Multiple transitions to sustainable energy systems in Senegal

An analysis of driving forces, institutional settings, regional capabilities, local embedding, and path creation processes

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List of abbreviations

RE – Renewable energy

SME – Small and medium-sized enterprise

Senelec – Société nationale d'électricité du Sénégal

IRENA – International Renewable Energy Agency

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Executive summary

There is great potential for renewable energy (RE) in Senegal. Like other countries in sub-Saharan Africa, Senegal needs a reliable and affordable energy supply to fuel its growing energy needs (IRENA, 2020a) and has abundant natural resources for renewable energy (IRENA, 2020b). Developing RE could promote energy independence, reduce energy costs, enable a robust energy supply, create new jobs, provide access to unserved rural areas, and, above all, contribute to the reduction of greenhouse gas emissions (Apfel and Herbes, 2021).

But the country still relies heavily on imported fossil fuels, and the factors in a transition to renewable energy are little understood (Apfel et al., 2021). Complex political, economic, and social systems interact in Senegal to influence the transition processes, and the research reported in this thesis was undertaken to better understand both these systems and their interactions. Two overarching questions drive the research: First, what leads small- and medium-sized entrepreneurial enterprises (SMEs) – nearly all the businesses in Senegal – to participate, or not, in the transition of the energy sector towards renewable energy? Second, what social, economic and political dynamics are behind the creation of emerging energy paths in Senegal?

Three intersecting approaches were taken to these questions. First, a systematic literature review of RE research in the Global South was done. Quantitative models, especially energy models, are found to dominate the discourse. Political and social processes are surprisingly under-researched. Established concepts and approaches appear inadequate to understand sustainable energy transitions in the Global South. To find more viable concepts, I derive five avenues for future research: socio-technical energy imaginaries, power in energy systems, social innovations, business factors and spatial dimensions (Apfel et al., 2021).

The second line of inquiry explores entrepreneurship in Senegal, specifically the factors influencing RE adoption by Senegalese entrepreneurs. Using an extended UTAUT 2 model to analyze interviews with 23 SMEs and 13 energy experts, I find effort expectancy is generally underestimated, usually due to inadequate knowledge about RE. Performance expectancy can be high and may have a positive impact on the adoption process, while social influence does not seem to play a role. Paramount among facilitating conditions is the support of the government, although the cost of

RE technologies is also an influencing factor. The factors motivating RE adoption associated with prosumerism in the West cannot be assumed in Senegal.

The third approach to understanding the energy transition in Senegal comes out of Evolutionary Economic Geography, where the framework of regional path creation processes of MacKinnon et al. (2019) is used to analyze interview data from 17 Senegalese energy experts. In this way, I identify three parallel emerging energy paths – path transplantation, indigenous path creation and path upgrading. Each is evolving in a different sector of the energy system and at its own pace and scale. Each differs greatly in its underlying legitimation and the support from institutions for its development. Dominant structures along each path are identified and future opportunities to address Senegal's energy futures are highlighted (Apfel, 2022).

In addition to contributing to researchers in the field, the results reported herein can inform and encourage professionals of development agencies, regional institutions, NGOs and private firms in shaping a sustainable energy system in Senegal.

Zusammenfassung

Im Senegal wird, wie auch in anderen Länder der Region Subsahara-Afrikas, eine zuverlässige und bezahlbare Energieversorgung benötigt um den wachsenden Energiebedarf des Landes decken zu können (IRENA, 2020a). Die reichlich vorhandenen natürlichen Ressourcen für erneuerbare Energien (EE) könnten dabei eine zentrale Rolle spielen (IRENA, 2020b).

Eine Entwicklung auf Basis von EE könnte die Energieunabhängigkeit fördern, die Energiekosten senken, eine moderne und nachhaltige Energieversorgung ermöglichen, neue Arbeitsplätze schaffen, den Zugang zu unversorgten ländlichen Gebieten ermöglichen und vor allem zur Minderung der Treibhausgasemissionen beitragen (Apfel and Herbes, 2021). Der Senegal ist jedoch weiterhin in hohem Maße vom Import fossiler Brennstoffe abhängig und Wissen über die Einflussgrößen, die den Transitionsprozesse hin zu EE zu Grunde liegen, sind kaum bekannt (Apfel et al., 2021).

Diese Transitionsprozesse der Energiesysteme werden von einem komplexen Zusammenspiel politischer, wirtschaftlicher und sozialer Systeme beeinflusst, deren Ausprägung und Wechselwirkungen im Rahmen dieser Dissertation analysiert werden. Meiner Forschung liegen zwei übergeordnete Fragestellungen zu Grunde: 1) Was veranlasst kleine und mittlere Unternehmen (KMU) - fast alle Unternehmen im Senegal - dazu, sich an der Umstellung des Energiesektors auf erneuerbare Energien zu beteiligen bzw. nicht zu beteiligen? und 2) Welche sozialen, ökonomischen und politischen Dynamiken liegen der Entwicklung neuer Energiepfade im Senegal zu Grunde?

Zur Beantwortung dieser Fragen wurden drei sich überschneidende Ansätze gewählt. Erstens wurde eine systematische Literaturübersicht über die Forschung zu EE in Ländern des globalen Südens erstellt. Es zeigt sich, dass quantitative Modelle, insbesondere Energiemodelle, den Diskurs dominieren. Politische und soziale Prozesse sind hingegen erstaunlich wenig erforscht. Es stellt sich heraus, dass etablierte Konzepte und Ansätze unzureichend sind, um nachhaltige Energietransitionen im Globalen Süden zu verstehen. Um tragfähigere Konzepte zu finden, schlage ich daher folgende fünf Forschungsthemen für die Zukunft vor: soziotechnische Energievisionen, Macht in Energiesystemen, soziale Innovationen, Unternehmensfaktoren und räumliche Dimensionen von Energiesysteme (Apfel et al., 2021).

Der zweite Forschungsstrang untersucht das Unternehmertum im Senegal, insbesondere die Faktoren, die die Einführung von EE durch senegalesische Unternehmer beeinflussen. Unter Verwendung eines erweiterten UTAUT-2-Modells analysiere ich Interviews mit 23 KMU und 13 Energieexperten. Die Ergebnisse zeigen, dass die Leistungserwartung (effort expectancy) generell unterschätzt wird, was in der Regel auf unzureichende Kenntnisse über EE zurückzuführen ist. Die Aufwandserwartung (performance expectancy) kann hoch sein und sich positiv auf den Einsatz von EE auswirken, während der soziale Einfluss (social influence) keine Rolle zu spielen scheint. Zu den förderlichen Bedingungen (facilitating conditions) gehört in erster Linie die Unterstützung durch den Staat, obwohl auch die Kosten der EE-Technologien eine Einflussgröße sind. Die Faktoren, die im Westen mit Prosumerismus in Verbindung gebracht werden, können im Senegal nicht als Motivation für die Einführung von EE-Technologien angenommen werden.

Der dritte Ansatz zum Verständnis der Energietransition im Senegal stammt aus der Evolutionären Wirtschaftsgeographie. Ich verwende das Rahmenkonzept regionaler Pfadbildungsprozesse von MacKinnon et al. (2019) zur Analyse von Interviewdaten von 17 senegalesischen Energieexperten. Auf diese Weise identifiziere ich drei parallel entstehende Energiepfade – Pfadverpflanzung (path transplantation), endogene Pfadbildung (indigenous path creation) und Pfadaufwertung (path upgrading). Jeder entwickelt sich in einem anderen Sektor des Energiesystems und in seinem eigenen Tempo und Umfang. Die Pfade unterscheiden sich stark in ihrer Legitimation und der institutionellen Unterstützung bei ihrer Entwicklung. Die vorherrschenden Strukturen entlang der einzelnen Pfade werden identifiziert und künftige Möglichkeiten zur Steuerung der Energiezukunft Senegals werden aufgezeigt (Apfel, 2022).

Die hier vorgestellten Ergebnisse leisten nicht nur einen Beitrag zur sozialwissenschaftlichen Energieforschung, sondern können auch Fachleute von Entwicklungsagenturen, regionalen Institutionen, NROs und Privatunternehmen bei der Gestaltung eines nachhaltigen Energiesystems im Senegal unterstützen.

List of publications

The present work is a compilation of three double-blind peer-reviewed journal articles, together covering the results obtained by my research.

Accepted and published articles:

Apfel, Dorothee; Haag, Steffen; Herbes, Carsten (2021): Research agendas on renewable energies in the Global South: A systematic literature review. In: *Renewable and Sustainable Energy Reviews* 148:111228. https://doi.org/10.1016/j.rser.2021.111228
The published article is reproduced in the appendix.

Apfel, Dorothee; Herbes, Carsten (2021): What drives Senegalese SMEs to adopt renewable energy technologies? Applying an extended UTAUT2 model to a developing economy. In: *Sustainability* 13(16):9332. https://doi.org/10.3390/su13169332
The published article is reproduced in the appendix.

Apfel, Dorothee (2022): Renewable energy transition in Senegal? Exploring the dynamics of emerging paths to a sustainable energy system. In: *Energy Research & Social Science* 92 (2022) 102771. https://doi.org/10.1016/j.erss.2022.102771
The published article is reproduced in the appendix.

Author‘s contribution

The author Dorothee Apfel has been the lead author of two articles and the sole author of one article. In this role, she has been responsible for the planning, coordination, content development, submission and peer-review process.

The specific contribution of Dorothee Apfel and her co-authors consisted of the following:

1) Article “Research agendas on renewable energies in the Global South: A systematic literature review”:
   - Conceptualization: Dorothee Apfel (80%) and Carsten Herbes (20%);
   - Methodology: Dorothee Apfel (100%);
   - Data analysis: Dorothee Apfel (33%); Steffen Haag (33%) and Carsten Herbes (33%);
   - Data curation: Dorothee Apfel (100%);
   - Writing–original draft preparation: Dorothee Apfel (80%); Steffen Haag (15%) and Carsten Herbes (5%);
   - Writing–review and editing: Dorothee Apfel (95%) and Steffen Haag (5%)
2) Article “What drives Senegalese SMEs to adopt renewable energy technologies? Applying an extended UTAUT2 model to a developing economy”:
   - Conceptualization: Dorothee Apfel (80%) and Carsten Herbes (20%);
   - Methodology: Dorothee Apfel (80%) and Carsten Herbes (20%);
   - Data analysis: Dorothee Apfel (100%);
   - Data curation: Dorothee Apfel (100%);
   - Writing–original draft preparation: Dorothee Apfel (80%) and Carsten Herbes (20%);
   - Writing–review and editing: Dorothee Apfel (100%)
3) Article “Renewable energy transition in Senegal? Exploring the dynamics of emerging paths to a sustainable energy system”:
   - Conceptualization: Dorothee Apfel (100%);
   - Methodology: Dorothee Apfel (100%);
   - Data analysis: Dorothee Apfel (100%);
   - Data curation: Dorothee Apfel (80%); Steffen Haag (20%)
   - Writing–original draft preparation: Dorothee Apfel (100%)

1. Introduction

This introduction first presents general information about the importance of energy in Senegal before identifying research gaps. Then, the conceptual framework and methodological approach are presented including the study areas of my thesis. An outline of the thesis concludes the introduction.

