per the conceptualisations of sociotechnical niches and to derive suggestions about how the community might advance towards the broader diffusion of the innovations that are being nurtured. The second perspective aims to reflect on the applicability of the conceptual framework to the studied case and emphasises the particularities of the case, which point at aspects that are still underrepresented in the conceptualisation of sociotechnical niches.

Characterising the analysed community of initiatives

The analysed community of initiatives that advances sustainable family farming practices in Colombia displays features of the inter-local and global phases proposed by Geels and Deuten (2006). Generic lessons are being systematically put into practice by supportive NGOs and researchers within the community. Over the past two or three years, there have been increased efforts to consolidate and transfer knowledge from the niche community to wider audiences – and in particular to policymakers – in order to feed into the political debate about rural development, which is a crucial issue in the ongoing peace process. Moreover, supportive NGOs are often involved in the replication of experiences, i.e. by framing and coordinating new local projects. However, our analysis indicates that the scope of influence and the expansion of the niche depends, to a large extent, on the resources and agency of almost the same constellation of supportive NGOs and international donors that have been actively promoting the niche community since its initial stages. Broadening the type of actors involved in the niche is imperative for the expansion of the niche. The involvement of relative outsiders can increase the scope of the cognitive frameworks and resources (e.g. knowledge, access to other networks, political influence and finance), which, in turn, can increase the influence of the niche and its capacity to replicate generic lessons more widely. This lack of breadth points to poor communication and dissemination of consolidated knowledge and generic lessons to wider audiences, i.e. beyond actors already involved in rural development and agricultural issues. Important lessons and resources for the niche might be found in other communities that deal with environmental sustainability issues, such as water protection, climate change or biodiversity. Moreover, links to urban contexts seems to be scarce and these could be important for developing the commercial aspects that are prominent in the niche learning processes.

Related to the lack of breadth of the niche is the irregular and unsystematic involvement of state entities. The sporadic involvement of state entities in supporting single projects points to difficulties in the flow of lessons between the niche and regime actors; or a lack of translation processes as conceptualised by Smith (2007). The guiding vision of the niche community (which could be summarised as strengthening Colombian family farmers' livelihoods) calls for the adoption of lessons from the niche by state entities. For state entities are fundamental in preserving the incumbent sociotechnical regime by the continuous promotion of mainstream agronomic techniques for increasing market competitiveness as a means of improving the living conditions of family farmers. The required adaptation of lessons learned involves dealing with the paradox of niches that aim to reformulate the existing sociotechnical configurations, whose lessons should now be made functional in the regime, i.e. the sociotechnical configurations that are being challenged. This translation process comprises "reinterpreting elements of socio-technical practice in the niche and inserting them into regime settings, or modifying the niche in the light of lessons learnt about the regime" (Smith, 2007). To achieve this, greater involvement of state actors in the niche would be necessary. The type of actors required are those who find promising options for their own field of work in practices being applied in the niche, and who can contribute to the niche learning processes with cognitive frameworks as used by incumbent

state entities. Innovations being nurtured in the niche can offer promising alternatives for state entities, particularly at local (e.g. municipality and '*cabildos*') and regional (e.g. water basin agencies and '*departamentos*') administrative levels.

A prominent characteristic of the analysed niche is the great variety of topics that are tackled in the learning processes and the emphasis on organisational issues. As well as the technical innovations directly linked to sustainable family farming practices, the niche can be considered to nurture organisational innovations; i.e. novel configurations and strategies within farmers' associations to advance the most basic elements of the shared vision – food sovereignty, autonomy, fair commercial channels and agroecology. This characteristic implies an additional paradox to further development: variety in the learning process is desirable in order to increase the likelihood of changes in cognitive frameworks and assumptions that might be fundamental to advance sustainability, but too much variety can also be problematic as it "dilutes precious resources and prevents accumulation […], creates uncertainty and may delay choices/commitments (by consumers, policymakers)" (Schot and Geels, 2008). This paradoxical situation might translate into additional difficulties for broadening the niche community, making it challenging for new actors to embrace the same range of expectations and innovation strands that have provided consistency to the niche.

Reflecting on the applicability of the conceptual framework

Applying the analytical concepts of sociotechnical niches to the community of initiatives that promote sustainable family farming practices in Colombia is not without difficulty. The challenges emerge from two main particularities of the case: a) the analysed niche does not fit the basic assumption of market-based diffusion of innovations; and b) the case appears to be an example of supportive interaction (alignment) between the levels of the niche (the analysed community of initiatives) and the landscape (peasant movements).

Sociotechnical niches are more often associated with innovation trajectories of single technologies. Ideal trajectories lead to the consolidation of commercial products that compete in the corresponding markets (Raven, 2007). Markets are the societal institutions through which the broad diffusion of sustainable technology innovation is expected to be reached. The analysed case implies difficulties with these central assumptions. The motivations of the niche actors to engage in testing and adapting sustainable farming practices do not rest on expectations of commercialisation of the nurtured technologies. The organisational forms that are applied and co-created are based on solidarity values (e.g. associations and peasant schools), rather than on commercial interests (e.g. business models or companies). In this respect, the analysed niche displays features of what some academics refer to as "grassroots innovation" (Seyfang et al., 2014; Smith et al., 2016).

Moreover, in our study these particularities of the niche seem to reflect certain characteristics of the incumbent sociotechnical regime. The various aspects that are the subject of experimentation within the analysed niche can be seen as a search for alternatives to the provision of agricultural extension services for Colombian family farmers, i.e. training, technical innovation and commercial channels. Market-based structures for the provision of these services have not yet been established in the incumbent regime. The state is central to the provision of such functions through different policies, programmes and executive entities at all administrative levels; from national research institutions – such as the Colombian Corporation for Agricultural Research (CORPOICA) – to single municipalities through the Municipal Agriculture Extension Units (UMATAs). Private/commercial firms play a marginal role in the provision of the system elements that provide extension services to small farmers. Thus, the organisational innovations that are co-created in the analysed niche can be seen as alternatives to the structural deficiencies of components of the regime that deal with the techno-economic issues of small farmers. Some innovations – such as promoters' programmes, peasant agroecology schools, rotary funds and environmental committees – assume tasks that are

generally provided by state entities, such as technical assistance, training, targeted financial schemes and environmental standards assurance. Consequently, one potential pathway for the niche to achieve the broad diffusion of the nurtured technical innovations implies the reconfiguration or substitution of socio-political structures that provide extension services in Colombia, rather than the growth and stabilisation of a market niche. However, additional research and analysis is needed to identify how and to what extent non-technical innovations from the niche might be translated into socio-political reconfigurations of the relevant components within the regime, which in turn could facilitate the broader diffusion of the sustainable family farming practices nurtured in the niche.

The community of initiatives can be considered as a practical expression of broader social movements aiming for the socio-political recognition of peasants and their lifestyles. This link has connotations which are not solely national: the adoption and further development of agroecology by peasant movements in Latin America and other regions has been gaining interest amongst academics in the field of rural studies (Altieri and Toledo, 2011; Sevilla and Martinez-Alier, 2006). Peasant movements embrace agroecology as a means of achieving greater autonomy and control over their territories. "It aims at and materializes as the creation and development of a self-controlled and self-managed resource base" (Rosset and Martínez-Torres, 2012). Our analysis also suggests supportive interaction (alignment) between the niche (the analysed community of initiatives) and the landscape (peasant social movements in Colombia and Latin America) levels. The peasant movement(s) provide a general ideological framework, which serves as a basis for articulating common understanding of the problematic issues and expectations of alternative solutions, while the niche tests and demonstrates concrete alternatives for specific problematic issues around the livelihood of peasant families, which helps to support the niche expectations and the ideological base of the peasant movement(s). This is, however, a simplified description of the interactions that might take place and more detailed analysis is still needed to fully understand how landscape components interrelate with niche level dynamics. The interaction between the niche and landscape levels attracts little attention in the literature on sustainable transitions (Geels, 2011), and when landscape elements are considered they are mostly analysed as sources of pressure to incumbent regimes (Elzen et al., 2011; Smith et al., 2005).

8.2.7 Conclusion

The study presented here aimed to provide insights into and recommendations for the development and diffusion of sustainable family farming practices in Colombia. A transformative methodology to induce learning processes was applied, which sought the generation of robust knowledge on strategies for strengthening the Colombian family farming sector in the economic, social, environmental and cultural domains. Moreover, the methodology enabled the investigation of the community of initiatives advancing sustainable family farming practices in Colombia in the light of conceptualisations of sociotechnical niches.

We found indications that a niche of sustainable family farming is developing in Colombia. It can be considered to be at a mature level of development (global phase), where generic lessons are being consolidated and used for framing new local projects. However, the niche lacks breadth (i.e. requires greater diversification in the type of actors involved), which results in a low capacity for expansion and a dependency on international donors for reproducing experiences. In this respect, and based on the conceptualisation of the sociotechnical niche, we recommend that the lessons learned from the niche should be communicated and disseminated to wider audiences, beyond those actors already involved in rural development and agricultural issues. Additionally, the niche has been ineffective in influencing policymaking at any government level in Colombia. The general recommendation in this context is to promote the re-interpretation of niche lessons through the cognitive frameworks and legal system of state entities. Awareness and caution is needed in this respect, as the process implies striving for a balance between the multidimensional and holistic approach rooting the sustainable family farming practices nurtured by the niche and the search for standards and models that are easily replicable and

compatible with existing administrative and governmental structures. Further research is needed to explore effective ways of broadening the niche and translating niche lessons to state policies, while maintaining (or reinforcing) the niche's strong sustainability approach.

The analysed niche may be searching for pathways that do not necessarily rely on markets for driving broad diffusion. The diverse non-technical innovations nurtured by the niche can be understood as responses to structural deficiencies within the regime. The open question here is whether those niche innovations can be translated into or induce socio-political reconfigurations of the relevant components of the regime. Thus, additional research would be needed to clarify the suitability of such pathways. Finally, the analysed case provides an example of alignment between niche and landscape levels. The interaction between these two levels is a field of study that has attracted little attention in the literature on sustainable transitions.

There is strong potential for family farming to contribute to the transition towards sustainable agriculture. It is an integrative and productive way of life directly linked to the environment, and is often based on a profound knowledge of the ecosystem. In the Colombian context, the socio-political dimension of agriculture is particularly relevant and strengthening sustainable family farming will be key to advancing the practical realisation of the peace agreements. The analysed sociotechnical niche is a source of promising alternatives that can contribute to shaping the transition to a fair, peaceful and ecologically friendly society in Colombia.

8.2.8 Acknowledgments

Financial support from the WISIONS initiative (www.wisions.net) was invaluable for this study. Our most sincere thanks go to the management and promoters team at ASPROINCA and the coordinators of the RedBioCol network for their support for the organization and of the *cb*MLS. Moreover, this research would not have been possible without the valuable contributions made by all the participants at the case encounter in Riosucio; the experiences, knowledge and ideas they shared were essential for this study and we would like thank them all. We would also like to thank the two anonymous reviewers whose comments helped us to improve the quality of the article.

9 Transits of knowledges and practices from the bottom-up

9.1 Charting article 4 in the research

This is a conceptual study that took a detailed look into the concept of "grassroots innovations". This concept was first proposed by Seyfang and Smith (2007), and has been applied and further developed in the last decade by scholars studying sustainability innovations that emerge and develop in spaces of civil society. The interest of the study is on theoretical insights into the way novel knowledges and practices developed by grassroots innovation initiatives eventually diffuse, i.e. transit to and are applied in other social arrangements. To that end, an analytical perspective is developed that responds to the shortcomings of conceptualisations of grassroots innovations, based mainly on theoretical insights from strategic niche management. Two main conceptual modifications are introduced. First, the diffusion pathways of innovations from the bottom-up are conceptualised as transdisciplinary research process. Second, particular attention is placed on the multiplicity, situatedness, and permeability of cognitive frames, and on the relevance of these categories for understanding and supporting diffusion from the bottom-up. In the framework of this doctoral research, this article advances a conceptual framework that permits the conceptualisation of diffusion processes that transcend the localities of bottom up initiatives. It also takes first conceptual steps towards the conceptualisation of transformative research alliances, in which the academic research of innovation diffusion is a constitutive part of transdisciplinary endeavours that promote the diffusion of innovations.

9.2 Article 4

This section comprises the preprint version of the article with the title "Transcending the locality of grassroots initiatives. Diffusion of sustainability knowledges and practices through transdiciplinary research". It was submitted for review to the journal Environmental Politics on May 31, 2019.