1.1. General introduction

A secure energy supply is of central importance for economic and social development. The use of renewable energies is of particular importance in this context, as they reduce dependence on fossil resources, enable decentralized supply, can contribute to the generation of new jobs, promise access for unserved areas, and make a clear contribution to sustainable development (Apfel et al., 2021).

Although Africa's renewable power generation capacity almost doubled from 27.33 GW in 2010 to 48.44 GW in 2019 (IRENA, 2020b), its ever growing energy demand has not been met significantly by RE. Data from the International Energy Agency shows sub-Saharan Africa (SSA) to have the lowest electrification rate in the world: 48% in 2019, while the global average for the same year was 90% (IAE, 2020).

This is also the case in Senegal, where the lack of stable and affordable energy continues to impede economic progress, the development of industries, and the empowerment for income generation (Cissokho and Seck, 2013; Muriithi, 2017; Cissokho, 2019; Apfel et al., 2021). While 92% of the people in urban areas had access to electricity in 2018, the corresponding rate in rural areas was only 44% (IEA et al., 2020). This reveals a large urban-rural disparity in livelihoods in Senegal, leading to inequalities in social and economic development.

The Senegalese economy and its energy landscape mirror the development of national economies and enterprises in much of the world where small and medium-sized enterprises (SMEs) play a significant role. In Senegal, 95 percent of all enterprises are SMEs. They employ about 40 percent of the workforce, generate about 20 percent of the GDP and account for 30 percent of domestic value added (Cissokho, 2019). Furthermore, like in other developing economies, the informal sector in Senegal plays the main role in the GDP (Musara and Nieuwenhuizen, 2020). Indeed, an economic census of 2017 (ANSD, 2017) showed the informal sector in Senegal accounts for 97 percent of the enterprises.

This economic structure, with its numerous informal and formal SMEs, creates a milieu where individual companies do not require large amounts of energy, but are nevertheless highly dependent on a stable and affordable energy supply. The challenges that result became evident in a 2012 survey by Cissokho and Seck (2013) on the effects of power outages on firms in Senegal. Of the SMEs surveyed, 57 percent said electricity supply was a major challenge for their business, and 55 percent said the risk of power outages influenced their investment decisions. It is unlikely that the figures have changed much since the survey, given that energy costs in Senegal are still among the highest in the world (Senelec, 2020).

Provoked by these energy challenges, large-scale civil demonstrations have given voice to the massive dissatisfaction of the Senegalese people with their energy supply. Energy riots in 2009 and 2011 broke out in the greater Dakar area after prolonged and repeated power outages (Al Jazeera, 2011; Ba, 2011). Protests broke out again in 2019 in response to a 10% electricity price increase by the national electricity provider, Senelec.

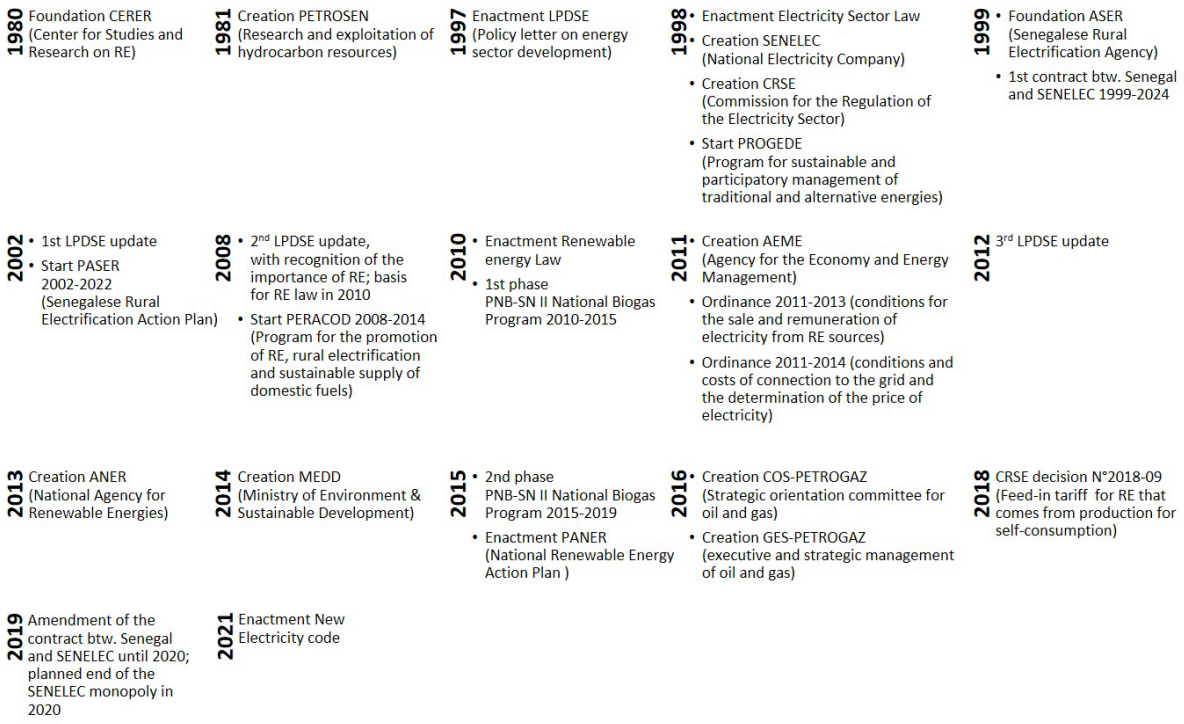
Renewable energies (RE), as a decentralized form of energy generation, have the potential to help the struggling companies. Companies that have problems with the grid-connected energy supply could find a stable energy source in RE. New business ideas and models could emerge for SMEs, e.g. the operation of charging stations for cell phones powered by renewable energy (Diouf et al., 2013). Moreover, from a macro perspective, the shift to RE represents a strategy to mitigate climate change, especially in developing economies with their rapidly growing energy demands as predicted by IRENA (IRENA, 2020a).

Senegal is rich in wind and solar resources that can be used to generate electricity from RE technologies. This potential means energy generation can be reoriented toward the future. In fact, the sector has already begun to shift to RE and has steadily increased its installed capacity of RE. From 2000 to 2019, electricity generation capacity increased from 28 MW to 209 MW (IRENA, 2020b), mainly due to the realization of large-scale projects, such as the solar parks of Bokhol (20 MW) and Méouane (30 MW) and the Taïba Ndiaye wind park (50 MW by 2019, with a planned final capacity of 158 MW). This development fits into the general trend in sub-Saharan Africa toward large-scale grid-connected RE projects (Bhamidipati and Hansen, 2021).

Facing huge present and future energy challenges and seeking to leverage the country's resource potential, the Senegalese government has committed to reforming the energy sector and solving the structural problems of the national utility Senelec. The recent discovery of oil and gas fields in 2014-2016 offers further hope for energy independence and the prospect of unshackling the Senegalese economy from expensive imports. Several new energy regulations have been adopted, and Senelec has undertaken strategic planning to better meet the country's energy needs (Senelec, 2020). The reforms aim to attract private capital, which is urgently needed to overcome the country's dependence on expensive oil imports and its huge investment backlog. Figure 1 depicts the timeline of the national energy programs and energy sector reforms.

The reforms and programs most important for my research include the creation in 2013 of the National Agency of Renewable Energy (ANER), established to promote and develop renewable energies in all forms; the adoption in 2014 of the "Plan for an Emerging Senegal 2035", which aims to ensure a geographically balanced energy supply, increase production capacities, reduce consumption and energy losses, and increase energy production from renewable sources (Presidency of Senegal, 2022); the enactment in 2015 of the National Renewable Energy Action Plan (2015-2020/2030) (PANER) (République du Sénégal, 2015), which specifies the RE commitment; and, finally, the adoption in June 2021 of a new electricity code (Law No. 2021-14). Among the main provisions of the law, Senelec will be transformed into an electricity holding company with subsidiaries for each stage of the value chain. The law also regulates the long-awaited grid access for third parties, as well as the promotion RE and off-grid rural electrification (République du Sénégal, 2021).

Figure 1: Timeline of the energy sector reforms and national energy programs. Source: Apfel (2022).



Given these characteristics of the Senegalese economy and the challenges in providing affordable and stable energy, I undertook research to gain a better understanding of the dynamics within the energy system. The focus of this dissertation is thus to analyze the driving key actors, institutional settings, regional capabilities, local embedding, and path creation processes so as to characterize the multiple transitions to sustainable energy systems in Senegal.

1.2. State of research

Over the past 10-15 years, the scientific consideration of socio-technical transitions has received increasing attention, as evidenced by numerous publications on transition research (Geels and Schot, 2007, 2010; Coenen et al., 2012; Markard et al., 2012; Truffer, 2013; Hansen and Coenen, 2015; Truffer et al., 2015; Turnheim et al., 2015; Wittmayer et al., 2017; Fastenrath and Braun, 2018). However, most of these transition studies focus on disruptive processes and the emergence of technological innovations (MacKinnon et al., 2019). The processes of path creation, such as the co-evolution of industries and knowledge; the role of institutions; and the growth of multi-scalar knowledge bases – topics that form a central area of research in economic geography (Chlebna and Simmie, 2018; Gong and Hassink, 2019; Hassink et al., 2019; Heiberg et al., 2020) – have received scant attention. Moreover,

an article search for scientific research on RE and its contribution to an energy transition reveals that most research has been conducted in and focused on developed countries. Scholars that explore RE in the countries of the Global South play a minor role in this large field of research (Marquardt, 2017).

An emerging avenue of research investigating energy transitions in sub-Saharan Africa highlights the role of transnational actors in providing financing, technology and knowledge needed for the realization of large-scale RE projects. Research also positions these actors in neoliberal processes that are reshaping national energy systems to open them up to the private sector (Rodríguez-Manotas et al., 2018; Bhamidipati et al., 2019). However, Klagge and Nweke-Eze (2020) find that public investment and public actors are necessary for the realization of large-scale projects in sub-Saharan Africa, and they question the financialization of these projects in the near future. Others have investigated community-investor relations in large-scale projects, using case-based studies to look at benefits for local communities. Bhamidipati and Hansen (2021) point out that satisfaction of local needs by large-scale projects, as is often assumed, cannot be confirmed. Local expectations for community development and job creation are often high, but rarely really met. Klagge et al. (2020) use the idea of cross-scale linkages and multilevel governance to explain that investor-community relations can be two-sided. On the one hand, local benefits can serve to secure the legitimacy of large-scale projects; on the other hand, an active local population can also have an influence on the progress of the project, since local needs are not completely met, as already noted by Bhamidipati and Hansen (2021). The focus of these scholars is on the East African countries of Kenya and Rwanda.

Several studies have focused on Senegal, each with different scopes to shed light on emerging energy path development: Van den Bold (2021) examined the electricity sector reforms in Senegal with focus on the influence of private sector investments. Diouf and Miezan (2019) analyzed shortcomings in the biogas program initiated by the government of Senegal and in another paper the failure of the government's concession-led model of rural electrification (Diouf and Miezan, 2021). Cissokho (2019) investigated productivity loss in small and medium enterprises caused by power outages. Other studies have examined Senegal in multi-country contexts concerning RE policies and their efficiency in national energy transition processes (Müller et al., 2020), the local benefits and durability of rural electrification

initiatives (Almeshqab and Ustun, 2019) or systems for village-scale solar power supply (Ulsrud et al., 2018).

Further research relevant to my research is found in the literature on African entrepreneurship. There, a research community has pursued an understanding of African entrepreneurship, focusing on marginalized groups, the firm and its form of organization, as well as macro-socioeconomic conditions, such as policy, poverty, corruption and internationalization (Devine and Kiggundu, 2016).

A line of inquiry missing from the already sparse literature is into the thinking of entrepreneurs who are considering integrating RE into their business activities (Andrews and Johnson, 2016). This thesis takes up this line, aiming to fill gaps of missing knowledge about: (1) research agendas on renewable energies in countries of Africa and regions of the Global South, (2) considerations motivating Senegalese entrepreneurs to integrate RE in the operation of their SMEs, and (3) emerging sustainable developments paths in the Senegalese energy system. These research topics are discussed in more detail in section 2 “Specific objectives”.

1.3. Outline of thesis

The thesis proceeds as follows: Chapter 2 explains my specific research objectives and introduces my research questions. Chapter 3 presents the analytical approaches and the research methodology I used. Chapter 4 provides a discussion of the main results, acknowledges research limitations, and concludes with implications for future research and policy.

2. Specific objectives and research questions

The aim of my research is to shed light on how complex political, economic, and social systems are intertwined with the processes leading to transitions to a sustainable energy system in Senegal.

My research objective are: First, to understand the current status of RE in small- and medium-sized enterprises and how Senegalese entrepreneurs are or are not participating in the transition of the energy sector towards renewable energies; second, to identify the dynamics that are leading to new emerging energy paths in Senegal by applying a multi-dimensional approach, unbiased by individual technologies or resources. The next section lists the three major research topics that address the research gaps identified above; each corresponds to one of the three publications in this thesis.

Research topic 1: Research agendas on renewable energies in the Global South

This topic is addressed in my first article, "*Research agendas on renewable energies in the Global South: A systematic literature review*", (see appendix). This systematic literature review provides a comprehensive analysis of the research agendas on RE in the Global South to characterize research strands and identify significant knowledge gaps. Given the importance of using renewable energies, the relevant research landscape is surprisingly sparse, not only in Senegal but also in the region of sub-Saharan Africa. To obtain more meaningful results, the review includes articles on the regions of Africa, Asia, and South America. The results address these research questions:

- What are the dominant topics, theories and research approaches on the current research agenda about RE in Global South countries?
- What differences and similarities exist between the studies on Africa, Asia and South America?
- What research gaps can be identified, especially those revealed from a perspective of social science?

Research Topic 2: Determinants influencing Senegalese SMEs in the adoption of RE technologies in their firms for stable energy supply

This topic is addressed in my second article, "*What Drives Senegalese SMEs to Adopt Renewable Energy Technologies? Applying an Extended UTAUT2 Model to a Developing Economy*", (see appendix). Although RE as a decentralized form of energy generation offers potential for SMEs, such as obtaining a stable source of energy, developing new business ideas and models, there is little knowledge about entrepreneurs' reasoning regarding the possibility of integrating RE into their business activities. Therefore, this second article pursues the following research questions:

- What considerations motivate Senegalese entrepreneurs to adopt RE in the operation of their SMEs?
- Which dimensions of the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) apply for RE adoption in Senegalese SMEs?
- What other influencing factors play a role in the context of Senegalese SMEs?

Research Topic 3: Emerging paths to a sustainable energy system in Senegal

This topic is dealt with in my third article, “*Renewable energy transition in Senegal? Exploring the dynamics of emerging paths to a sustainable energy system*”, (see appendix). The processes underlying the formation of new energy paths in energy system transitions have been well studied in Global North countries, but insights into the processes shaping the energy transition in sub-Saharan Africa are still limited. The third study follows these central research questions:

- What new energy development paths are emerging in Senegal?
- Which ones go beyond "greening" the energy mix?

3. Conceptual framework

In this section, the conceptual approaches that serve as the basis of this thesis are presented and the research methodology is explained. In addition, the study areas in Senegal are briefly outlined to situate the empirical studies.

3.1. Conceptual approaches

The analytical approaches are presented in terms of their main features and their contributions to answering my research questions. A detailed discussion can be found in the corresponding articles in Appendices A and B. In addition, Figure 2 provides an orientation to the three approaches.

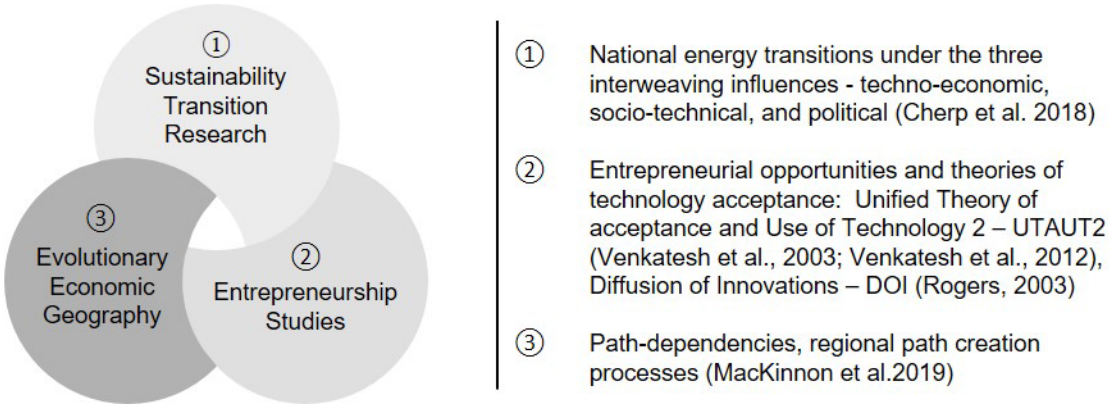
First, the systematic literature review of studies of RE in countries of the Global South is done through the lens of sustainability transition research. The meta-theoretical framework provided by Cherp et al. (2018) is particularly helpful. They present energy transitions as a process not restricted to the change of individual technologies or resources, but rather a change in an entire energy system. They differentiate between three interweaving influences: the techno-economic, the socio-technical, and the political.

Second, insights into how entrepreneurs evaluate potential investments in RE technologies for use in their companies are drawn from theories of entrepreneurial action. Since the aim is to better understand how entrepreneurs evaluate potential investments in RE technologies, a model that focuses on the decision-making processes of individuals is considered most appropriate. That reasoning was behind selection of the framework of the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) (Venkatesh et al., 2003; Venkatesh et al., 2012), extended by insights from the Diffusion of Innovation Theory (DOI) (Rogers, 2003). Extended by DOI, UTAUT2 can better capture the entrepreneurial realities in Senegal.

Third, an understanding of the emerging paths to sustainable energy systems in Senegal rests on recognizing which aspects of path creation processes are important determinants. By applying the integrative theoretical framework on regional path creation processes by MacKinnon et al. (2019), I seek to explore the critical factors behind the dynamics and processes of new energy path creation in Senegal. Their framework incorporates insights from established research strands in fields other than evolutionary economic geography, including transition research, sociological and institutional perspectives, global production networks, and geographic political

economy. This integration provides a view of path creation processes that can capture the interplay across economic, political, social, and environmental systems.

Figure 2: Conceptual approaches of the thesis. Source: Author.



3.2. Research methodology

The empirical basis of this research draws on three sources. The first comprises scientific articles by scholars investigating RE in the Global South. This literature is evaluated in a systematic review based on the 'PRISMA statement' that provides a minimum set of evidence-based items for reporting in systematic reviews and meta-analyses (Moher et al., 2009). For the review, the 90 most highly cited articles published on RE in Africa, Asia and South America were selected, limiting the review to 30 articles per region for practical reasons. Selections were restricted to peer-reviewed journal articles written in English.

The second, and most significant, source of data used in this research is primary data collected through two qualitative interview studies with 23 Senegalese SMEs and 17 experts in the Senegalese energy sector. The sampling process for the two groups was conducted separately. The SMEs were identified based on the following data sets: The online search tool of Go Africa Online (Go Africa Online, 2019), information from the chambers of commerce, and a cartography which was provided by the University of Saint-Louis, Senegal. 40 SMEs were selected for each city, Saint-Louis and Dakar. The sampling took place on the basis of the cities' affiliation, the definition of SMEs according to the Senegalese Ministry of Economy and Finance (ANSD, 2017), as well as grouping in the following ten economic sectors: 1. Agriculture, livestock and fishing, 2. Food industries, 3. Textile industries, 4. Other industry, 5. Construction and public works, 6. Trade, 7. Transport and

telecommunications, 8. Hotels, bars and restaurants, 9. Services provided to companies, 10. Personal services, other. The 40 companies per city were then selected by quota sampling across all ten sectors. The actual interview process had to be adapted to the availability of the entrepreneurs.The sampling of the experts and their institutions was based on a document analysis. Relevant actors and institutions were identified based on their knowledge about the energy transition in Senegal and their potential to foster it. Döringer's understanding was followed, who defines “experts are considered knowledgeable in a particular subject and are identified by virtue of their specific knowledge, their community position, or their status” (Döringer, 2020, p. 1). A few interviews were initiated via snowballing.

The interviews were conducted face-to-face during two visits to Senegal in 2019, followed by telephone interviews and video calls in 2020 to accommodate COVID-19. Qualitative content analysis, as developed by (Mayring, 2014), was used to evaluate the transcripts.

The third source of data, used to complement insights gained from the interviews, includes policy legislation, technical documents, and press releases related to the energy transition in Senegal. These were reviewed for regulatory actions, objectives, and results claimed.