Transcending the locality of grassroots initiatives. Diffusion of sustainability knowledge and practices through transdiciplinary research

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Abstract

Grassroots innovation initiatives are spaces for civil society reflection and action for advancing sustainability. Scholars focusing on grassroots innovations have often taken theoretical insights of strategic niche management (SNM) as the conceptual basis for their analysis. With an increased volume of empirical studies, the shortcomings of relying on the SNM conceptualisations have become apparent. The aim of the present study is to develop a conceptual framework that responds to those shortcomings by conceptualising the diffusion pathways of grassroots innovations as transdisciplinary research processes. Furthermore, the study focuses on the multiplicity, situatedness and permeability of cognitive frames. The developed framework shifts the focus from stabilising single cognitive frames to creating spaces of knowledge articulation where diverse cognitive frames work jointly to (i) process experiences from grassroots initiatives; (ii) create knowledge and promote practices; and (iii) facilitate the transit of such knowledge and practices across different localities and scales.

Keywords: grassroots innovation, strategic niche management, sustainability transitions, innovation diffusion, diffusion pathways, transdisciplinarity

9.2.1 Introduction

Grassroots innovation initiatives are spaces for civil society reflection and action for advancing sustainability. They are conceptualised as 'networks of activists and organisations generating novel bottom–up solutions for sustainable development; solutions that respond to the local situation and the interests and values of the communities involved' (Seyfang and Smith, 2007). They provide space for articulating alternative understandings of sustainability and for crafting practical alternatives for its realisation that are not aligned to mainstream systems of consumption and production. Several recent studies have focused on grassroots initiatives seeking innovative ways to tackle sustainability challenges in different fields, such as energy (Ornetzeder and Rohracher, 2013; Seyfang et al., 2014), food (Smith, 2006; White and Stirling, 2013), communications (Ilten, 2009), farming practices (Ortiz et al., 2018), complementary currencies (Longhurst, 2012; Seyfang and Longhurst, 2016) and eco-housing (Smith, 2007).

While the initiatives studied through the concept of grassroots innovations vary in their aims and processes, the cumulative analytical insights highlight three specific values and contributions that such civil society action for innovation can make in shaping sustainable realities. (1) First, grassroots initiatives provide *space for reflection and action*. They 'serve as a dialogical device for reflecting critically upon mainstream reforms'. (Seyfang, 2009) They can help to overcome the limitations of individual attempts to change unsustainable patterns of production and consumption by fostering the mutual search for, and experimentation with, alternatives. (Seyfang and Smith, 2007) (2) Grassroots initiatives generate *critical knowledge* on the issues they address, which represents a valuable 'resource for debating and constructing different pathways to sustainable futures'. (Smith et al., 2014) Situated at the margins of mainstream innovation, consumption and production, they can help to make visible the socio-political structures that dominate the issues in question and generate ideas about how to overcome these issues. (Ortiz et al., 2018) (3) Finally, grassroots innovation initiatives can bring about proven *practical solutions* with the potential for broad adoption, for instance by being incorporated into mainstream market-based diffusion channels. (Ornetzeder and Rohracher, 2013)

Most studies focusing on grassroots innovations over the last decade have taken theoretical insights from strategic niche management (SNM) as the conceptual basis for their analysis (Smith and Seyfang, 2013). Framed under SNM, the emergence and potential broad diffusion of grassroots innovations is understood as the outcome of the development of sociotechnical niches. SNM explains the progress of sociotechnical niches as resulting from reiterative relational work between local projects (e.g. local initiatives and activists), the global niche level (particularly characterised by the emergence of intermediary actors), and the broader context (notably the incumbent sociotechnical regimes). Intermediary actors play a crucial role in consolidating the niche and facilitating diffusion dynamics. '[T]hey aggregate learning and resources to help grow the niche through replication of projects, and influence regimes to adopt niche ideas and practices.' (Seyfang et al., 2014)

SNM can be useful for analysing the evolution and consolidation of communities of grassroots initiatives. However, this approach has shortcomings when applied to grassroots initiatives on innovation, particularly in its inability to account for the relevance of the local context (apart from generalised lessons learnt) and of skills (apart from knowledge) (Smith and Seyfang, 2013). The approach is also inadequate for reflecting the emergent and contesting character of grassroots initiatives (Smith et al., 2016). Furthermore, SNM has focused on technical components of innovative practices and how to fit these into commercial production and consumption structures. (Raven et al., 2016) This, in turn, is reflected in a strong orientation towards consensual processes where the generalised is extracted and valuated, while differences, contradictions and tensions are sorted out and neglected. Moreover scholars often follow a twofold purpose of 'studying and supporting' grassroots innovations (Smith and Seyfang, 2013); i.e they have both epistemic and transformative goals. However, the conceptual basis and implications of embracing 'studying and supporting' have not been explicitly articulated in the standard literature.

Therefore, it seems reasonable to propose broader analytical perspectives on grassroots innovations: (i) perspectives recognising the diversity of potential contributions that might emerge from the grassroots instead of reducing it to a potential cradle of technical solutions (Smith et al., 2016); (ii) perspectives encompassing the emergent, critical, contesting and uncertain features of civil society initiatives instead of the strategic and managerial nature of company-driven innovation processes (Smith and Seyfang, 2013); and (iii) perspectives that allows for conceptualizing the diffusion of grassroots innovation as transdisciplinary research processes.

The present study develops such a perspective by means of three conceptual movements. In the first movement (section 'Conceptualising the diffusion of grassroots innovation'), we review recent scholarly work building and operationalising the concept of grassroots innovations, focusing on the mechanism explaining pathways for the diffusion and on the role of intermediaries. In the second movement (section 'Shortcomings of the grassroots innovation concept'), we focus on three lines of critique: (i) the applicability of SNM conceptual tools to grassroots innovation initiatives; (ii) the strong orientation towards that which can be generalised; and (iii) the lack of conceptual basis for the interrelation of science, civil society and other realms of society. In the third movement (section 'Diffusion as transdisciplinary knowledge articulation'), we reconsider the reviewed diffusion mechanisms by emphasising difference, in terms of different ways of knowing, acting and being (Vilsmaier et al., 2017). This leads to the conceptualisation of grassroots initiative-based transdisciplinary research spaces to foster innovation and diffusion. We analyse the diversity that emerges from the different cognitive frames involved in attempts to facilitate or modulate the transit of knowledge and practices across localities and across sociotechnical levels. At this stage, the focus is on how knowledge and practices from the grassroots are processed by exploring, articulating and negotiating diverse interpretations, and how this can be coupled with scientific research to learn *about*, *with* and *for* the grassroots. The final chapter summarises the proposed conceptualisation

for transcending the locality of grassroots initiatives through transdisciplinary research and outlines further fields of inquiry.

9.2.2 Conceptualising the diffusion of grassroots innovation

Grassroots innovations are described in contrast to conventional 'market-based' innovations. Table 9 illustrates this contrast based on Seyfang et al. (2014): the guiding motivation (social and/or environmental challenges rather than profit); the context in which sustainability innovations are expected to work (civil society rather than market economy); the organisational forms involved in the innovation process (diverse types of associations rather than companies); the values underlying the search for innovation (focus on solidarity and sustainability rather than efficiency and profit); and the resource base for advancing the innovation (voluntary input, reciprocal relationships and grants rather than commercial loans and access to research and development infrastructure). Over the last decade, scholars researching grassroots innovation have applied and expanded conceptualisations of sociotechnical niches and SNM to build theoretical approaches to understand the role of these innovation initiatives in broader transitions towards sustainability. In this section we review these conceptual advances.

Table 9 Characterisation of grassroots innovation in contrast to market-based innovations, based on Seyfang et al. (2014)

	Grassroots	Market-based
Motivation	Social justice; environmental sustainability	Profit
Context	Civil society	Market economy
Organisational forms	Diverse: e.g. cooperatives, associations, community initiatives	Companies
Resource base	Voluntary input, mutual exchange, reciprocal relationships, grant funding	Business loans, commercial incomes, R&D infrastructure
Primary values	Solidarity, strong sustainability	Efficiency and profit

The development of sociotechnical niches

The development of sociotechnical niches is conceptualised around four main aspects: protection, co-evolution, internal niche-building processes and two-level development. *Protection* is a fundamental property allowing for experimentation with novel approaches that do not meet the sociotechnical arrangements and assumptions of the conventional systems of production and consumption. Protection implies shielding the innovation from a broad set of societal selection processes such as industry structures, infrastructure, dominant practices, technological paradigms, policies, political power and cultural values. (Smith and Raven, 2012) In the case of grassroots innovations, protection is particularly relevant in contrast to the mainstream, i.e. as 'spaces where stronger sustainability values are expressed and practiced' (Seyfang et al., 2014) or as spaces outside the reach (or on the margins) of incumbent infrastructure or socio-political arrangements (Gupta et al., 2003; Ortiz et al., 2018). The experiences gained by experimenting with novel approaches allow for testing, validating and – when needed – adjusting not only the technical qualities of the innovation, but also learning about the social environment in which they are embedded. (Schot and Geels, 2007) The *co-evolution* of non-technical aspects seems to be particularly important for the development of grassroots innovations. For instance, organisational practices and skills have been highlighted as crucial resources for the emergence and consolidation of single initiatives (Seyfang et al., 2014) and as a field of experimentation to strengthen and maintain long-lasting initiatives (Ortiz et al.,

2018), as well as being a central aspect when civil society initiatives move to profit-oriented professional providers (Ornetzeder and Rohracher, 2013). This co-evolution is promoted through three *internal niche-building processes*: (i) by consolidating lessons on both the technical and social dimensions of the innovation (learning); (ii) by maintaining and expanding the network of actors supporting the niche (networking); and (iii) by creating and communicating narratives about the positive future in which the niche innovations play a crucial role (articulating expectations). These niche-building processes lead to the aggregation of knowledge and experiences from different single initiatives and projects, and the consolidation of a 'community that share cognitive, formal and normative rules' (Schot and Geels, 2008). The progress of that community is conceptualised as *two-level development*: the local level, which represents the set of single projects in which niche actors engage in experimenting with innovations, and the global level, which represents the institutional infrastructure that allows and promotes the aggregation, storage and circulation of generalised knowledge.

Diffusion pathways of grassroots innovations

The formation of the global niche level is crucial for explaining the diffusion of niche innovations. The development of the global niche level is conceptualised as the process by which a shared 'cognitive frame' (Raven and Geels, 2010) evolves. Cognitive frames consist of 'problem agendas, problem-solving strategies, search heuristics, theories, testing procedures, and design methods and criteria' (ibid). They serve as endogenous determinants for their own evolutionary process, i.e. how sociotechnical variation, selection and retention take place. Variation is guided by shared expectations about novel (better, more sustainable) solutions and these variations are tested through diverse local projects, the outcomes of which are collectively interpreted and codified. This implies a social process of selection (comparing locally-achieved outcomes to the shared expectations) and retention (embedding meaningful data from local experiences into the abstract cognitive frame). In the ideal development of niches, cognitive frames evolve and stabilise, providing a repertoire of decontextualised knowledge able to guide action for a larger sets of local contexts (Geels and Deuten, 2006). Based on this conceptualisation, Seyfang and Haxeltine (2012) suggest three diffusion pathways through which grassroots innovations can transcend their locality and contribute to broader transitions:

(1) Replication: Replication is the process by which generalised knowledge is applied to populate the niche with local projects that enact and reproduce shared and (increasingly) stable cognitive frames.
(2) Growth in scale: This pathway implies that the decontextualised knowledge helps single local projects to reframe themselves, enabling them to expand their own coverage. In this pathway the diffusion is linked to the successful growth of single initiatives likely to be adopted by professional and commercial companies and to gain high shares of the corresponding niche markets. (Ornetzeder and Rohracher, 2013)
(3) Translation: The third diffusion pathway refers to the circulation of grassroots innovations (or rather some elements of them) beyond the community of niche actors where they have been nurtured. The focus is on the interactions between the niche and regime levels. Analytically this interaction implies the encounter of different – and potentially antithetic – cognitive frames.

Functions of intermediaries

Intermediaries are actors who assume the relational work to connect single and often isolated initiatives with each other and with actors beyond the niche community. Expanding on the work of Geels and Deuten (2006), Hargreaves et al. (2013) propose four functions that describe the role of intermediaries. Figure 9 provides a schematic illustration of them:

(1) *Aggregation* consists of de-contextualising knowledge gained through local experiments by niche actors, resulting in more generalised knowledge that can circulate among different local situations.
(2) *Institutionalisation* consists of establishing stable rules and procedures for the production, storage and circulation of the aggregated knowledge. Examples include regular conferences, workshops, proceedings and online platforms.
(3) *Framing and coordination.* By taking advantage of the collective knowledge reservoir generated at the global niche level, intermediaries can frame and coordinate the progress of existing projects, or establish new local projects.
(4) *Brokering*. Intermediaries engage in brokering and managing partnerships beyond the niche community aiming to ensure broader support for the niche and expanding the resource base for niche development and growth.