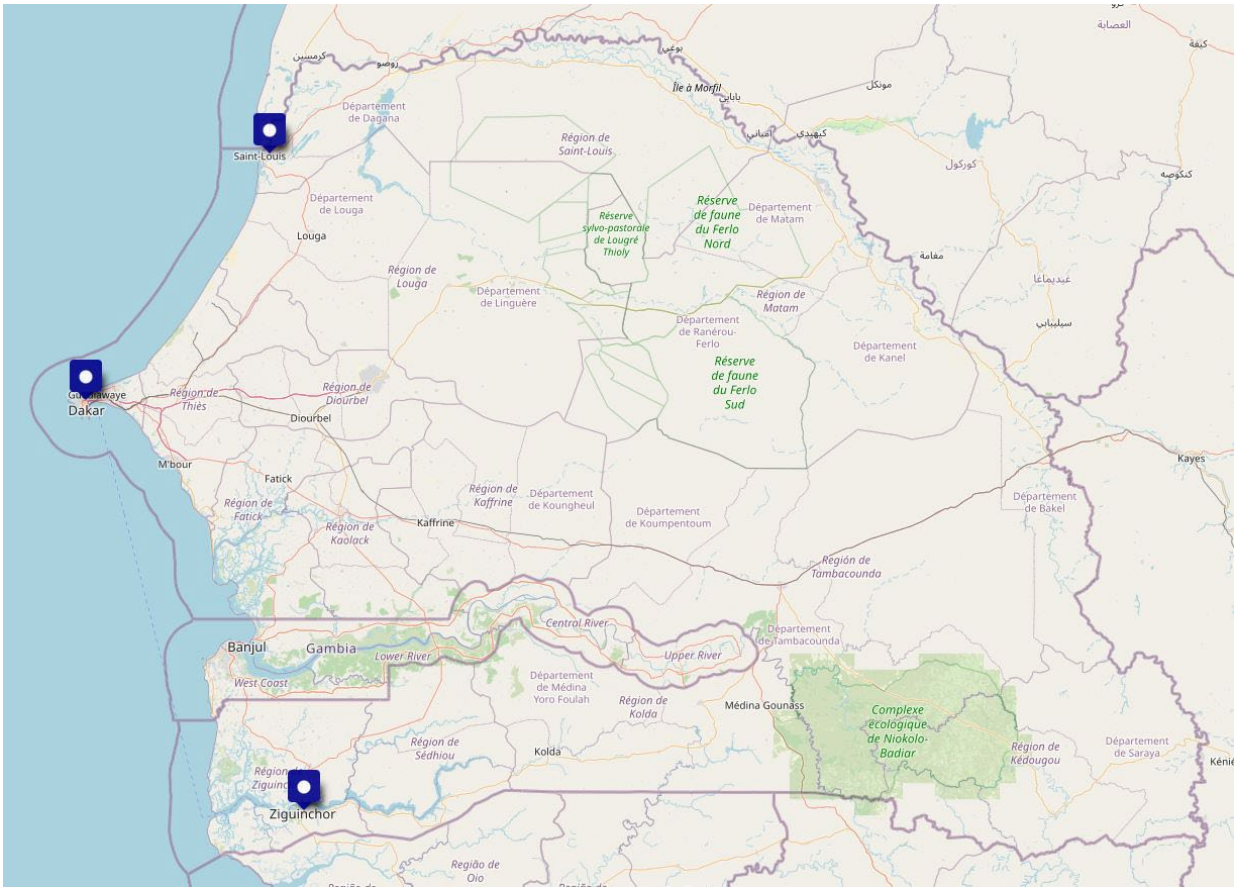
3.3. Study areas

The two qualitative interview studies conducted for this thesis took place in 2019 during two research visits to three different regions of Senegal, as shown in Figure 3. These regions were chosen because they have considerable economic capacity and provide important regional services. They are also the partner regions of the project LoSENS, under which this dissertation was carried out.

The first study area is the capital Dakar, which is not only the seat of all national ministries, agencies and institutions but is also where international development agencies, the banking sector, and similar actors are based. The greater Dakar area counts a population of 3.1 million inhabitants (Senegal Data Portal, 2015)[1] and is Senegal’s economic center. As far as the concentration of formal enterprises is concerned, 75 percent are located in the Dakar region (ANSD, 2017).

[1] In Senegal, the last census took place in 2013 and the next one is planned for 2024. It can be assumed that the number of inhabitants has continued to rise, especially in the capital Dakar.

Figure 3: Study areas. Source: Author on basis of OpenStreetMap contributors under ODbL (2022)



In addition, research took place in two municipalities, which in terms of population are much smaller than the capital, but are the 3rd and 4th largest municipalities in Senegal. Both municipalities are the centers of their respective regions, with important infrastructures such as regional representation offices, higher education institutions, healthcare facilities and service structures for their regions.

The municipality of Saint-Louis, is the second research area. It has a population of 210.000 inhabitants (Senegal Data Portal, 2015) and is located in the northwest of Senegal on the border with Mauritania. The third study area is the municipality of Ziguinchor, located in southwestern Senegal, with 205.000 inhabitants (Senegal Data Portal, 2015).

4. Results and discussion

The overall objective of this research is to bring to light processes and dynamics of sustainable transitions in the Senegalese energy sector. Given the significance of a reliable energy supply for economic and social development of nations (Apfel and Herbes, 2021), understanding the factors influencing the transition from fossil fuels to RE is particularly important, especially in a development context, such as Senegal. My research aims to fill knowledge gaps in the research agendas on renewable energies in Africa, looking particularly at factors influencing Senegalese entrepreneurs in deciding whether or not to integrate RE into the operation of their SMEs. My research also segues into emerging sustainable developments paths in the Senegalese energy system. In the following, I discuss the main results, acknowledge research limitations, and conclude with directions for future research and policy.

4.1. Summary of the main results

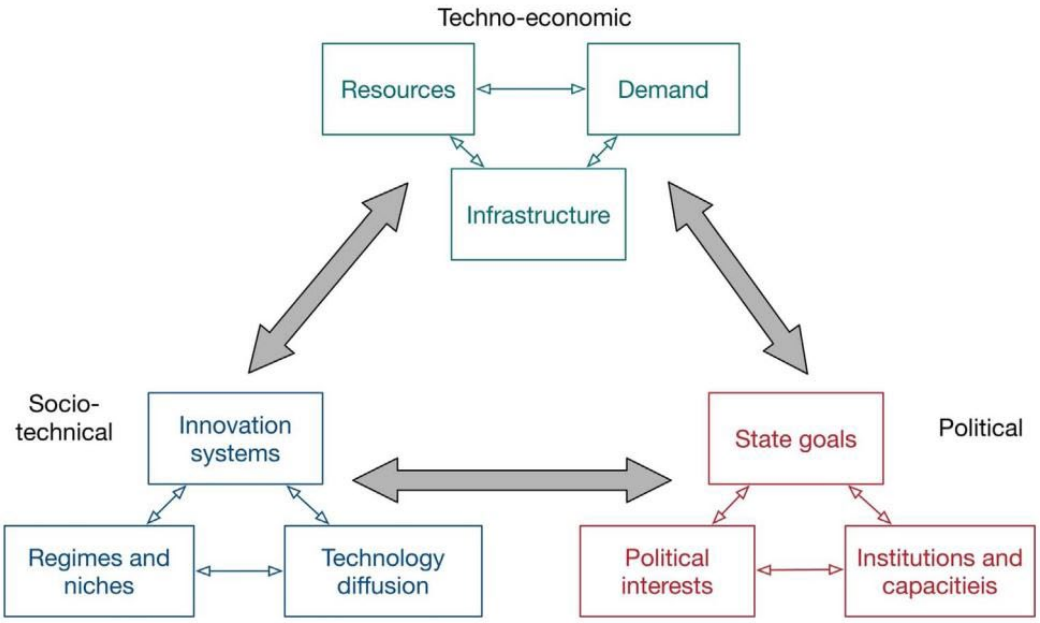
While a wide range of literature addressing all facets of RE in the Global South exists, little is known about the actual role of RE in transforming the energy systems of African countries. There was, before this research, no comprehensive review available to guide such studies. The first achievement of this dissertation is one such review, conducted systematically to summarize existing findings.

To extend the insights gained, the review was not limited to Africa, but also included the regions of Asia and South America. Nor did it focus only on business contexts. This procedure allowed dominant trends and approaches in research agendas on RE to be identified, highlighting principal modes of thought. These findings could then be positioned in the ongoing energy transition debate by applying the meta-theoretical framework developed by Cherp et al. (2018) to evaluate the review results along the three interweaving techno-economic, socio-technical and political perspectives (see Figure 4). A comprehensive overview of the research gaps identified in this way is provided in Figure 5.

An initial finding was that most articles in the sample examine RE from a growth-oriented view. This represents the techno-economic perspective which focuses on energy resources, demand, and infrastructure systems (Cherp et al., 2018). While natural resources and the demand side are well covered, insights on infrastructure system design, potentials for network expansion and on-grid solutions, as well as

business potentials arising from renewable energy on the supply side (e.g. energy companies and agribusinesses) are limited. The sample netted no investigation or discussion of the productive use of energy by the industrial sector, nor did it find research on the demands and development potentials of manufacturing companies with respect to RE (Apfel et al., 2021), both of which areas intersect directly my research interest. The research paradigm of the sample consists of quantitative studies, such as economic models, energy scenarios, energy models, input/output analyses, cost (benefit) analyses, life cycle analyses, and applications of geoinformatics.

Figure 4: The three perspectives of national energy transitions and their main variables. Source: Cherp et al. (2018)



The factors which are decisive for innovations and their diffusion are captured within the socio-technical perspective shown in Figure 4. Here, the so-called regimes play an important role, as they are understood to be stable systems, carrying shared rules and routines that allow technological innovations to emerge following established paths and along predictable trajectories. In addition, niches provide a protected area where “novelties” (innovations) can develop outside the influences of the current regime (Cherp et al., 2018). Both factors – regimes and niches – are instrumental in answering research questions that address the involvement of local enterprises in the energy transition and that seek understanding of new energy path

creation. Despite the powerful roles they likely play in a transition, these factors have largely been ignored by the studies in the research sample.

The story is quite different for questions of technology diffusion. Here are found numerous articles that address global maturity of technologies and their application across core and peripheral locations (Apfel et al., 2021). However, let us remember that the number of implemented RE technologies doesn't provide information about social context. Nor do numbers of commercially available technologies tell much of a relevant story in a Global South context. There, the availability of technologies is affected by factors that include import dependencies, high prices, and low quality standards. Moreover, urban/rural diffusion differences play a much larger role in these countries than in developed nations of the West.

A further aspect of technology diffusion uncovered by this research relates to actors and knowledge networks. A number of studies captured in the sample recognize the significance of knowledge transfer and exchange in actor-networks, but beyond recognition, there is no further investigation into these critical dynamics (Apfel et al., 2021). Unfortunately, many questions are left open about location-specific parameters, entrepreneurship, experiments, and social and institutional innovations that influence technological change – each representing a missing piece of the puzzle where Senegalese companies play a role in the energy transition.