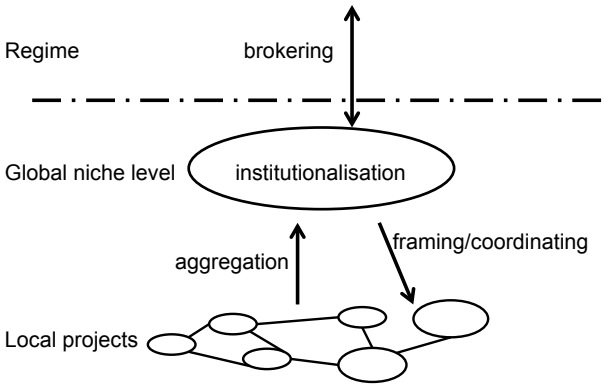

Figure 9 Schematic description of the functions of intermediaries in the consolidation of global niche levels. Own illustration based on Geels et Deuten (2006) and Hargreaves et al. (2013).

9.2.3 Shortcomings of the grassroots innovation concept

Applicability of SNM to grassroots innovation

Scholars applying SNM theoretical tools to grassroots initiatives have identified limitations to their application. These limitations can be classified in three critical aspects: the singularity of localities, the relevance of abilities and the challenging character of grassroots initiatives.
Growing empirical evidence on grassroots innovations highlights that the use of lessons learned by local projects is not as straightforward as a re-application of codified knowledge, for instance by following guidelines or manuals (Hargreaves et al., 2013). The particularity of grassroots initiatives as 'heavily grounded in local civil society and community engagement' (Seyfang et al., 2014), re-contextualisation of those lessons may be required, particularly when considering grassroots initiatives as spaces for reflection and action. While toolkits and guidelines can inspire and support the creation of new projects, or strengthen existing ones, the iteration of action and reflection requires sensitivity, a critical attitude and experience-based knowledge about the local particularities in which each initiative takes place.

The re-application of lessons also requires a variety of abilities – implicit and explicit – which are unlikely to be equally present in any local grassroots initiative. Seyfang et al. (2014) suggest two types of 'skills' important for the functionality of civil society initiatives: a) professional skills, which include diverse types of expertise that can be easily linked to standard professions, e.g. engineering, management and accountancy; and b) soft skills, which are related to the capacity to shape and maintain interpersonal relationships that foster confidence and emotional stamina and which are key 'to deal with setbacks and lengthy project development phases'. (ibid) Consequently, the formation of a global niche level from grassroots innovations requires not only knowledge circulation, but also a wide range of abilities among the niche community, many of which can only be acquired in practice and depend on personal attributes. Moreover, some

case studies have found that peer-to-peer interaction formats are applied by civil society initiatives as means of fostering the circulation of knowledge and skills among niche community (Ortiz et al., 2018; Seyfang et al., 2014). This demonstrates that mutual learning among niche actors, in addition to the circulation of codified knowledge, may be necessary for consolidating grassroots innovations.

Finally, brokering on behalf of the niche community becomes particularly problematic when it includes building relationships with actors who are better aligned to regime configurations. Looking for successful intermediation – i.e. achieving broader support and expanding the resource base of the niche – might lead to focusing on those components of grassroots innovations 'that fit easily into the mainstream context, or that can be added on without too much cost or difficulty'. (Smith, 2007) This, in turn, implies sorting out components of critical thinking, i.e. 'criticism to the social structures reproducing vested economic interests, positions of political authority, cultural privileges, social norms, technological designs, and research agendas', (Smith et al., 2016) and practices challenging such criticised issues. Consequently, brokering increases the dichotomy that exists between the challenging character of grassroots initiatives and the aim of making them – or some of their components – more appealing to the mainstream. Case studies indicate that this tension finally leads to alterations to the niche community, such as adjusting the niche positive narratives (e.g. by strengthening the contrasting features versus the mainstream), fragmenting the niche (Smith, 2007) or re-orientating key niche actors (Ornetzeder and Rohracher, 2013).

Oversimplified relationship of science and society

As shown above, a twofold purpose to simultaneously analyse and support grassroots innovation initiatives has been identified (Smith and Seyfang, 2013). On one hand, the aim is to advance understanding about the processes by which civil society actively engages in crafting innovations for sustainable development. We refer to this aim as *epistemic*. On the other hand, a *transformative* purpose is often spelled out, which points in two directions: to support the emergence and development of grassroots initiatives and to capitalise on them to advance broader sustainability transformations. As outlined above, in order to tackle the epistemic purpose several studies on grassroots innovations apply theoretical tools from strategic niche management (SNM). However, conceptual frameworks that address the transformative aim of grassroots innovation research have not been explicitly articulated in the standard literature. A common underlying assumption is that researchers provide contributions that can be translated into policy recommendations and inform decisions made in socio-political arenas of society. The interconnection between research and policy is suggested, but not elaborated, by Seyfang and Smith (2007):

> A twin track approach is needed. On the one hand, we need research and policy that contributes to the creation of diverse grassroots innovations and engenders a variety of sustainable practices. On the other, research and policy is needed that learns from this wealth of alternative means of provision and embeds that social learning into the mainstream. [599]

Additional specific roles of research have been suggested in the literature, e.g. to open and feed into political discussions (Smith et al., 2016) or to 'engage grassroots innovators in explorations of whether and how they might navigate a course for wider recognition and support'. (Smith and Seyfang, 2013) However, this *transformative* purpose of research remains unelaborated or relies on implicit and simplistic assumptions about the relationship between research and policy, or more broadly between research and society. What has not been taken into consideration is the question of how far research can be solely attributed to science. Grassroots initiatives have made proven contributions with valuable knowledge gained from within their own realm. Similarly, the effects of scientists supporting and consequently intervening in the diffusion processes of grassroots innovations have not been fully assessed. What has become apparent in

the literature concerning the relationship between scientific research and grassroots initiatives is the need to ascertain whether the attribution of objectives – scientists following epistemic goals and grassroots initiatives following transformative goals – is an oversimplification and needs to be re-visited to clarify roles, tasks and contributions in this interplay.

Undermining the difference

While the 'niche metaphor' (Longhurst, 2012) has some analytical value, it is strongly oriented towards consensual processes where niche experiences are extracted, valuated, and generalised/standardised; while differences and contradictions are excluded and consequently, neglected. The focus on streamlined processes and consensual decisions does not properly account for the plurality and emergent dynamics that characterise how civil society initiatives evolve (Seyfang and Haxeltine, 2012), nor the multiplicity of mainstream practices (incumbent regimes) that are often challenged by grassroots innovations (White and Stirling, 2013).

The consensual orientation of SNM is strongly linked to its underlying emphasis on technology firms as the prevailing agents of innovation and markets as the prevailing societal institution for diffusion. The emphasis of SNM has been on the technical components of innovative practices and how to fit these into the commercial structures of production and consumption. (Raven et al., 2016) In this way, the focus is on avoiding deviation, i.e. on achieving a situation where '[l]ocal practices become part of a stabilised global technological regime, from which it is hard to deviate' (Geels and Deuten, 2006), rather than on searching for and validating new solutions. In this vain, technical standards play a vital role. Standards ultimately normalise the social practices linked to the use of corresponding technical solutions. (Shove, 2012) They are a means of fixing, integrating and reproducing the constitutive elements of those social practices.

Moreover, SNM emphasises codified knowledge as the sole or main determinant for the diffusion of innovations: 'through aggregation, formalisation, and codification of experiences [from] local practices' (Raven and Geels, 2010) 'context-free' (Geels and Deuten 2006) knowledge is produced, which is able to 'travel between local practices' (ibid). This emphasis restricts the analysis of diffusion processes. It sorts out a multiplicity of non-cognitive and non-codifiable aspects such as abilities and tacit knowledge that forge the sustainable practices with which grassroots initiatives are experimenting.

Looking through this 'niche metaphor', grassroots innovation initiatives can only be valuated as possible cradles of technical solutions, while other potential contributions for advancing sustainability remain overlooked. In this vein, Smith et al. (2016) propose a critical analytical perspective to niches, which highlights their value 'in challenging prevailing discourses and shifting the terms of debate by generating critical knowledge.' (ibid.) From this perspective, successful niche trajectories are not represented by the conventional idea of novel technical products and services diffusing through the market, but by the mobilisation of critical insights from the niche and of political agency beyond the niche. To achieve this, the critical analytical perspective as outlined still needs to clarify how to amend the consensual orientation of SNM conceptualisations. Furthermore, the intrinsic value of grassroots initiatives, as spaces where sustainability is debated and joint action is crafted, remains underestimated. Therefore, other (or broader) analytical perspectives recognising the value of these spaces appear reasonable; perspectives that consider the processes by which these initiatives might replicate. Interestingly, this type of perspective seems to resonate in the question posed by Seyfang and Smith (2007) at the end of what can be considered the inaugural article of the grassroots innovation concept, as applied in the present study: 'How to create and capitalise on grassroots diversity and populate mainstream systems of production and consumption with transformative sustainability ideas and practices?' (ibid.)

We argue that any response to that question must emphasise, value, articulate and bring to fruition (cultural) differences. This is the central argument for the conceptualisation of diffusion

through transdisciplinary research elaborated here. To that aim, we take a closer look at the cognitive frame concept, highlight the multiplicity and situatedness of the concept and analyse in detail the implications of recognising those features, thereby developing a perspective of grassroots innovation initiatives able to account for the multiplicity of cognitive frames in the diffusion process. However, the question of how to account for the non-cognitive, non-codifiable aspects of grassroots innovation initiatives remains unexplored. A thorough inquiry into this shortcoming would exceed the extent of this article and should be the focus of a further study.

9.2.4 Diffusion as transdisciplinary knowledge articulation

When tackling diffusion of grassroots innovations, the multiplicity and situatedness of cognitive frames, as well as their dynamics, are relevant. This is because, the way in which one's own and others' knowledge and experiences are interpreted, evaluated and appropriated is moderated by the cognitive frames that the actors bring to and incorporate into the process.

At this point, insights from discussions on transdisciplinarity can shed light on the implications of striving to generate and diffuse knowledge by involving different cognitive frames, i.e. producing knowledge that can be understood and applied by all involved parties to advance shared visions and actions of sustainability transition. Transdisciplinary research practices differ significantly in terms of how those aspirations are realised. While some propose and apply a science-centred approach in which scientific knowledge production is complemented through participatory processes and contributions from so-called non-scientific actors (Klein, 2001; Lang et al., 2012), we call for a critical and culturally sensitive transdisciplinarity where analysis and activism, research and decision-making – as well as knowledge production and societal transformation at large – are no longer separated, but considered and articulated as constitutive components of the same process. (Vilsmaier et al., 2017, 2015) This can be seen in terms of knowledge alliances (Stigendal and Novy, 2018) where different cognitive frames, motives and objectives are explored, articulated and debated to produce socially (Nowotny et al., 2001) and culturally (Vilsmaier et al., 2015) robust knowledge and action. It is not only the multiplicity and situatedness of knowledge, but also the dynamics generated in mutual learning processes (Ortiz et al., 2018; Vilsmaier et al., 2015) that create a promising approach for the diffusion of sustainability innovations. In this way, the permeability of cognitive frames becomes particularly important for understanding and achieving diffusion. Spaces of knowledge articulation can emerge '[i]n which the own, the uncertain and the differences can perpetually be fathomed, interpreted and negotiated' (Vilsmaier et al., 2017), spaces that are constituted through different ways of approaching sustainability challenges.

Spaces for knowledge articulation

From this perspective, a niche of grassroots innovation initiatives is expected to produce and diffuse socially and culturally robust knowledge by taking the multiplicity of cognitive frames into account. Framed in this way the consolidation and – ultimately – the success of niches of grassroots initiatives is linked to the construction and maintenance of spaces in which knowledge that can be effectively applied for advancing the niche's shared vision can be continuously generated. The focus, therefore, shifts from stabilising single cognitive frames to creating spaces of knowledge articulation where diverse cognitive frames work jointly. A niche understanding with the first focus implies that sociotechnical transformation happens through closure: the search for practical solutions to the sustainability issue of concern ends when broad adherence to the corresponding practices is more likely to be achieved. The focus on the knowledge articulation process, however, implies a more dynamic understanding where different transformative impulses can be generated. The socially and culturally robust knowledge and the joint actions that emerge within these spaces can take the form of stabilised technical designs (i.e. the form of the conventional niche metaphor). However, such results are not the sole or overarching goal and other forms of transformative impulses are possible, such as the generation of critical knowledge and its mobilisation in socio-political arenas or the reproduction of grassroots initiatives populating the mainstream with local spaces for reflection

and action. Moreover, adopting the proposed perspective on grassroots innovations also (re)opens questions about the subject, the means and the target of diffusion. In other words, what should be diffused, how and where become subjects to explore, articulate and negotiate between diverse cognitive frames.