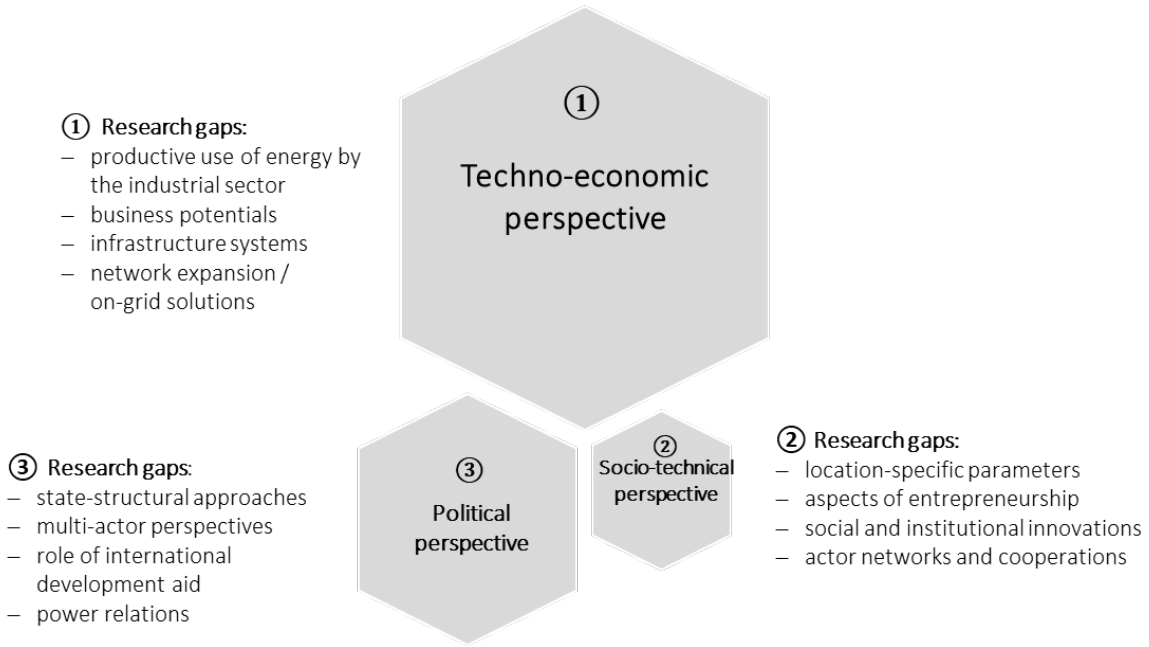
The third perspective in Cherp et al.'s meta-framework is the political perspective, and my research found numerous articles addressing political issues and providing information on state goals, political interests and institutions and capacities. Interestingly, most articles see the state as an autonomous actor, the main agent capable of shaping and asserting national energy interests.

In the given context of RE in developing countries, insights into a state-structural approach would have been very helpful. Such a conceptualization would help to shed light on the governance systems of competing interests and goals that emerge with reference to social interest groups and lobbying activities of private corporations. Also significant in countries of the Global South are cooperation with international aid agencies. In this context, illuminating the role of institutions is important, but few if any of these factors are explored by the articles reviewed. Overall, perhaps the most important finding from this stage in my research is that established concepts are often inadequate to meet the challenge of decarbonizing energy systems in the Global South (Apfel et al., 2021).

At this point, one interesting finding regarding the regional contexts should be highlighted. Only in the African sub-sample do studies take a general perspective on the entire continent; in the sub-samples of Asia and South America, studies are far more often country specific. In the multi-country studies in Africa, it is noticeable that most tend to consolidate the countries studied rather than contrasting the conditions in them. This yields something of a research blind spot to political perspectives in the studies on African countries. Africa is mostly viewed as a single continent and its diversity is largely neglected. This means ignoring the large differences in culture, wealth and the natural environment between countries in Africa, a major shortcoming of past research (Apfel et al., 2021).

This literature review through the framework shown in Figure 4 revealed existing dominant research paradigms, allowing critical knowledge gaps to be identified, as illustrated in Figure 5. It is toward filling these gaps that the two further empirical studies reported in this thesis were undertaken.

Figure 5: Research gaps in the reviewed sample. Source: Apfel et al. (2021).
The size of the hexagons indicates the distribution of the reviewed articles in the three perspectives, as developed by Cherp et al.(2018)



A most notable finding illustrated by Figure 5 is that the roles of business, the productive use of energy, business potentials, aspects of entrepreneurship, actor networks and cooperation, as well as power relations and the influence of international development aid on enterprises in the energy transition, have scarcely

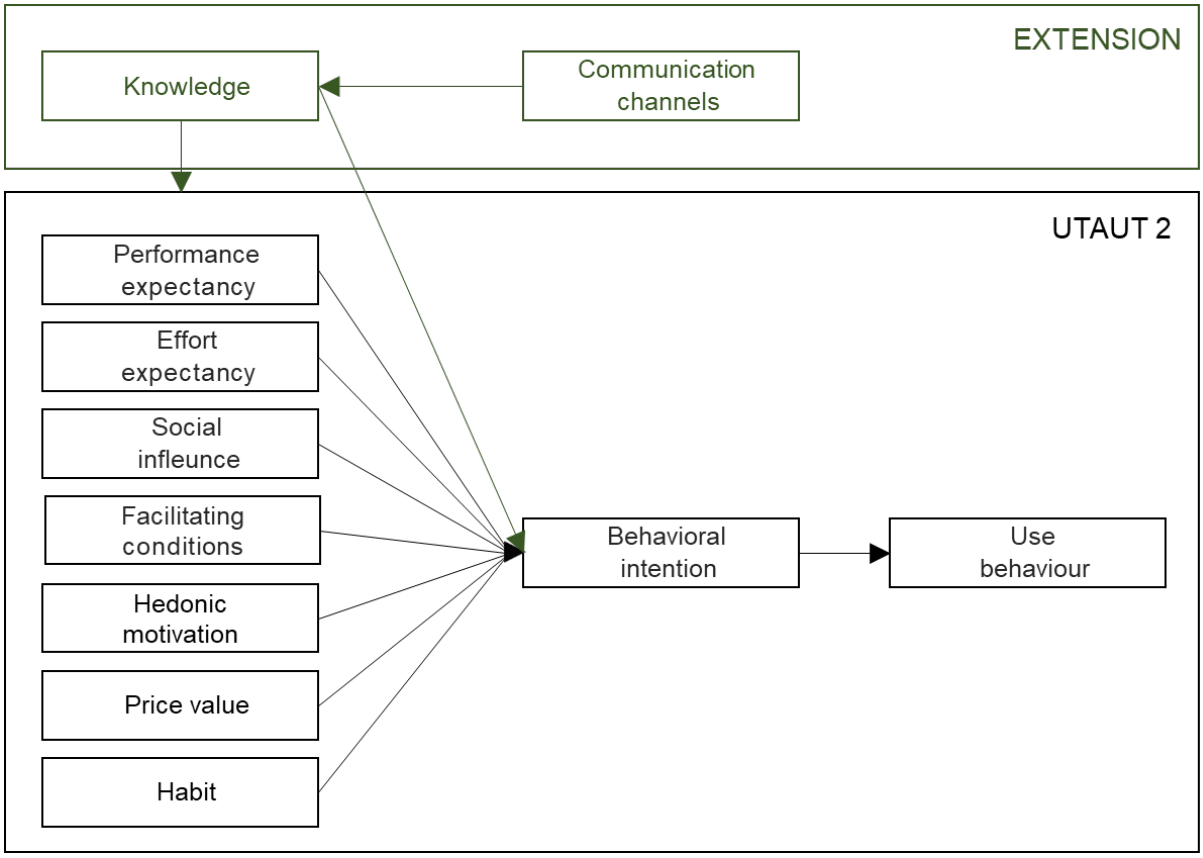
been researched. Few additional contributions are found on this topic (Gabriel, 2016; Zhang and White, 2016; Avilés A. et al., 2019; Israel and Jehling, 2019).

And so, the second major step in this research was taken with the article "*What drives Senegalese SMEs to adopt renewable energy technologies? Applying an extended UTAUT2 model to a developing economy*" (Apfel and Herbes, 2021) where several of these questions were examined. The goal was to adopt a human-centered approach focusing on the entrepreneurs. For this, the Unified Theory of Acceptance and Use of Technology-Model (UTAUT2) was used (Venkatesh et al., 2003; Venkatesh et al., 2012), but extended with insights from the Diffusion of Innovation Theory (DOI) (Rogers, 2003).

Because this study aimed to better understand how entrepreneurs evaluate potential investments in RE technologies, technology acceptance models lend themselves to framing the analysis of the interview data. With the UTAUT2 a model that focuses on individuals' decision-making processes was chosen, as the decision-making processes in Senegalese SMEs are the most similar to those of individuals. This is characterized by the entrepreneur deciding often without consulting others, by decision-making processes that are mostly informal, and by the entrepreneur bearing the immediate consequences of the decision, including its financial impact. In addition, it should be taken into account that the consequences of entrepreneurial decisions must be carefully considered and weighed. The decision whether to use RE technology that takes time most likely a cost-benefit analysis, if for no other reason than to obtain financing (Apfel and Herbes, 2021). Due to these characteristics, the UTAUT2 extended by the DOI is suitable for investigating the research question. The dimensions of the UTAUT2 cover the entrepreneurial consideration processes, the extension by two dimensions from the DOI allows to capture the external information and learning processes of the entrepreneurs.

The extended conceptual framework results in a model with nine dimensions: knowledge, communication channels, performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, and habit (see Figure 6).

Figure 6: Extended UTAUT2 model. Source: Apfel and Herbes (2021)



Interviews were conducted to answer the central research question "What considerations motivate Senegalese entrepreneurs to adopt RE in the operation of their SMEs?" – 36 in all, 23 with entrepreneurs and 13 with energy market experts in Senegal. Analyzing the captured perspectives of both groups against the extended UTAUT2 provides evidence that the enabling conditions central to the adoption of RE technologies in Senegalese SMEs are the two in the extension: knowledge and communication channels. Effort and performance expectancy seem to play a subordinate role although they are generally rated very positively by the entrepreneurs. The prices of the renewable energy technologies are a key challenge and outweigh other considerations of many interviewees. However social influence, hedonistic motivation, and habits do not influence the decision to adopt or not renewable energy in the businesses (Apfel and Herbes, 2021).

But what can be derived from the findings, especially the three most influencing categories, for aspects of entrepreneurship and the role of entrepreneurs in the energy transition? On the one hand, the entrepreneurs interviewed consider the use of renewables as desirable but tend to view the adoption of such technologies in their

business from the perspective of limiting factors rather than that of entrepreneurial opportunities. As a result, they place little emphasis on their own entrepreneurial responsibility for creating opportunities, whereas they see the government as responsible for creating support programs and other enabling factors.

At first, this finding seems somewhat contradictory, since the energy market experts referred in their interviews to existing supporting mechanisms, such as microfinancing opportunities and capacity building options that are demanded by the entrepreneurs. What appears as a contradiction, however, is in fact a key finding: the SMEs interviewed lack knowledge about existing support, which can be seen as an effect caused by limitations in communication channels. The day-to-day business realities already absorb the full capacities of the SMEs, so they have no time for strategic planning or active consideration of the possibilities of new innovations in the company. The limited networking activities that exist serve only social purposes; what would be called strategic networking is almost nonexistent (Apfel and Herbes, 2021).

On the other hand, both the entrepreneurs and energy market experts believe in the benefits of prosumerism, producing energy for self-use and to sell it to others, an approach that finds advocates in Western thinking (Eid et al., 2014; Picciariello et al., 2015; Kubli, 2018; Campos and Marín-González, 2020). This could be an interesting entry point in the energy transition for Senegalese entrepreneurs, as they could sell their surplus renewable energy to generate income, while benefiting the system as a whole by having more energy available. However, this will require a strong commitment from the government as well as national utilities. A feed-in tariff would have to be created, while at the same time the loss of numerous business customers would have to be absorbed. Technical challenges would also have to be solved, such as the integration of many prosumers of different size into grid management. So far, Senegalese SMEs have not yet taken advantage of this potential in the Senegalese energy transition. However, no evidence could be gleaned from the interviews that this situation is the outcome of a deliberate decision by the government not to create a framework that would enable entrepreneurs to play a prosumer role.

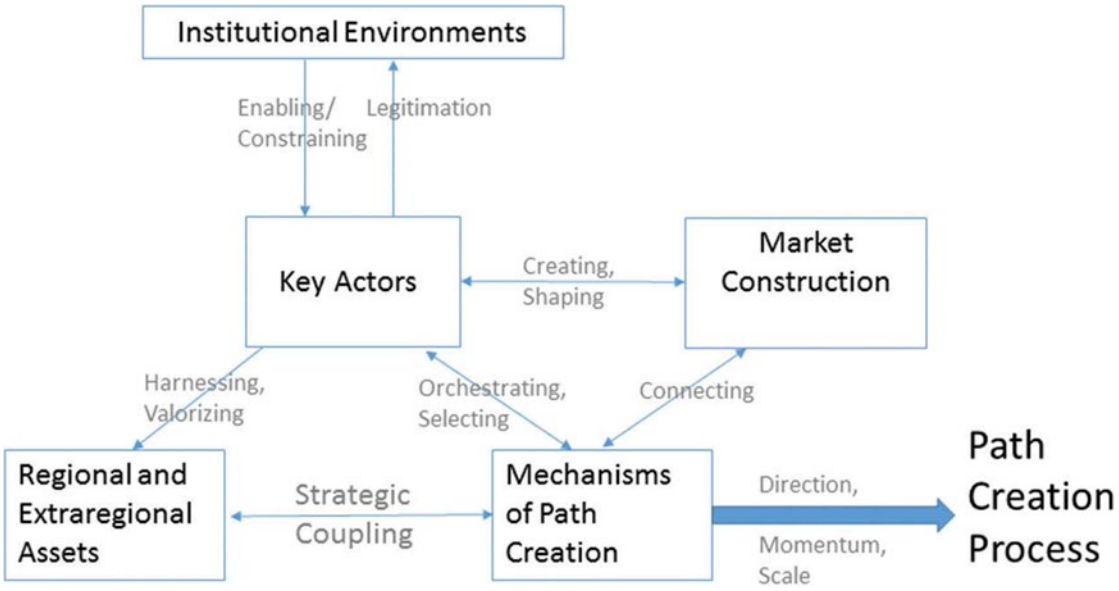
But the question underscores the role that Senegalese entrepreneurs could play in emerging energy path creation and the position of the government in the creation processes of new energy paths, and this line of inquiry was pursued in the third stage of my research, as reported in the third paper in this thesis, “*Renewable energy transition in Senegal? Exploring the dynamics of emerging paths to a sustainable*

energy system" (Apfel, 2022). Here, I sought to identify new energy development paths emerging in Senegal, especially those that go beyond "greening" the energy mix. For this reason, I chose to investigate processes of change in their relation to the entire energy system, instead of as driven by individual technologies or resources. This approach to understanding transition processes draws on the meta-framework of Cherp et al. on national energy transitions that I applied to conduct a systematic literature review in the first stage of my research.

The study was an empirical analysis grounded within the literature of evolutionary economic geography. Recent work in this field shows how path-building processes can inform sustainability transitions (Chlebna and Simmie, 2018; Gong and Hassink, 2019; Hassink et al., 2019; Chen and Hassink, 2020; Heiberg et al., 2020). With their framework on regional path creation processes, MacKinnon et al. (2019) provide an integrative analytical approach that does not privilege any of the key sector elements influencing path creation processes, but rather embeds them in multiscale processes. Their framework integrates insights from established research strands other than evolutionary economic geography, including findings from transition research. The integration of these aspects fits well into the direction of my research, as not only are the three perspectives Cherp et al. illuminating in an adapted form, but a theoretical linkage is also provided to follow up on the research gaps identified in the systematic literature review.

Figure 7 illustrates MacKinnon et al.'s five key elements of institutional environment, key actors, regional and extraregional assets, market construction and mechanisms of path creation. Using these, I analyzed 17 qualitative interviews with experts in the Senegalese energy system, revealing insights into the political, economic and institutional processes shaping the emerging energy paths in Senegal.

Figure 7: Integrative framework on regional path creation processes. Source: MacKinnon et al. (2019)



With this approach, I identify, characterize and report on three parallel emerging energy paths – *path transplantation*, *indigenous path creation* and *path upgrading* – each evolving in a different sector of the energy system at its own pace and on its own scale, each differing greatly in the role of institutions enabling its development and in its underlying legitimation. Key features and predominant structures along each path are highlighted below.

Path transplantation is characterized by the dominance of large-scale projects, realized by independent power producers (IPPs) under power purchase agreements (PPAs). Here becomes evident the influence of transnational key actors who are creating an enabling environment to realize their own goals along the entire value chain. This touches on all types of agency introduced by MacKinnon et al. in their framework: innovative entrepreneurship by actors who see the market opportunities for their technologies, institutional entrepreneurship by actors who gradually transform established environments to prepare them for a new market, and path advocacy by actors who can influence decision-making processes. These actors strongly influence both the institutions in Senegal and the trajectories of RE projects undertaken there.

In performing their roles, the international actors draw on their own evolved structures, financial resources, technologies, and companies from the Global North, and bring them together. This knowledge base is then transferred to the Senegalese context and adapted for project implementation. But this knowledge, so crucial to

designing the complex structures of large-scale-projects, is formed and pooled outside the local context and then brought into Senegal. The Senegalese are not directly involved, and so do not share in the knowledge creation. The risk to Senegal is described by (Trippl et al., 2018), who observe that such dependency on foreign actors and direct investments introduces the risk of a lock-in to the transnational RE networks. Establishing such strong ties is one of the goals of such transnational alliances.

Under these circumstances, it is not surprising that local Senegalese companies are not able to access these transnational stakeholder groups, and thus cannot benefit from these large-scale projects. However, these projects are expected to secure the electricity supplied by the grid. They also contribute to Senegal's emission reduction targets. This means these projects acquire local legitimation through international credibility, not through local engagement. And even though some interviewees question the implementation of large-scale projects, none question their necessity for the state's energy future.

The second emerging energy path I identify and report on in this thesis is detached from the development of large-scale projects. This is a process that can both help balance the energy supply and contribute to greening the energy mix. The focus here is on *indigenous path creation,* the emerging sector of mini-grids and stand-alone solutions not yet penetrated by foreign investors. Here, local companies have the opportunity to shape the market according to their capabilities, the needs of the population, and local conditions.

This opportunity has not yet found much support from the Senegalese government, and so depends principally on the ability of Senegalese RE companies to develop these markets. In contrast to the large-scale projects, agency for indigenous path creation is weak. Critical support from formal state institutions is missing, such as reshaping the banking sector or designing tenders which enable domestic companies to participate. This is a glaring deficit, as state support could promote universal access to energy, and related projects would find clear legitimation among the local population. This governmental neglect is quite remarkable compared to the endorsement of large-scale RE projects. Given the adaptability of small-scale projects to local conditions, their scalability to individual customer needs, and their operation by Senegalese companies, these projects should receive more attention in the future.

The third emerging energy path I identify is that of *path upgrading*. The use of in-country oil and gas resources drives the reconfiguration of this market. The ambition is to shift towards self-sufficiency through these resources and so become independent of expensive imports. In this sector, numerous domestic actors exist who can bundle the existing competences in this field and generate new knowledge, which can take place apart from international actors. In contrast to its neglect of the *indigenous path,* the Senegalese government's intent is to support local companies and include them along the entire value chain of path upgrading. If this proves to be true, there will be ample opportunities for a wide range of Senegalese stakeholders to benefit. Not only will companies in the field of service and maintenance, technical infrastructure, resource exploitation and energy generation and distribution be able to profit, but also universities and vocational schools that can engage in innovative technologies.

This path has received national legitimacy and the support of national institutions from the moment of the first discovery of oil and gas fields. Legitimation derives from the reduction of energy costs and the increase in energy security. Another reason for legitimation is the integration of national companies into the value chain, while in the renewable energy sector, both for large- and small-scale RE projects, the possible role of Senegalese companies has been overlooked by the government.

4.2. Significance of the results for the research questions

My two main research objectives were first, to identify the current state of renewable energy in small and medium enterprises in Senegal to understand Senegalese entrepreneurial engagement in the energy transition, and second to identify the dynamics leading to new emerging energy paths in the country by analyzing the driving forces, institutional settings, regional capabilities, local embedding, and path creation processes that are underway.

The engagement of local companies in the energy transition in Senegal faces two challenges. First, development and private finance are the driving forces behind the transition to renewable energy underway in Senegal. As identified in the article "*Renewable energy transition in Senegal? Exploring the dynamics of emerging paths to a sustainable energy system*" (Apfel, 2022) the financing of large-scale projects is through experienced actors from outside Senegal, and implementation through IPPs leaves little room for local entrepreneurs to participate in the projects.

However, access to a reliable energy supply remains elusive in Senegal, especially for people in rural areas, most of whom live without any access. In areas that do have grid connections, the energy supply is neither reliable nor affordable, which hampers the development of the economy (Cissokho and Seck, 2013; Cissokho, 2019; Apfel and Herbes, 2021). These are opportunities where local companies could fill supply needs by acting as prosumers, or by ensuring supply through mini-grids or standalone systems. As these markets would operate on a small-scale, local companies should be able to take advantage of financing opportunities such as existing micro-credit solutions.