In applying the outlined perspective to the diffusion of grassroots innovations, we must consider a more elaborated understanding of the settings in which the processing of knowledge and experiences of different actors and local conditions take place. The streamlined idea of one single actor (or type of actor, i.e. intermediary) assuming or modulating the transit of knowledge across different contexts is insufficient. Recognising this shortcoming of SNM as a tool for analysing grassroots innovations, Hargreaves et al. (2013) suggest thinking about intermediation as a process for opening spaces 'in different contexts (whether local, policy, market, social etc.) for new and diverse kinds of activity, rather than about developing a single successful approach or a strategic vision for (…) growth and diffusion.'

Multiplicity of cognitive frames

To achieve this, we shift the attention to the multiple cognitive frames that can be operating in settings directed towards diffusion of grassroots innovations, and differentiate them by means of their level of generalisation. To clarify what is meant by level of generalisation, we recall the notion of rules as 'generalisable procedures' and the situatedness of actors applying those rules. The rules of social life can be considered 'generalizable procedures applied in the enactment/reproduction of social practices.' (Giddens, 1984) A rule is considered 'generalizable because it applies over a range of contexts and occasions, [and] a procedure because it allows for the methodical continuation of an established sequence.' (ibid) Thus, the level of generalisation of social rules is determined by the range of situations in which they can be applied for building meaning and guiding action. In the same vein, the usefulness of a rule for an actor is determined by the specific situation in which that actor is located. This issue can be first explored at the global niche level. At this level, learning from the outcomes of local projects is 'a process of collective and negotiated sense making' (Raven and Geels, 2010). The global niche's cognitive frame comprises elements such as problem agendas, shared expectations and criteria by means of which single experiences and knowledge are interpreted and valuated. The resultant meanings and values are expected to be valid for the community of niche actors, i.e. for those who constitute the niche and incorporate the niche's specific cognitive frame. However, a single niche actor can also be a member of a local initiative, which in turn comprises (or continuously produces and reproduces) its own cognitive frame. Positioned in the situation and the context of the local initiative, the same actor might adhere to other interpretations and valuations of the same concrete experience; for instance an interpretation built against a problem understanding that is enriched with local specificities, which in turn leads to other set of evaluation criteria. Similarly, it is possible to explore what happens when moving to higher levels of generalisation, like in the case of a scientific actor (e.g. a single scientist or a research group) who is not only supportive but also actively engaged in the niche community. Positioned as a member of the niche, the scientific actor is expected to share the interpretations and values collectively ascribed to single observations or experiences. However, positioned in their own field of research (and if the empirical observations from the niche activities are relevant to that field) the same actor might be able to derive (or more probably link those observations to) general, more abstracted and universally valid statements about the behaviour of the empirical world, e.g. in the form of theories, models or concepts from their scientific discipline. Therefore, cognitive frames can be characterised by the range of situations and contexts for which they provide useful procedures of interpretation. The larger that range, the higher the generalisation level of the cognitive frame.

Furthermore, multiplicity can also be found within each generalisation level. For instance, at the level of single initiatives, each grassroots innovation initiative represents a space in which their members jointly articulate cognitive elements such as shared problem definitions, sustainability

visions, search heuristics and valuation criteria. These elements provide a shared frame for crafting and experimenting with novel practices and evaluating outcomes against the aim of transforming the unsustainable situation of concern in their local context. Multiplicity at this can emerge from differences between the localities in which each initiative is embedded. Moreover, multiplicity at higher levels of generalisation is also possible and ultimately relevant for diffusion dynamics. This can be illustrated by considering the generalisation level represented by sociotechnical regimes and scientific theories. For instance, the sociotechnical configuration of novel biogas technologies in the Netherlands and Denmark, continuously reinterpreted by changes, resulted in national energy and agricultural regimes. Accounting for both regimes was important to explain the different development paths in those countries (Raven and Geels, 2010). Moreover, different universal statements from academic disciplines can help to make sense of – and potentially strengthen – particular aspects of niche development. These may include *social* features of sociotechnical innovations, for instance questions about preferences and habits of individuals, organisational practices or political relevance, as well as *technical* aspects, such as the assessment and improvement of the performance of devices and techniques.

Mapping cognitive frames and knowledge articulation

Settings of knowledge articulation directed towards diffusion of innovative practices can be visualised based on the proposed characterisation of cognitive frames by mapping the frames on two coordinates: the vertical illustrating variation in the level of generalisation and the horizontal representing the multiplicity of cognitive frames that can feature similar levels of generalisation. Figure 10 illustrates this and presents examples of generalisation levels described in the previous section (i.e. local initiatives, global niche level, regime and scientific theories). The represented generalisation levels illustrate how the multiplicity of cognitive frames can be mapped along the proposed coordinates, they do not represent any fixed typology.

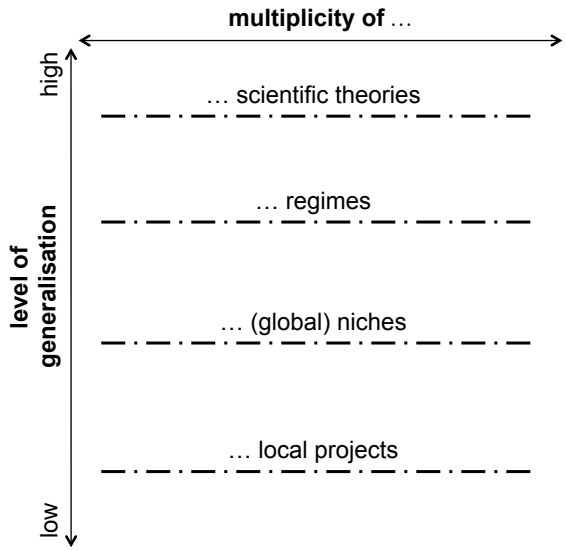

Figure 10 Mapping space for visualising settings of knowledge articulation directed towards diffusion. The dashed lines represent different levels of generalisation on which multiple cognitive frames can be found.

Replication pathway

This pathway comprises two different transits across different levels of generalisation, as indicated in Figure 11. In a first transit, outcomes and features of several local projects are (re)interpreted by global niche actors (e.g. intermediaries) and incorporated (in a re-interpreted form) into the global niche cognitive frame (*aggregation*). In the second transit, elements of the

global niche cognitive frame are transferred to local initiatives (*framing*), which are expected to integrate those generic elements into their own cognitive frame. As discussed before, this conceptualisation of the *framing* function lacks the requirements for re-contextualisation and mentoring found in grassroots innovation studies. As a result, the transit from the global niche to local projects should at least allow for reinterpretation of generic lessons by applying local cognitive frames. In the following discussions both intermediary functions (i.e. *aggregation* and *framing*) will be reconsidered by applying the proposed perspective on grassroots innovation as spaces for knowledge articulation.

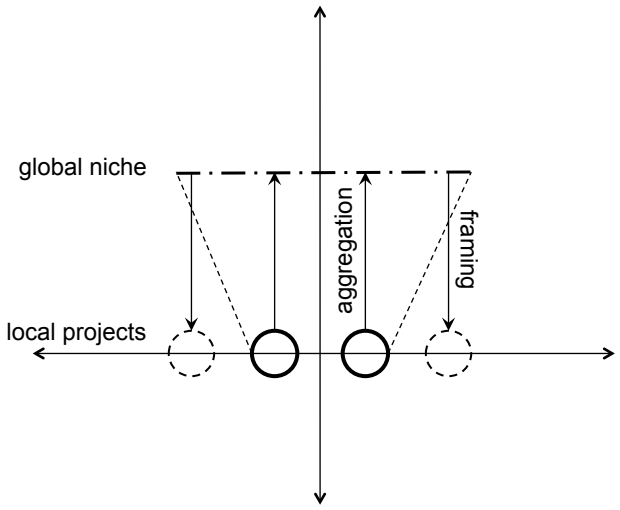

Figure 11 Intermediary functions (aggregation and framing) according to SNM visualised through the proposed tool for mapping the processing of knowledge and experience.

Transits towards the global niche level

Framed as spaces for knowledge articulation, any endeavour by niche actors that aims to extract generic lessons from local projects is conceived as a process that produces socially and culturally robust knowledge. To increase certainty that the knowledge can be understood and applied by all actors supporting the shared vision of sustainability transition, the process should involve the cognitive frames of those supportive actors. Figure 12 illustrates such a process, in which the experiences of one local project provide the basic material for mutual learning about the sustainability issue of concern. By interpreting the local project experiences through different cognitive frames, the process promotes in-depth understanding of the complexity and contextualisation of the local experiences, as well as the extraction of generic knowledge on the sustainability issue in question. The robustness of this knowledge can be fostered by articulating interpretations from different cognitive frames; for instance, those embodied by: (a) representatives of other local projects and intermediary organisations actively engaged with the sustainability issue in question; (b) regime actors with some interest in and/or relevant resources for advancing that issue; and (c) scientists with disciplinary knowledge and expertise to better understand relevant aspects of the local project and its relation to more general sustainability discussions. The cognitive frames of such actors are schematically mapped in Figure 12 as reference points from which the local project is observed and reflected on, towards the generation of 'collective knowledge repertoire' at the global niche level.

The actual composition of the setting illustrated by Figure 12 varies according to the subject, means and diffusion target. For instance, if the focus were on technical solutions that might be adapted and adopted in conventional systems of production and consumption, the involvement of regimes actors who could contribute insights from those conventional systems would be meaningful; e.g. representatives from companies and associations from the corresponding sector and political actors dealing with governance mechanisms for that sector. The contribution

of scientists from the field of organisation and management would also be important. However, if the focus were on consolidation and mobilisation of critical knowledge pointing to deeper structural issues of society and politics, expertise on how to feed into the political debate, as well as knowledge about the structures and processes by which political decisions are made and implemented, would be more relevant. Consequently, in this case it would be meaningful to involve actors such as staff from state administration agencies, representatives from political parties and/or leaders of social movements. Contributions from scientific fields such as sociology, political sciences and public administration would also be more suitable.

In addition, considering opposing perspectives also contributes to the robustness of the results. This could include the involvement of actors who are not aligned to, or supportive of, the sustainability concern in question and transformation option represented by the local project. Such a process should allow for the respectful recognition of and operation with contradictions and discrepancies. The aim is not necessarily to quash the opposing view to integrate it into the generic knowledge generated, but to make it explicit and consider it in relation to the more certain and consensual pieces of the collective knowledge repertoire.

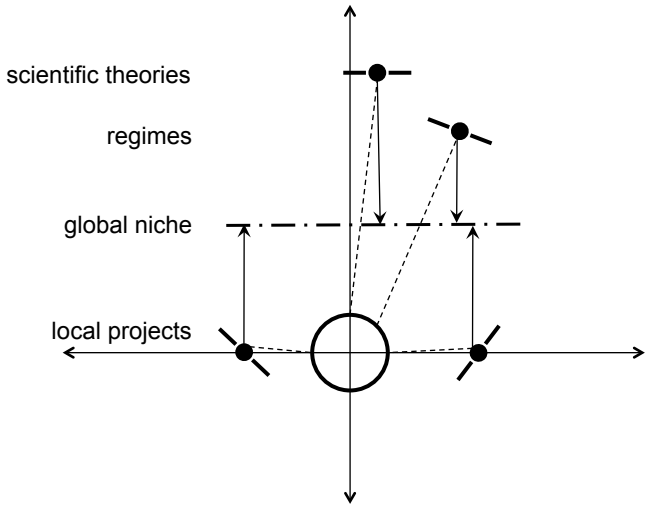

Figure 12 Extracting generic lessons from a single local project as generation of socially and culturally robust knowledge through a transdisciplinary transit of knowledge and experiences from the local to the global niche level.

Transits towards local projects

Figure 13 illustrates a setting that aims to incorporate knowledge and experiences about innovative sustainability practices in the particular cognitive frame and practices of a local project. In the illustrated example the basic material for the process is not only obtained from the global repertoire of knowledge of the niche, but also includes knowledge, experiences and expertise from an exemplary project (e.g. a civil society initiative with advanced results in the sustainability issue of concern). As a result, the process includes peer-to-peer interaction. Moreover, the transit can be promoted by involving cognitive frames of higher generalisation levels able to provide useful perspectives for the situation and context of the new local project.
As with transits towards global generic knowledge, the composition of the setting to promote replication depends on the subject, means and diffusion target of diffusion. However, in this case the target appears to be particularly pertinent, specifically in terms of the state of the initiative(s) that is expected to adopt the innovative sustainability practices. If the new local projects are embedded in well-established initiatives, the process can directly promote mutual learning on the practical solutions or critical knowledge that is being generated in the niche community. Expertise and knowledge that can contribute to that aim may include, for instance, officials from corresponding municipalities or from higher administration levels dealing with

the sectors directly addressed (e.g. energy, food, health, education etc.); entrepreneurs or representatives of companies present in the local context and in business sectors relevant to the sustainability practices of concern; and local political leaders. However, if the initiative is not already well-established, the process firstly has to tackle the challenges of initiating and consolidating civil society action at local level. This in turn requires other or additional knowledge and expertise; such as social workers, group psychologists or founding leaders of existing initiatives, as well as local actors who might eventually lead the new initiative.

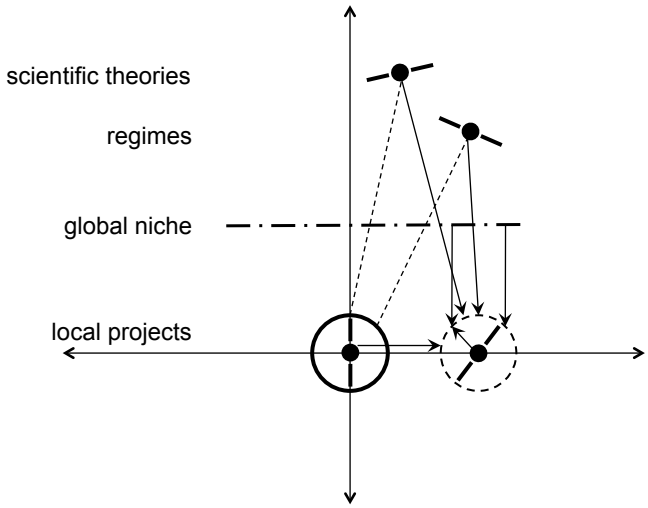

Figure 13 Framing local project as transit of knowledge and experiences on grassroots innovations through the articulation of multiple cognitive frames.

Translation pathway

The translation pathway has been suggested in order to explain particular patterns of interaction between niche and regime levels. In sustainability transition theories, niche innovations play a key role in the reconfiguration of sociotechnical regimes. In general terms, niche-innovations can feature competitive or symbiotic character towards incumbent regimes. Competitive: innovations nurtured in sociotechnical niches may have the potential to substitute conventional technologies. Symbiotic: they may be 'adopted as competence-enhancing add-on in the existing regime to solve problems and improve performance.' (Geels and Schot 2007) In this sense, translation refers to the process by which niche practices eventually transit into regime configurations.

Based on empirical studies, Smith (2007) suggests two types of translation processes that vary 'in the degree of involvement by actors from each context, and the degree of change being deliberated: is it about transferring practices or negotiating re-framings?' Figure 14 schematically illustrates the characteristic features of the transfer type of translation, which focuses on regime actors (re)interpreting practices nurtured in the niche according to the regime cognitive framework. The final outcome is the adaptation and integration of those practices that are most easily incorporated into the regime's cognitive framework. For instance, in the two specific cases analysed by Smith (2007) this form of translation resulted into: (a) adjusted codes and standards for house building, promoting the application of certain niche practices (like solar water heating and water recycling) by mainstream house builders; and (b) increased demand for organic produce at premium prices with food regime actors adopting elements of niche organic practices. In this type of translation process, 'a narrower sustainability is diffusing more broadly' (ibid) and stronger sustainability understandings or more critical values constitutive of the niches resulted sorted out. This translation process also implies modifications or change dynamics within the niche itself. More prominent is the need to re-define or strengthen the contrasting stance of the niche in relation to the regime. In practice, this

can translate into the fragmentation of the niche and increase the emphasis on those sustainability values that were sorted out in the translation process.

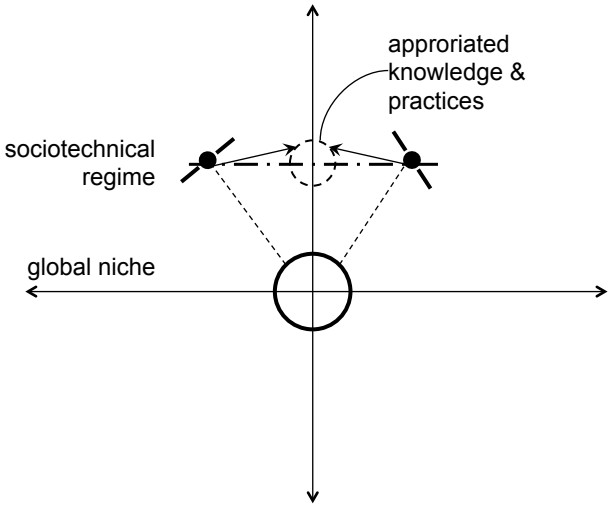

Figure 14 Regime actors (re)interpreting knowledge and practices nurtured in a sociotechnical niche.

The second type of translation suggested by Smith (2007) 'recognizes niche-regime differences more profoundly and seeks to understand the values, principles and activities that underpin each.' Translation in this case is a learning process in which niche and mainstream actors engage together with the explicit aim of expanding the capacities of mainstream actors to adopt sustainability practices nurtured in the niche. This process has similarities with the framing function discussed before. The important difference is that such a project is meant to provide a space in which not only niche actors but also regime actors experiment with niche practices. Figure 15 illustrates such a space, referred to by Smith (2007) as an 'intermediary project'. At this point, the importance of the permeability of cognitive frames for diffusion becomes particularly evident. Setting an intermediary project does not only require recognising the multiplicity of cognitive frames (in this case niche and regime); it also requires acknowledging and – more importantly – explicitly exploring, (re)interpreting and negotiating precisely those differences between the cognitive frames themselves. In this way learning is not restricted to techno-economic considerations that can be – for instance – codified into standards and regulations. Mutual adaptions of the cognitive frames can be part of the learning processes.

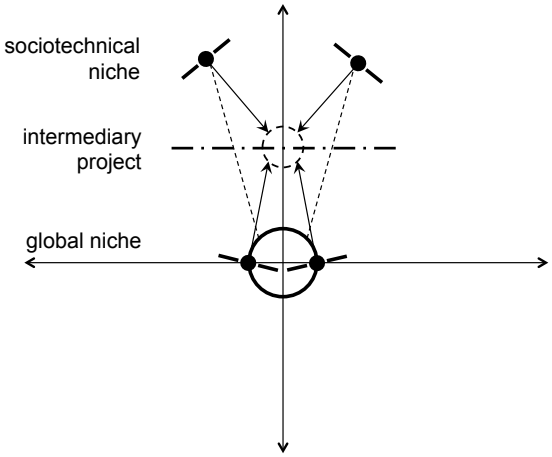

Figure 15 Schematic illustration of an intermediary project as a means of promoting diffusion from grassroots innovations, based on insights from Smith (2007).

Transits beyond the niche

Recognising and accounting for the permeability of cognitive frames allow us to conceive a generic setting for knowledge articulation targeting diffusion. schematically illustrates such a setting. Diffusion can target any socio-political arena for which the experiences of the niche are expected to offer valuable contributions in addressing sustainability concerns. We adopt here the term socio-political arena to reduce the emphasis on grassroots initiatives as a potential cradle for technical solutions which contribute to reconfiguring sociotechnical regimes. Moreover, the term signals the possibility that sustainability knowledge and practices from the grassroots can contain valuable contributions for different realms of society and in particular for those where political and policy debate takes place. As previously discussed, the actual composition of the setting depends on the subject, means and diffusion target, and the involvement of actors embodying cognitive frames of different generalisation levels and contexts is deemed to foster the robustness of the knowledge produced.

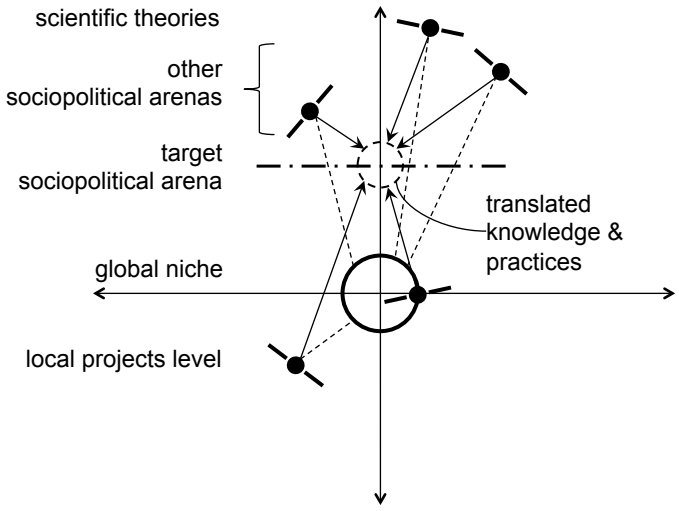

Figure 16 Schematic illustration of a generic setting of knowledge articulation promoting the transit of sustainability practices and knowledge beyond the niche community.

9.2.5 Summary and conclusions

In this study we develop a conceptualisation of the diffusion of grassroots innovations in response to the shortcomings of analytical perspectives mainly based on theoretical insights from SNM. The concept of sociotechnical niches offered by SNM helps to explain the development and potential diffusion of practical responses to sustainability challenges from the grassroots resulting as a result of reiterative relational work among local initiatives, intermediary actors and the broader context. However, SNM is oriented toward consensual and streamlined processes, which gives rise to: (i) a strong emphasis on grassroots initiatives as a potential cradle for technical solutions, ignoring other valuable contributions for advancing sustainability (such as production of critical knowledge and the creation of spaces for reflection and action); and (ii) a prevailing focus on the generic and the standard, with a tendency to neglect differences, ambiguities and contradictions. These shortcomings particularly relate to the cognitive frame concept. This concept – as conceptualised in SNM – refers to a repertoire of context-free knowledge able to guide action for a broad range of local situations. Furthermore, grassroots innovation research follows often epistemic and transformative purposes, but SNM does not provide a conceptual basis for addressing the transformative purpose.

To tackle these shortcomings, we introduce two main conceptual modifications. Firstly, we conceptualise diffusion pathways of grassroots innovations as transdisciplinary research processes. The focus shifts from stabilising single cognitive frames to creating spaces of knowledge articulation where diverse cognitive frames work jointly to (i) process experiences

from grassroots initiatives; (ii) create knowledge and promote practices that can be effectively applied for advancing the niche's shared vision; and (iii) facilitate the transit of such knowledge and practices across different contexts.

Secondly, we focus on the multiplicity, situatedness and permeability of cognitive frames and the relevance of these categories for understanding and realising the diffusion of grassroots innovations. Cognitive frames provide social actors with procedures of sense-making which are applicable to a specific range of situations and contexts. To increase certainty that the knowledge created and practices promoted can be understood and applied in a broad range of contexts, the involvement of multiple cognitive frames is crucial for achieving diffusion. Which cognitive frames are relevant depends on the features of the desired diffusion; i.e. what should be diffused, how and where. Consequently, knowledge articulation aiming at diffusion should consider the involvement of actors who are able to embody those cognitive frames regarded as relevant. Moreover, envisioning a critical and culturally sensitive approach to transdisciplinarity, diffusion does not only imply the transit of knowledge and practices across localities and scales. It also calls for exploring, acknowledging, interpreting and negotiating difference between the cognitive frames.

By incorporating insights from discussions on transdisciplinary research, the developed conceptualisation facilitates first steps for dealing with the two-fold aim of 'studying and supporting' grassroots innovations. It allows the work of grassroots innovation researchers to be considered as a constitutive part of transdisciplinary knowledge articulation in diffusion processes. These diffusion processes can be considered as a particular civil-society based type of 'problem solving transdisciplinarity' (Klein, 2014) where 'solutions […] respond to the local situation and the interests and values of the communities involved' (Seyfang and Smith, 2007). However, the consequences of entangling the epistemic and transformative aims in transdisciplinary diffusion processes are far-reaching and a comprehensive account would exceed the purpose of the present article. They include issues such as the reconsideration of the ontological subject-object separation in research, the examination of epistemological hierarchies that determine what is considered true or valid knowledge, and questions about the role of science in civil society and in administrative-political arenas of society. Furthermore, the operationalisation of the conceptualised transdisciplinary diffusion requires suitable methodological strategies. We have already collected initial experiences with a methodology that combines a case-based mutual learning format and qualitative content analysis. (Ortiz et al., 2018) However, a thorough elaboration of methodological implications of the developed conceptual framework should be the central topic of a future article.

We see great potential in transdisciplinary research where grassroots innovation researchers investigate *about*, *with* and *for* civil society initiatives tackling sustainability. Such alliances can contribute to conceiving and realising research processes in which knowledge generation and practical experimentation are coherently and systematically interwoven. In this study we have conceptualised research alliances for transcending the localities of grassroots initiatives and for the diffusion of sustainability knowledge and practices through transdisciplinary research.