However, both market segments – prosumerism and mini-grids/standalone systems – are new for Senegalese companies. This underscores the second challenge to entrepreneurial engagement in the renewable energy transition in Senegal, namely that any such depends highly on the capabilities of the Senegalese entrepreneurs. As the article "*What drives Senegalese SMEs to adopt renewable energy technologies? Applying an extended UTAUT2 model to a developing economy*" (Apfel and Herbes, 2021) reveals, four factors impede entrepreneurial engagement in the transition: knowledge gaps, missing network structures, weak entrepreneurship skills, and lack of experience with RE. All four must be overcome if the possibilities of the two market segments, as mentioned above, are to develop into real opportunities for Senegalese companies.

The path to development of energy from fossil fuels is where Senegalese firms have better prospects. It would be beneficial for all local actors in the energy sector if, despite the different energy sources, learning effects were to emerge that would enable all companies active and interested in the energy sector to take an active role and participate in the market. This would certainly require extensive support from the government, knowledge transfer through Senegalese educational institutions such as universities, but also cooperation through international development agencies (Apfel, 2022).

Regarding the dynamics of new energy paths in Senegal, clear evidence exists for the emergence of three distinct paths (Apfel, 2022) where, in addition to the characteristics already reported, similarities with the results of the systematic literature review of this thesis (Apfel et al., 2021) can be identified. Seen from the three perspectives of national energy transitions and their main variables (Figure 4), the transition in Senegal shows strong linkages at work between the political and

techno-economic domains, while connections to and interactions with the socio-technical domain are relatively much weaker.

Investment in large-scale RE projects comes from development and private finance, and comprises the most dominant path of energy development in Senegal – *path transplantation.* Through financing mechanisms, international share-holders are engaged whose primary objective is to maximize profit. The government establishes regulatory conditions that create an enabling environment for these investments to unfold. At the same time, these projects can reduce CO2 emissions, which is why they enjoy a favorable review among officials and in the literature. Indeed, the systematic literature review conducted as the first stage of my research found that most articles on RE in the Global South worked from a growth-oriented techno-economic perspective, from which energy is seen solely as an economic good, produced, traded and consumed by society like all other goods. As amply demonstrated by my research, this *path transplantation* idea in its current form has little potential for improving the living and working conditions of the Senegalese people, especially those who are not connected to the grid.

Additionally, there are powerful dynamics emerging in the area of fossil-fuel based energy generation, as development in this direction can contribute both to improving the energy supply and reducing dependence on expensive imported oil. The government's efforts in this sector, especially to integrate local companies into the exploitation of national reserves, show that the government is sensitive to the local companies in this sector. Nevertheless, it is questionable what contribution this sector can make to better access to energy (Apfel, 2022). In this field, too, thinking is locked into and limited by a techno-economic understanding of energy.

The sector that could most directly address the needs of the Senegalese people is the one that is the least developed and receives the least attention from all the actors studied as part of this research. Neither the institutional framework nor the regional capacities are currently in a constellation that would allow locally embedded off-grid solutions for better energy access or the integration of small-scale producers as prosumers (Apfel and Herbes, 2021; Apfel, 2022). We can understand this finding using the three perspectives from the systematic literature review. From the socio-technical perspective, technologies are not traded goods but social phenomena involving shared knowledge, practices, and networks. An energy transition has to be seen from that perspective. But key knowledge gaps exist about location-specific

influences, aspects of entrepreneurship, social and institutional innovations and actor networks of cooperation (Apfel et al., 2021). Deeper understanding of these factors is needed to accelerate the few transition processes at work in this area.

4.3. Research limitations

As far as methodological and data limitations of this thesis are concerned, I would like to address the following points.

In the article "*Research agendas on renewable energies in the Global South: A systematic literature review*" (Apfel et al., 2021), insights were drawn from the literature about RE in the developing countries of Africa, Asia and South America. Based on the experiences from this study, it was challenging to integrate the different research methodologies uniformly. It was relatively straightforward to process the articles that used quantitative methods. The review process was more complex for the qualitative articles because they were written in a less standardized way, which stems from the underlying research questions (Mallett et al., 2012).

I also recognize the bias that comes from focusing on citation history. Articles that have been published more recently or articles that address some of the identified research gaps may have fallen outside the sample because they have too few citations. Due to the feasibility and data size of the systematic review, I had to limit the sample to 90 articles, which meant 30 articles per region. While the results can only characterize the sample, a sample of the 30 most cited articles on a region serves to highlight the dominant structures and key aspects of the research agendas. The systemic review was revealing, but the paradigms revealed were not enough to explore my research interests. However, in combination with the meta-framework, published in 2019 by Cherp et al., the literature sample fit very well into the energy transition debate. This approach added value to my findings, as it helped further identify methodological characteristics, knowledge gaps and promising future research directions.

In the article "*What drives Senegalese SMEs to adopt renewable energy technologies? Applying an extended UTAUT2 model to a developing economy*" (Apfel and Herbes, 2021), the empirical analysis finds its footing within the theoretical framework of the Unified Theory of Acceptance and Use of Technology (UTAUT2) (Venkatesh et al., 2003; Venkatesh et al., 2012) combined with insights from the Diffusion of Innovation Theory (DOI) (Rogers, 2003). The use of this model may have

led to overlooking the influence of entrepreneurs' social practices on their decision-making. Because the goal of the exploratory qualitative study was to open up avenues in an under-researched field, the UTAUT 2 was deliberately chosen as it is a robust analytical model tested and used successfully in other studies on developing countries. Insights into the social practices of entrepreneurs could be drawn to a certain extent from the DOI categories of knowledge and communication channels. This is enough to make a start, but future research should include factors that probe deeper into the decision-making processes of entrepreneurs. The concept of individual entrepreneurial orientation (IEO) is promising for this purpose, as it allows investigation of the “deep-rooted beliefs and values associated with a tendency to be simultaneously proactive, risk taking and innovative” (Goktan and Gupta, 2015, p. 98).

The study “*Renewable energy transition in Senegal? Exploring the dynamics of emerging paths to a sustainable energy system*” (Apfel, 2022) draws on the framework of MacKinnon et al., which has proven extremely valuable in shedding light on the emerging energy paths in Senegal. Although this integrative approach helped me identify the energy development paths, characterize dominant structures, and highlight future opportunities, the inherent nature of a meta-theoretical approach limits the scope of analysis of the multi-layered interconnections among Senegal's major key elements.

4.4. Recommendations for future research and policy recommendations

The results reported in this thesis can be used to guide further research on renewable energy in sub-Saharan African countries, encourage investment in existing energy niches, and enhance the role of local companies in sub-Saharan Africa's energy transition.

There are several avenues for further research stemming from the results of this dissertation. Given that local companies could play an important role in the energy system through self-supplying energy, feeding the surplus energy into the grid, and improving the living conditions in rural areas, further research should investigate entrepreneurial needs and competencies; it should also consider policy possibilities provided by regulatory frameworks. Further research could also address social innovations co-evolving with a further engagement of local companies into the renewables market (Apfel et al., 2021; Apfel and Herbes, 2021).

Continuing with the results of the identified emerging development paths, it would be fruitful to apply further approaches from economic evolutionary geography to path development. In particular, interpath dynamics in regional contexts, as explored by Frangenheim et al. (2020), may be relevant in the Senegalese case. Their approach could be used to determine whether there is competition between the two RE paths for the same scarce assets and whether synergies could be actively leveraged by the national authorities.

This leads to questions about power relations in energy transitions in developing economies, an issue that also became evident in this thesis, particularly with regard to the three emerging development paths. The western predominance of financial resources and knowledge heuristics raises questions with regard to participation, ownership and responsibilities (Apfel, 2022).

As shown by the reform processes and confirmed by the empirical studies conducted, the Senegalese government has taken numerous steps to support the energy transition. The specific business factors of companies in the informal sector should be taken into account, as these make up the majority of Senegalese companies. In addition, policy makers and consultants, such as international development agencies, should investigate the opportunities but also the technical and regulatory challenges of local companies who can contribute to a sustainable energy transition as prosumers (Apfel and Herbes, 2021).

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6. Author’s declaration

I hereby declare that this doctoral thesis is a result of my own work and that nothing other than the indicated aids have been used for its completion. All quotations and statements that have been used are indicated. Furthermore, I declare that the work has not been used, either completely or in parts, for achieving any other academic degree.

Tübingen, 2022

Dorothee Apfel

7. Appendix

Article 1

Apfel, Dorothee; Haag, Steffen; Herbes, Carsten (2021): Research agendas on renewable energies in the Global South: A systematic literature review. In: *Renewable and Sustainable Energy Reviews* 148:111228. https://doi.org/10.1016/j.rser.2021.111228

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Article 2

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Article 3

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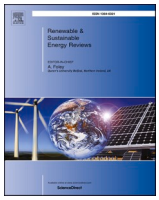

Research agendas on renewable energies in the Global South: A systematic literature review

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ABSTRACT

Given the global importance of deploying renewable energies (RE) in countries of the Global South, the relevant research landscape is still sparse. Through a systematic literature review and analysis of the 90 most highly cited articles on RE in Africa, Asia and South America, we characterize the topics and approaches explored so far. We find that quantitative approaches, especially energy models, dominate the research, with topics focusing on resources, potential energy demands, and production of energy using RE technologies. The political and social processes so critical to a sustainable energy transition are underresearched. Work on the development nexus is scarce, especially considering articles selected for analysis focus specifically on the Global South. Analytic perspectives are predominantly techno-economic, with a conspicuous lack of thought given to business potentials and energy infrastructure. Some recognition exists that the concept of technology maturity has to be expanded to capture the specific local conditions that affect technology diffusion. And while the role of actors in an energy system is acknowledged, it is done so only in general, giving us little insight into knowledge acquisition and transfer, or networks of social capital. Policy perspectives are of course addressed, but these tend to regard the state as an autonomous actor. Governance systems where policies evolve through competing interests are largely ignored. Established concepts are often inadequate to meet the challenge of decarbonizing energy systems. To find viable solutions, scientists should therefore investigate in new research directions, which we highlight in the conclusion of our analysis.

1. Introduction

Humanity is currently facing the challenge of climate change, which calls for sustainable energy solutions [1,2]. These solutions lie in higher energy efficiency and a shift from fossil fuel sources to renewable energy (RE) [3]. This is also reflected in the UN's sustainable development goals that feature RE in a central role [4].

While power generated from renewable sources is increasing worldwide [5], and research on the development of renewables in the Global North is abundant, less research focuses on the low carbon energy supply in the Global South [4]. But development of such a supply is crucial in countries of the Global South, for three reasons. First, they are most vulnerable to the effects of climate change [6]. Second, their energy demands are growing rapidly [7], and meeting them by fossil fuels is not an option. Third, many of these countries are rich in the sustainable natural resources that RE solutions rely on [8].

But it is not only from the Global South's perspective that the shift to renewable energy is essential. Globally, these countries are expected to account for two-thirds of the world's energy consumption by 2050 (own calculation based on [7]), a share far too big to be overlooked by RE research. Numerous empirical studies and reviews that address the contribution of renewable energy to economic growth in countries of the Global South have been carried out in recent years, however based on different assumptions and models. As researchers point to bidirectional causalities [9–13] no positive impact of renewable energy consumption on economic growth can be confirmed per se.