10 Recapitulation and Conclusions

This chapter's aim is to set the findings that were found along the four journey stages in relation to the research horizon, and in that way elaborate my contribution to a deeper understanding of the actual phenomenon towards which my research advanced. In order to facilitate the reading of this manuscript, I recall the final shape of that horizon, as presented in Chapter 3:

Research question:
How can bottom-up initiatives contribute to the diffusion of sustainability innovations, and in that way contribute to social change?

Analytical aim:
To understand the role of bottom-up initiatives in the diffusion of sustainability innovations and in the involved social changes

Methodological aim:
To outline a research approach that provides a solid conceptual and methodological framework for attaining both the analytical and the transformative aims, i.e. research where:
- social processes of innovation diffusion from the bottom-up can be traced, and
- innovation diffusion and the involved social changes can be promoted

Transformative aim:
To contribute, with my research, to the actual diffusion of sustainability innovations

In the final shape of my research horizon, four interrelated subjects can be discerned: (i) the role of the bottom-up in diffusion, (ii) the social changes involved in such diffusion, (iii) the outline of a research approach, and (iv) the contribution of my research to actual diffusion. In the following sections, this recapitulation is structured along these four subjects.

10.1 The role of the bottom-up in diffusion

Along the research journey, the notion of bottom-up took different forms: small-scale energy projects, associations of family farmers, a network of civil society organisations, and the analytical category of grassroots innovation initiatives. The diffusion processes studied also exhibited different characteristics, i.e. different types of innovations were the subject of diffusion (e.g. technical devices, agroecological techniques, organisational practices, financial schemes), which were directed towards different targets (single households, local entrepreneurs, farmers associations, networks of civil society organisations), and through different means (markets, internal programs of farmers associations, diverse mutual learning formats). The question is how the contributions of those bottom-up dynamics in the corresponding diffusion processes can be conceptualized. I argue that the findings from the studies points at two types of contributions: mobilising transformative resources, and creating spaces for experimentation with novel knowledge/practices/devices.

10.1.1 Mobilising transformative resources

To start the argument here, it is convenient to recall the concept of diffusion as outlined in Chapter 4. In that chapter, I proposed that diffusion can be understood as the process by which innovations transit across different social arrangements and which comprises immanent changes of form (transformations) of the following: the innovation itself (adaptation), the receiving (adoption) social arrangements, and the departing (reform) social arrangements involved in the process. In the first stage of the research journey, the particular transformative challenge of completing adoption was analysed in depth. The analysis proved that undertaking

this task requires the capability to act otherwise, i.e. "being able to intervene in the world, or to refrain from such intervention, with the effect of influencing a specific process or state of affairs" (Giddens, 1984). This in turn presumes the ability to deploy power, i.e. the ability to mobilize (transformative) resources, either one's own or from other social actors, in order to influence the required changes. The study presented in Chapter 6 focused on the transformative challenge of rural households adopting domestic biodigesters. However, the same schema of relationship between influencing change and resource mobilisation can be applied to conceptualise adaption and reform. Adapting innovations is likely to require cognitive resources and the corresponding abilities in particular. For instance, technical knowledge and skills for adjusting features of novel devices, or the managerial knowledge and abilities required to adapt novel organisational practices. The mobilisation of financial resources is probably of particular relevance when reform involves the transformation from civil society initiatives into commercial firms.

The studies presented in Chapters 7 and 8 comprised different types of bottom-up initiatives mobilising transformative resources for inducing diffusion. Building and managing one's own pool of transformative resources is an important role of the organisational structures of bottom-up initiatives. I elaborate on this point later. Additionally, the studies' results illustrate the significance of collaboration and of building alliances as a strategy for securing access to resources beyond initiatives' own pool of resources. Thus, the role or task of mobilising transformative resources also entails the tasks of building and coordinating alliances for securing access to resources beyond one's own pool.

10.1.2 Creating spaces for experimentation

At this point, attention should be placed first on the crucial relationship between 'novelty' and 'deployment' for the concept of innovation as described in Chapter 4. On the one hand, the novelty of an innovation is not just related to the knowledge (potential) adopters have about it, but more important it is also related to the effective deployment of the innovation. Moreover, it is through the effective deployment of the new knowledge/practice/device that an invention moves towards the status of a meaningful innovation. In sociological studies of innovation, the focus is on the institutional renovation involved (*Erneuerung*). In the conceptualization of diffusion developed in this doctoral research, the concept of *Erneuerung* refers to the three transformations discussed in the previous section.

Two aspects appear relevant at this point: first, inducing these transformations implies to foster the innovation's effective deployment, that is to say the actual implementation of the innovation in new social arrangements. Second, implementation is unlikely to be a straightforward process, because the novel character of innovation translates into uncertainties. "Surprises" (Holling, 1986) are very likely to occur during the implementation process. In other words, during the course of interventions aimed at the deployment of innovations, the observed reality – the actual behaviour of the involved social arrangements and of the innovation itself – may differ from the initial expectations. Therefore, the implementation of an innovation may be better conceived as "*Realexperimente"* (Gross et al., 2005), i.e. as spaces for experimentation under real-world conditions. These are spaces in which social actors engage in recursive learning processes including practical interventions under real conditions, and in which the interventions can be adjusted according to the outcomes of reiterative reflexion, agreement by the actors involved in the process, and the assessment of actual observations (ibid).

In the empirical cases studied in Chapter 7, implementation for diffusion took the form of small energy projects. The analysis demonstrated that the implementation strategies applied by the bottom-up organisations comprised components for on-going assessment, reflexion, and adjustment of activities. It was proposed that these projects can be conceptualised as experimental spaces, in which the actors involved in the process can test and adjust the new socio-economic structures and practices required to ensure the sustained operation of the applied renewable energy solutions. Other forms of experimental spaces for inducing diffusion can be found in Chapter 8. For example, one space takes the form of recurrent mutual learning

sessions which gathers farmers and other experts on the farm of one of the participants, with the aim of sharing, discussing, and applying novel sustainable family farming practices. Another space takes the form of a program of farmers associations that aim to promote, initiate, and accompany the agroecological transformation of single-family farmers. It is a recursive process in which members of the association that have particularly advanced experiences and abilities in agroecological practices act as mentors of other members.

All those examples illustrate the role of bottom-up initiatives in creating spaces for experimentation. As Chapter 7 proves (building on the literature on transition management) the specific strategies of bottom-up initiatives for creating those spaces can be conceptualised as fulfilling four functions: (i) developing a shared vision, (ii) building local alliances, (iii) implementing through participation, and (iv) continuous learning and problem solving.

10.2 The role of the bottom-up in social change

In order to start this argumentation, it is important to recall the conceptualisation of 'social change' that consolidated along the research journey and is presented in Chapter 4. 'The social' refers to arrangements of human interactions with certain stability in time and space, which provides the means for, and also set limits to, human doings and beings. The concept not only accounts for the sociological arrangements of interactions, i.e. institutions in the sense of "the more enduring features of social life" (Giddens, 1984), it also accounts for interactions from other realms of society such as techniques, economy, politics, and their relationships. Therefore, this section focuses on the modifications experienced by such arrangements when diffusion is pursued. In particular, it focuses on understanding the social changes to which bottom-up initiatives contribute, in their efforts to advance the diffusion of sustainability innovations. To this end, I start by considering social changes within the localities of bottom-up initiatives, i.e. changes within their spatial scope, and then differentiate these changes according to the purpose. These changes can be differentiated into (a) changes for the effective deployment of innovations, and (b) changes aiming at binding transformative resources. This part of the argument is based on the recapitulation of the findings from the three empirical studies presented in Chapters 6 to 8. After that recapitulation I turn to consider the potential contribution of bottom-up initiatives to social changes beyond their localities. This part of the argumentation is based mainly on findings from the conceptual disquisitions of the fourth article that was presented in Chapter 9. The term 'potential' refers to the fact that the empirical studies along the research journey did not provide suitable data for tracing this kind of changes in the considered cases.

10.2.1 Social changes for ensuring effective deployment of innovation

These types of social changes correlate with the notion of adoption previously explained, i.e. the actual modification of social arrangements in order to integrate the innovation in question in such a way that it effectively opens the possibility of new doings and beings to the social actors involved. The empirical studies presented in Chapter 6 to 8 analysed the empirical deployment of innovations at two different social scales:

(i) At a household level, the emphasis is on the *sociotechnical* configurations that enable and constrain the daily practices of single family farmers. For example, the study on the diffusion of biodigesters (Chapter 6) clearly demonstrated that the material, normative, and cognitive elements involved in the routines of family farmers can become incompatible with the procedures required for the proper operation of the biodigesters. The effective deployment of the novel technology presented a transformative challenge, which in turn required the mobilisation of diverse resources such as financial capital (for modifying stables), knowledge (for adequate water use and cleaning practices), and technical skills (for design and installation of devices). The autonomous programs of Colombian farmers associations presented in

Chapter 8 illustrated how bottom-up initiatives can initiate, support, and accompany sociotechnical transformations of single-family farmers.

(ii) The community-based energy projects studied in Chapter 7 aimed at deploying renewable energy solutions at the community level, which refers to the population of single villages or clusters of rural households. The analysis demonstrated that implementing organisations assume a role of facilitators for the reshaping of local *socioeconomic* structures. The aim is the reconfiguration of the interactions among social actors, in order to ensure and sustain the supply of services and goods related to the implemented energy solution.

10.2.2 Social change for binding transformative resources

The bottom-up initiatives provide spaces in which local organisations – in the sociological sense of the term – can emerge, develop and consolidate. In other words, they allow for the rise of social arrangements that (a) pursue specific purposes, (b) define means-ends relationships that guide actions and standardise systems of control over activities and actors, (c) regard things and people as resources, and (d) rely on cultural elements that provide them coherence as collective actors (Scott, 2001). In the case of bottom-up initiatives considered in this doctoral research, the relation of individuals to a shared locality is particularly relevant to providing coherence. Because of the physicality of a shared place and the meanings and values linked to it. The rise of these social arrangements facilitated the building and binding of knowledge, financial capital, skills, and access to networks.

This contribution of bottom-up initiatives to the construction of the local available "storage" (Giddens, 1984) of transformative resources was particularly well illustrated by the findings of the study of initiatives for sustainable family farming practices in Colombia, which was presented in Chapter 8. Mutual learning about organisational issues was one of the main aims of the network of initiatives studied. Moreover, their interest was in how to effectively improve and maintain the autonomy of farmers' associations. Some specific topics of interest in their internal learning processes, illustrate how those organisations deal with the task of building and binding resources locally: (a) the establishment of revolving funds managed by the associations, (b) the training of farmers with the technical knowledge and methodological skills to provide technical advice to other members; (c) the development of tools and methodologies for diagnosing, planning, and monitoring the agroecological transformation of their members, and (d) the continual maintenance of documentation about the progress of individual farms and/or programmes implemented.

10.2.3 Potential contributions to social change beyond localities

The study of the concept of grassroots innovations (Chapter 9) provides an in-depth view of the processes by which knowledge and practices from the bottom-up can transit to other social scales, that is, beyond their own localities. The developed analytical approach focuses on the creation of spaces for knowledge articulation, in which actors embodying diverse cognitive frames work jointly to translate knowledge and experiences from the bottom up, into knowledge and practices that can be deployed in social arrangements of larger scales. Framed in this way, it is possible to envision social actors from the bottom up contributing to social change in socio-political arenas beyond their localities. Empirical examples can be found in the literature, which illustrate how knowledge and experiences from the bottom up have been translated and deployed by conventional systems of consumption and production. Examples include the cases of organic food and eco-housing in the UK (Smith, 2007), car sharing practices, and solar collectors and wind turbines in some European countries (Ornetzeder and Rohracher, 2013). Deployment in those cases was linked to social changes like adjustments in regulations and standards in order to promote the application of some practices developed by bottom-up initiatives, and the adaptation and adoption of some bottom-up practices by commercial firms. In the study of family farming initiatives in Colombia, potentials for reshaping socio-political structures that provide extension services to agricultural producers in the country were

identified. However, this is a possible type of diffusion process and social change from the bottom-up that requires further study.

Following the classification of social changes into those pursuing deployment and those binding transformative resources (as elaborated in the previous section), it appears meaningful to think about social changes beyond bottom-up localities that lead to increases of their own transformative capacity. One possible pathway for achieving such types of social changes is by linking the knowledge and practices from the bottom-up to broader social movements. The analysis of family farming initiatives in Colombia provides some indications of this possible relation. The bottom-up initiatives considered there appear to be aligned with broader social movements for the socio-political recognition of peasants and their lifestyles.

Moreover, some scholars have coined the term "grassroots innovation movements" to refer to networks of academics, activists, and practitioners that advance alternative models of technological change. These models emphasise "processes that are socially inclusive towards local communities in terms of the knowledge, processes and outcomes involved" (Smith et al., 2014). Historical examples indicate that such movements have been able – at least for some periods – to achieve support from mainstream development and science and technology institutions (Fressoli et al., 2014). While those encounters with the mainstream are not free of tensions, they illustrate that changes at higher socio-political arenas can be induced. This translates into significant increases in the resource base, that are available for catalysing activities that are more or less aligned with the visions and principles of those movements. The encounters of grassroots innovation movements appear to be limited to the socio-political fields of development, science, and technology. The question remains as to whether interactions and possible influences on other socio-political fields are possible. Moreover, the interactions between the micro-level (local bottom-up innovation initiatives) and the macro-level (social movements) still need further exploration.

10.3 Contributions to transformative research

For this research journey, transformative research refers to a practice that aims to understand the contribution of bottom-up initiatives to the diffusion of sustainable innovations, and at the same time to support the realisation of that diffusion. One central challenge of that aim is to find or build conceptualisations of the diffusion from the bottom-up, which account for (academic) research as one constitutive part of the diffusion process itself. The fourth article (Chapter 9) advanced precisely in this direction. In that chapter, an analytical approach was developed for conceptualising the process by which knowledge and practices from the bottom-up are reprocessed and re-contextualised (translated) in a way that can be meaningfully deployed in other social arrangements. I start the argument in this section by recapitulating crucial findings from that article. However, that article only focused on the translation process. Further conceptual work is needed that considers also the deployment process, i.e. to conceptualise the practice of (academic) research as constitutive part of the process by which social arrangements deploy those translated knowledge and practices. A comprehensive elaboration of this part of the argument will exceed the limits of this section. Therefore, this discussion is limited to pointing at some conceptual developments that appear valuable for future explorations in this line.

10.3.1 Academic research as constitutive part of knowledge articulation for diffusion

In the fourth article (Chapter 9), two main conceptual strategies were followed. First, the pathways for the diffusion of innovations from the bottom up were conceptualised as transdisciplinary knowledge articulation processes. Second, the focus was set on the multiplicity, situatedness, and permeability of cognitive frames, and the relevance of these categories for understanding and realising diffusion. In this way, it was possible to demonstrate

the importance of involving multiple cognitive frames, in order to increase the certainty that the translated knowledges and practices can be understood and applied in a broad range of social arrangements. Involving knowledge from academic disciplines in those knowledge articulation processes can improve the quality of the diffusion process. For instance, they may contribute towards understanding and translating the *social* features of innovations, such as questions about, organisational practices, political relevance or the preferences and habits of individuals. They may also help with *technical* aspects, such as the assessment and improvement of the performance of devices and techniques. The case of innovation research and innovation researchers is of particular interest, because, the theoretical insights and methodological skills from these researchers represent valuable resources for the configuration and realisation of transdisciplinary knowledge articulation targeted at diffusion. What is emerging here is a configuration that can be better described as transdisciplinary "knowledge alliances" (Stigendal and Novy, 2018), in which (academic) researchers investigate *about*, *with,* and *for* bottom-up initiatives.

The methodological strategy employed by the study of family farming innovations in Colombia (Chapter 8) was a first attempt of operationalising such transdisciplinary knowledge alliances. It combined a *case-based* mutual learning format and qualitative content analysis. *Case-base* mutual learning sessions (*cb*MLS) can be considered as transdisciplinary research spaces, in which a case or a set of cases serve as boundary objects, through which different perceptions and conceptualisations of the generic phenomenon the case stands for are analysed and negotiated (Vilsmaier et al., 2015). Three aspects of the strategy applied by the study appears to be particularly relevant to operationalising the notion of transdisciplinary knowledge alliances:

(1) The research space is created through collaboration between actors from bottom-up initiatives and academic researchers. The research space for the study in Colombia emerged in-between three parties: (i) a farmers association, which also acted as the case for the mutual learning process, (ii) a network that gathered bottom-up initiatives dealing with family farming innovations in Colombia, and (iii) academic researchers interested in the diffusion processes of innovations from the bottom-up (i.e. myself and Professor Ulli Vilsmaier).
(2) Co-construction of the research spaces implies, amongst other things, that the research objective of the mutual learning sessions articulates the epistemic and transformative aims of all the actors involved in the co-construction of the research space. Therefore, the particular research question of the academic researchers involved is not necessarily the research question of the *cb*MLS. Instead, the academic interests are interwoven with the epistemic and transformative interests of the actors from the bottom-up initiatives.
(3) Along with the stages foreseen by the *cb*MLS format (preparation, case encounter and post-processing), multiple materials are developed for the bottom-up initiatives and academia (textual, graphic or multimedia). These materials represent a main source of data for disciplinary analysis. In the Colombian case, this involved qualitative content analysis techniques.

10.3.2 Academic research as constitutive part of spaces for experimentation

At this point, it is appropriate to recall the following: (a) the centrality of deployment for understanding and realising diffusion, and (b) the role of bottom-up initiatives in mobilising resources for creating spaces for experimentation, in which deployment of innovations can be pursued. It is precisely in such spaces where the transformative moment takes place, that is to say where interventions are executed with the aim of effecting actual social changes. The question is, how can academic research be entangled with such interventions in 'the social', without compromising scientific rigour? That is, to maintain "the same seriousness of purpose and cultivated discipline to which traditional university research has aspired" (Fals Borda, 2001).

In the broader field of sustainability sciences, diverse approaches have been proposed and applied in order to deal with that challenging question. Wanner et al. (2018) reviewed several approaches in detail, which entailed interventions in the "real-world" as an explicit part of the research process and derived eight key components that can help in conceptualising transformative research approaches: (1) normative framing (i.e. sustainable development), (2) production of systems, target, and transformation knowledge, (3) real-world problems as a starting point, (4) boundaries demarcated by content and space, (5) transdisciplinary collaboration, (6) real-world intervention, (7) cyclical learning, and (8) empowerment of change agents and capacity building.

The disquisition of Wanner et al. features a movement that aims at incorporating the 'real world' into existing disciplinary research traditions. It "seeks to bridge the extremes of classical scientific experiment: 'placeless research' (…) and a 'just-do-it' workshop mentality" (Wanner et al., 2018). The disquisition I developed until now has a similar purpose, but it follows a slightly different approach: how to integrate academic research into those spaces for experimentation, which are already practiced by bottom-up initiatives. However, some components appear to be well aligned with the conceptualizations elaborated along the research journey. For example, sustainable development provides the general normative frame of the research journey (component 1). Real-world problems, as perceived and understood locally, are the starting point for reflexion and action of bottom-up initiatives (component 2), which in turn translates into the deployment of innovations (component 6) in the frame of spaces for experimentation that comprise recursive learning processes (component 7). Differences appear to be relevant in some other components: for a transformative research engaged in the diffusion of innovations from the bottom-up, the definition of boundaries (component 4) is related to the features of the diffusion that is being pursued. Boundaries of the space for experimentation may extend over diverse localities (for instance when pursuing replication), or it may cover social arrangements of a larger scale (for instance when pursuing translation into socio-political arenas). Moreover, the alliances with bottom-up initiatives as conceptualised in this research journey, can contribute to expanding the local "storage" of transformative resources. The process can be better described as strengthening the existing capacities of the involved actors, rather than as empowering disempowered non-science actors (component 8). Furthermore, it is probably the academic research, which results empowered through such alliances, because they open the possibility to contribute to social change in a more direct way. Therefore, the conceptual advances on transformative research approach from sustainability sciences offer a good basis for further elaborations of transformative alliances with bottom-up innovation initiatives. Additionally, it may be also interesting to explore the possibility of taking advantage of the conceptualisations with more radical stances towards the dichotomy between reflexion and action, such as the concept of 'vivencia' (Fals Borda, 2001) and 'praxis' (Freire, 1970), which have been central for alternative research concepts and practices in Latin America since the 1970s.

10.4 Contributions to actual diffusion

This section presents a brief reflection about the possible contributions of my doctoral research to the actual diffusion of sustainability innovations. It is important to clarify that this reflection is based on observations collected in an informal way; for instance through regular communications linked to WISIONS support to some of the bottom-up actors that had made part of the research presented in Chapter 8 (third paper) as well as further collaborations with some of the academic researchers involved in that research. Thus, the reflections presented here are not based on impact analysis about the actual effect of my research. The intention is rather to point at plausible effects of my research in observable diffusion dynamics.

The research alliance built for the realisation of the study in Colombia was aligned well with the epistemic interests of the participating individuals and organisations. Moreover, the activities

comprised by the *cb*MLS exhibited similar features to activities that are regularly tacking place among the considered community of initiatives and organizations; i.e. dialogues, visits, workshops and other formats that promote the exchange of knowledge and experiences. The analysis presented in chapter 8 also demonstrated that the community of initiatives considers that contributing to the systematisation of experiences from the field is a crucial role of academic actors. Thus, the *cb*MLS in Riosucio can be understood as an exercise for consolidating and systematising knowledges from those bottom-up initiatives. The transit of those knowledges was promoted through (a) the active participation of representatives of different organisations in the production of that knowledge, and (b) the preparation, publication, and dissemination of a final report. Moreover, the *cb*MLS has probably contributed to a certain dynamic of increasing interest in the financial and commercialisation topics, which were discussed and processed during the mutual learning session. For instance, the national network for family farming (which was represented in the *cb*MLS) launched in 2016 a program that aims at identifying and strengthening existing initiatives of "peasant markets" in the Counrty (RENAF, 2017). In 2016, the Colombian network for the energy from biomass (RedBioCol, which was a partner for the conception and organisation of the *cb*MLS) issued and distributed a brochure in which the experience of Asproinca (the association that represented the case for the *cb*MLS) was featured (RedBioCol, 2016). I was invited to contribute to the completion of a study focusing on the experience of Asproinca with its self-managed revolving fund. The results of the *cb*MLS were the basis for designing the study, which in turn allowed for a deeper analysis of the history, operation, and status of Asproinca's revolving fund (Acevedo Osorio et al., 2018). Thus, it is plausible that my research journey – and more precisely the third study of this doctoral dissertation – has directly contributed to the consolidation and dissemination of knowledges and practices from bottom-up initiatives advancing sustainable family farming in Colombia.

11 Outlook and final words

In this last chapter possible research horizons for further research journeys are outlined. The attention is first on interesting trails that became apparent in the previous chapter, and which could not be deeply explored during the research journey. Those trails seem to reveal aspects of what can become the research horizon for further research journeys. I organise them into two potential fields of research: (a) diffusion beyond bottom-up localities involving changes of socio-political structures and (b) bottom-up transformative research alliances.

Diffusion involving socio-political change

Further research is needed to explore the envisioned diffusion pathways, in which the transit of sustainability knowledges and practices from bottom-up to broader social scales is aimed at inducing change in socio-political structures. This is a seemingly unexplored diffusion pathway. The more often studied cases of bottom-up initiatives comprise diffusion that induces changes in systems of consumption and production or sociotechnical regimes. The proposed exploration requires a deeper look on the political dimension of bottom-up initiatives that advance innovation. Conceptual clues for this exploration may be found in the field of political philosophy, particularly in elaborations on the role of civil society in broader societal transformations. For instance, the Gramscian concept of hegemony may provide a starting point for such an exploration, as it considers political leadership to be "based on the consent of the led, a consent which is secured by the *diffusion* and popularization of the world view of the ruling class" (Bates, 1975) (italics added). The role of civil society can be understood as the space in which those hegemonic world views (ideology) are not only questioned and in which demands for change are articulated (Habermas, 1992). It is also the space in which world views can be modified, new ones can be crafted and practiced (Castro-Gómez, 2015).

The focus of such an exploration would be on bottom-up innovation initiatives as spaces for reflection and action, in which critical knowledge is articulated about what sustainable development is and how to advance towards it. Empirical studies in this line can be envisioned by building transformative research alliances with networks of bottom-up initiatives, which already features explicit political stances related to their engagement in innovation processes. The case of initiatives advancing sustainable family farming innovations in Colombia, and, more generally, the great surge of bottom-up agro-ecology initiatives in Latin America provide good examples. They appear to be linked to broader social movements working for the socio-political recognition of peasants, indigenous and afro-descendant farmers in Colombia and in other Latin American countries (Acevedo-Osorio and Martínez-Collazos, 2016; Rosset and Martínez-Torres, 2012; Sevilla and Martinez-Alier, 2006).

The link between bottom-up innovation initiatives and broader social movements is also an interesting aspect in this field, which requires further explorations. As discussed before, scholarly work had been done on movements that advance alternative models of technological change (Fressoli et al., 2014; Smith et al., 2014). However, there still seem to be a lack of understanding of the interactions between the micro-level (local bottom-up innovation initiatives) and the macro-level (social movements). That is, whether and – if yes – how local experiences from bottom-up can feed into ideology, action frames and other components of social movements, and how social movements contribute to frame and replicate bottom-up innovation initiatives. The conceptual framework developed in the fourth article may help to trace and analyse such transits of knowledge and practices between those micro and macro levels.

Bottom-up transformative research alliances

In the forth article (chapter 9) processes of transdisciplinary knowledge articulation are conceptualised, in which academic research, and in particular innovation research, is constitutive part of endeavours targeted at diffusion of bottom up knowledges and practices. These knowledge alliances are restricted to the processing of experiences from bottom-up initiatives in order to facilitate the transit of knowledges and practices across social arrangements. However, further conceptual and methodological developments can be envisioned in which academic research can also be entangled with the processes by which the deployment of innovations is promoted by bottom-up initiatives. Such alliances can contribute to conceiving and realising research processes in which knowledge generation and practical experimentation are coherently and systematically interwoven. Those are alliances in which academic researchers investigate *about*, *with* and *for* bottom-up initiatives tackling sustainability. They draw on a broader concept of research, in which "other ways of knowing, acting and being in responding to a (…) phenomenon of concern" are recognised complementary to academic-disciplinary research practices (Vilsmaier et al., 2017) and systematically integrated in the production of knowledge. In section 10.3.2 I pointed at conceptual developments of transformative research approaches within the broad field of sustainability sciences, which provide useful indications about crucial features when conceiving such alliances. Further research is needed in order to build conceptual and methodological frameworks for such alliances, which recognise the particular roles that bottom-up initiatives already play in promoting the deployment of sustainability innovations and that provide indications about how the practice of academic research can better support those processes. In this respect there is great potential for dialog and mutual learning with modes of research committed to social change and human emancipation, which are been conceived and practiced in Latina America since the 1970s.

Furthermore, the WISIONS initiative has long-term experiences in the financial support, strategic advice and supervision of bottom-up actions in the field of sustainable energy access in the global south. These experiences can be of great value for conceiving methodological strategies of the envisioned bottom-up transformative research alliances. Moreover, the WISIONS initiative – with its strong partnerships with local energy practitioners and organisations and its well-established organisational procedures – represents a very promising institutional frame in which the operationalization of such alliances can be tested.

Final words

Departing from my own experience as researcher involved in the support to community-based energy projects and to local energy practitioners in the global south, I undertook this research journey as a mean for clarifying and building better understanding of several tensions, unsettled challenges, to which I was – and to which I remain – continuously confronted. Thus, my case is singular, is situated in time-space. Though, this singular experience can be also considered an expression, an specific manifestation of more general phenomena linked to (academic) research practices that aims at both understanding and realising sustainable development. Two strands of sustainability sciences provided the conceptual, theoretical and methodological fields in which my singular case could be placed in relation to more general academic inquiries: scholar work on sustainability innovation and sustainability transitions and academic debates on transdisciplinary and transformative research. Consequently, those are also the academic fields to which my research journey has yielded conceptual and methodological contributions. Those contributions can be synthetized in three subjects: (i) a detailed analytical account of how bottom-up initiatives engage in the building, binding and mobilisation of transformative resources in order to advance the diffusion of sustainability innovations, (ii) a conceptual framework for studying and supporting transdisciplinary knowledge articulations aimed at promoting the transit of sustainability knowledge and practices from bottom-up initiatives towards different social arrangements and scales and (iii) first steps in the conceptualisation of

bottom-up transformative research alliances, in which bottom-up initiatives and academic research; practical experimentation and knowledge generation are coherently and systematically interwoven.

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Annexes

A.1 Erklärung individueller wissenschaftlichen Leistung bei der Erstellung der Artikeln

Nr	Titel	Autoren & Autorinnen	Journal	Erscheinungsjahr	Konzeption Forschungsansatz			Entwicklung Forschungs-methode			Erhebung/Aufbereitung Daten			Analyse Interpretation			Schreiben & Überarbeitung			Gesamt Beitrag AutorInnen		
					Ortiz	Terrapon-Pfaff	Dienst	O	TP	D	O	TP	D	O	TP	D	O	TP	D	**Ortiz**	Terrapon-Pfaff	Dienst
1	Understanding the diffusion of domestic biogas technologies. Systematic conceptualisation of existing evidence from developing and emerging countries	Willington Ortiz, Julia Terrapon-Pfaff, Carmen Dienst	Renewable and Sustainable Energy Reviews	2017	80%	10%	10%	90%	5%	5%	100%	0%	0%	90%	5%	5%	85%	10%	5%	**89%**	6%	5%
					Ortiz	Dienst	Terrapon-Pfaff	O	D	TP	O	D	TP	O	D	TP	O	D	TP	**Ortiz**	Dienst	Terrapon-Pfaff
2	Introducing Modern Energy Services into Developing Countries: The Role of Local Community Socio-Economic Structures	Willington Ortiz, Carmen Dienst, Julia Terrapon-Pfaff	Sustainability	2012	70%	20%	10%	70%	20%	10%	50%	20%	30%	80%	10%	10%	80%	5%	15%	**70%**	15%	15%
					Ortiz	Vilsmaier	Acevedo	O	V	A	O	V	A	O	V	A	O	V	A	**Ortiz**	Vilsmaier	Acevedo
3	The diffusion of sustainable family farming practices in Colombia – an emerging sociotechnical niche?	Willington Ortiz, Ulli Vilsmaier, Álvaro Acevedo-Osorio	Sustainability Science	2018	60%	40%	0%	50%	50%	0%	50%	30%	20%	50%	20%	30%	70%	20%	10%	**56%**	32%	12%
					Ortiz	Vilsmaier		O	V					O	V		O	V		**Ortiz**	Vilsmaier	
4	Transcending the locality of grassroots initiatives. Diffusion of sustainability knowledge and practices through transdiciplinary research	Willington Ortiz, Ulli Vilsmaier	Environmental policy *(Submitted)*	N.A	60%	40%		70%	30%		N.A.	N.A.		70%	30%		80%	20%		**70%**	30%	

A.2 Other relevant milestones of the research journey

Table 10 Academic events in which advances of the research journey were presented and discussed.

Contribution title	Conference title	Place & Dates	Relevance to the research journey
The influence of the end user's context on the dissemination of domestic biogas systems in developing countries	Innovating Energy Access for Remote Areas: Discovering Untapped Resources	University of California, Berkeley, USA; April 10-12, 2014	Presentation and discussions of intermediate results of the study that led to paper 1
Understanding household energy transitions in developing countries. Review of existent approaches and potential contribution of a quasi-evolutionary socio-technical perspective	2nd Energy & Society Conference	Jagiellonian University, Krakow, Poland June 4-6, 2014	Presentation and discussions of intermediate results of the study that led to paper 1
Biogas innovations through grassroots movements. Learning from Latin American experiences	The 5th World Sustainability Forum	University of Bassel, Switzerland September 7-9, 2015	Presentation and discussions of the concept and first results of an unpublished study on bottom-up innovation initiatives in biodigesters in Latin America.
Family Farming Systems: Spaces for the sustainable management of the Water-Energy-Food Nexus	Understanding the WEF Nexus and its Implications for Governance	Osnabrück, Germany June 15-16, 2016	Presentation and discussions of the concept and first results of the study that led to paper 3
The diffusion of sustainable family farming practices in Colombia – An emerging sociotechnical niche?	International Sustainability Transitions Conference	Wuppertal, Germany September 7-9, 2016	Presentation and discussions of intermediate results of the study that led to paper 3
Transcending the local and alternative features of grassroots innovations. What can transdisciplanary research contribute to diffusion of sustainable innovations?	International Transdisciplinarity Conference	Leuphana University, Lüneburg, Germany September 11-15, 2017	Presentation and discussions of intermediate results of the study that led to paper 4
Transcending the locality of grassroots innovations. What can transdisciplanary research contribute to the transformative capacity of grassroots initiatives?	Third Brixen PhD Summerschool on Transformative Research and Development	Free University of Bozen-Bolzano September 28-30, 2017	Presentation and discussions of intermediate results of the study that led to paper 4

Table 11 Events that provided space for exchanges with multiple actors.

Contribution title	Title of the event	Place & Date	Relevance to the research journey	Online materials
Introducción de servicios modernos de energía en países en desarrollo: El papel de las estructuras socio-económicas locales	VIII Simposio internacional acceso a la energía y sostenibilidad	Bogotá, Colombia October 29-30, 2012	The symposium was organized by the IPSE, an entity of the Colombian energy ministry responsible for energy access in remote, non-interconnected areas of the country. This event allowed to present and discuss the results of paper 2 with different types of energy practitioners of Colombia. From officials of the energy ministry and of regional administration bodies, up to leaders of non-governmental organisations working on energy topics in rural areas of the Country	Presentation: http://tiny.cc/i84e7y
Factores influyentes en la adopción de sistemas de biogás familiar: Adaptaciones necesarias en el contexto de la familia usuaria	Webinar and workshop in collaboration with the Network of Biodigesters for Latin America and the Caribbean (RedBioLAC)	Webinar: Online July 2, 2014 Workshop: Cali, Colombia November 12, 2014	Objective of the webinar was to present first results of the study that led to paper 1 and discuss these results with biogas practitioners of Latin America. The inputs from the discussion was used to organize a mutual learning workshop in the frame of the annual conference of the RedBioLAC network. The inputs gathered through these two formats helped to refine the coding system generated in the study and in that way to facilitate the interpretation of the materials analysed in paper 1	Slides and notes of the webinar: http://tiny.cc/x54e7y Recording of the webinar: http://tiny.cc/f34e7y
Taller de Aprendizaje Mutuo en Fortalecimiento de la Agricultura Familiar en Colombia	*Case-based* Mutual learning session	Riosucio, Colombia March 30 - April 1, 2016	This cbMLS was organised in collaboration with the association of indigenous and peasant producers of Riosucio and Supia (ASPROINCA) and the Colombian network for biomass energy (RedBioCol). This collaborative work created the transdisciplinary space for undertaking the empirical research linked to paper 3	Report in Spanish: https://goo.gl/6x0lys

Resultados Taller de Aprendizaje Mutuo en Fortalecimiento de la Agricultura Familiar en Colombia	Segundo encuentro nacional RedBioCol	Villavicencio, Colombia September 30 - October 1, 2016	The national meeting of the RedBioCol convened several persons that had participated to the *cb*MLS in March of the same year, as well as many other bottom-up actors in the field of family farming in Colombia. This provided an opportunity to discuss with those actors my own analytical interpretations of the results produced in the *cb*MLS	
Universalización del uso de biodigestores en agriculturas familiares. ¿Es el enfoque "top-down" la única alternativa?	9° Congreso RedBioLAC	Buenos Aires, Argentina November, 8-12, 2017	During this annual conference of the RedBioLAC I presented the results of paper 3 and first advances of paper 4. The conference provided the opportunity to discuss with biogas practitioners of Latin America about their own understandings of the diffusion of biodigesters in their countries	Video of the presentation available at: http://tiny.cc/nx4e7y Beginning at minute 56

Table 12 Master theses for which I provided research guidance and which contributed to explorations directly linked to the research journey.

Name	Title of the Master Thesis	University	Date of Submission	Official Supervisors
María Clemencia Cerón Castilla	Monitoring small biogas digesters in rural areas of Bolivian valley and highland	Cologne University of Applied Sciences	27.8.2012	Prof. Dr. Michael Sturm Dr. Jaime Martí-Herrero
Julia Katharina Wäger	Small-scale Biogas Plant Diffusion Under Community-Led Initiatives: Analysis and Scalability of the Case of Asproinca in Colombia	Cologne University of Applied Sciences	20.12.2015	Prof. Johannes Hamhaber Willington Ortiz
Philipp Schaube	Dynamics of renewable energy niche building processes in Argentina	Bergische Universität Wuppertal	24.4.2017	Prof. Dr. Uwe Schneidewind Prof. Dr.-Ing. Manfred Fischedick
Sonia Rueda	Understanding the role of endogenous elements in the implementation of biogas initiatives in rural areas of sunbelt countries	Carl von Ossietzky University, Oldenburg	27.6.2017	Prof. Ulrich Scheele Dr. Hans Holtorf
Cordelia Pätz	Improving the Sustainable Livelihoods of Family Farms in the Global South through integrated domestic biogas production: A case study analysis	Carl von Ossietzky University, Oldenburg	4.12.2018	Apl. Prof. Dr. Ulrich Scheele Dr. Hans Holtorf