Indeed, such research can be the foundation on which rest sustainable solutions to the emerging energy needs in the Global South. Research is needed to assess the suitability of different renewable energy technologies (RETs) to the specific conditions in a given region. But most importantly, identification of local knowledge and practices needed to

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List of abbreviations

RE	Renewable Energy
RET	Renewable Energy Technology
DC	Developing Countries
WoS	Web of Science
PV	Photovoltaics

embrace RE can contribute to the governance of energy transitions.

To characterize the current research landscape and identify significant knowledge gaps, we provide here a comprehensive analysis of the research agenda about RE in the developing countries (DC)[1] of Africa, Asia and South America.[2] Through a systematic literature review, we identify 1) dominant topics, theories and research approaches; 2) differences and similarities between the studies on each of the three regions; and 3) research gaps, especially those revealed from the perspective of social science.

In the next Section, we introduce our research method to explain how we identified the articles to include for our analysis and how we went about that analysis. In Section 3, we present our results on research designs, contents and theories found. In Section 4, we put forward an interpretive framework for these results. This enables us to position our findings within the current debate about energy transition processes. We then close in Section 5 with our conclusions.

2. Research method

A broad body of literature has investigated renewable energies in the Global South, but no comprehensive review of the findings exists. This makes a systematic literature review the ideal approach to synthesizing current findings and identifying both dominant trends and significant gaps in the research agenda. Systematic reviews provide a transparent, well structured, unbiased analysis of existing research [14].

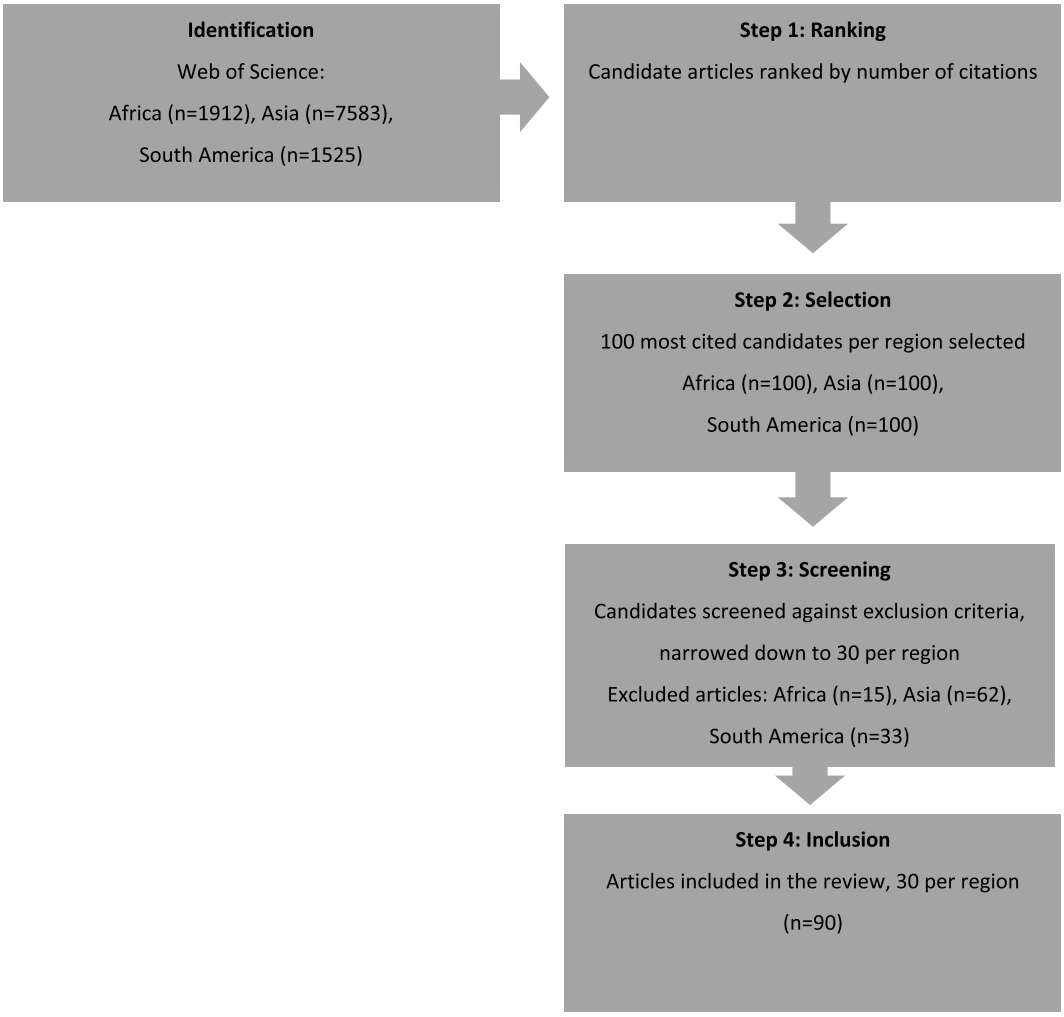

Fig. 1. Overview of systematic review design. Source: Authors, chart inspired by Ref. [107].

[1] This term has been criticized within the social sciences, because of its normative underpinnings. We thus prefer the term Global South. However, we also use "developing countries" when referring to our sample set, as we perceive that this term is still commonly used in the existing research agendas.

[2] In this article we refer to South America, including all DC of Central America, the Caribbean and Latin-/South America.

Our approach is based on the 'PRISMA statement', which provides a minimum set of evidence-based items for reporting in systematic reviews and meta-analyses [15]. These items cover the identification, screening, eligibility and inclusion of the material to be analyzed. Following the PRISMA logic ensures a transparent, comprehensible and replicable approach. The full review protocol can be found in the Appendix.

For our analysis, we reviewed the 90 most cited articles published on RE in Africa, Asia and South America. For practical reasons, we limited our analysis to 30 articles per region. The review includes only peer-reviewed journal articles written in English.

The process by which we selected articles for review is illustrated in Fig. 1. Relevant articles were first identified through the "Web of Science" (WoS) database by searching for articles with the phrase *Renewable Energ** in the title, keywords or abstract. The article search was further restricted to developing countries in Africa, Asia and South America.[3] Articles were then selected by highest number of citations. In the selection process, we screened the articles and selected them considering our defined set of exclusion criteria (see Appendix). Excluded articles were replaced by the next most-cited article. After the four steps of selection, we had 30 relevant articles per region for the review: Africa [17–46], Asia [47–76], South America [77–106].

To conduct a systematic evaluation of the article set, we used qualitative content analysis as developed by Mayring [108]. This approach was especially useful in deriving our coding framework with its category system. This is central to content analysis [108], as it permits reducing the material by selecting key aspects to concentrate on. After systematically analyzing the article set using our category system, we derived further subcategories by reviewing the relevant content of each article.

We used a mixed deductive-inductive approach to develop our analytical categories [108]. The main categories were formulated deductively, based on our knowledge from existing literature in the realm of RE and development. The subcategories were first formulated inductively, derived from our sample, and then deductively reduced to form an analytical framework. The main goal of combining the inductive and deductive methods was to develop a coding framework for our research questions. Once the framework was developed, we could count the number of articles in each category. This measure served to highlight the most important categories in our article set. Through this process we obtained the categories and subcategories shown in Table 1.

Table 1
Summary of research (sub-)categories. Source: Authors.

Category (deductive)	Subcategory (inductive-deductive)
Metadata	Journal affiliation
	Publication year
	Author's disciplinary affiliation
	Country affiliation of authors' institution
	Level of analysis (single, multi-country)
Research design	Theoretical framework
	Research methods
Technological focus	Type of renewable energy technology
	Position in the energy value chain
	Economic agents
Political perspective	Policies
	Institutions
Socio-cultural context	Actors
	Participation
	Acceptance
	Business models
Development aspects	Economic aspects
	Social aspects

[3] Country classification according to the UN World Economic Situation and Prospects 2020 [16], except Hong Kong, the Republic of Korea, Singapore and Taiwan.

After defining the subcategories, we re-evaluated the sample to systematically identify and then analyze patterns for each subcategory across different articles. For the qualitative content analysis, we used the software MaxQDA [109].

3. Results of the review

We selected for qualitative content analysis 90 of the most highly cited peer-reviewed articles in English on renewable energy in the developing countries of Africa, Asia, and South America. Here we review what emerged from that analysis.

3.1. Metadata

Looking first at the distribution of the journals, we found that four journals in particular carry the research agenda, representing 64% (n = 58) of the articles in this review: Energy Policy, Renewable Energy, Energy, and Applied Energy (Fig. 2). Most articles of the sample were published within the six years from 2006 to 2012, (63%, n = 57).

The disciplinary affiliation[4] shows that across all articles, authors from engineering have dominated the research conversation (67%, n = 60). They are followed at a considerable distance by authors from the social sciences (23%, n = 21), the sciences (8%, n = 7) and agriculture (2%, n = 2) (see Fig. 3).

Our sample shows that local institutions of all three regions are the driving forces behind the research: 67% of the articles (n = 20) about Africa were published by institutions from Africa; the numbers are 90% (n = 27) and 73% (n = 22) respectively for Asia and South America. Studies on single countries dominate the literature on all three regions. However, in Africa, our sample covers a wider range of countries than in Asia and in South America, where the diversity is more limited. In these two regions, articles about Malaysia and Brazil dominate.

In summary, we find a large number of journals that have published the articles in our sample, but only four carry the bulk of the discourse. Two out of every three voices in that discourse belong to engineers, with social scientists the most vocal in the remaining third. Research institutions from Africa, Asia and South Africa drive the publication record.

3.2. Research design

Under the category of research design, we look at the strategy an article adopts to answer its research question(s) and provide context for a reader. A research design is explicit when it clearly indicates the theories and frameworks underlying the study questions and the applied methods. The methods should refer to the techniques used to fulfill the research objectives [14].

Identifying the underlying *theoretical approaches* of the articles in our sample set turned out to be difficult. In total, a mere 9% of the sample (n = 8) clearly refer to a theoretical base. Seven articles are from social science [42,48,59,71,80,89,104] and one is an engineering article [34].

Screening our sample for *research methods*, we found numerous quantitative approaches, a small number of qualitative approaches and a good number of non-empirical approaches, which for want of a better category we call review articles. We did not classify case studies separately, because the authors themselves only rarely categorized them as

[4] For disciplinary affiliation we used the "Classification for the Social Sciences" after GESIS - Leibniz-Institute for the Social Sciences [110] Based on this classification we coded the self-information provided by the authors in the articles. If this information was not sufficient, we did an internet search to identify the authors' disciplinary affiliation. We decided to consider each of the authors not only the first named. The concrete assignment was made based on the article. This means that we assigned an article to the discipline where the majority of the article's authors came from.

Fig. 2. Journal affiliation. Source: Authors.

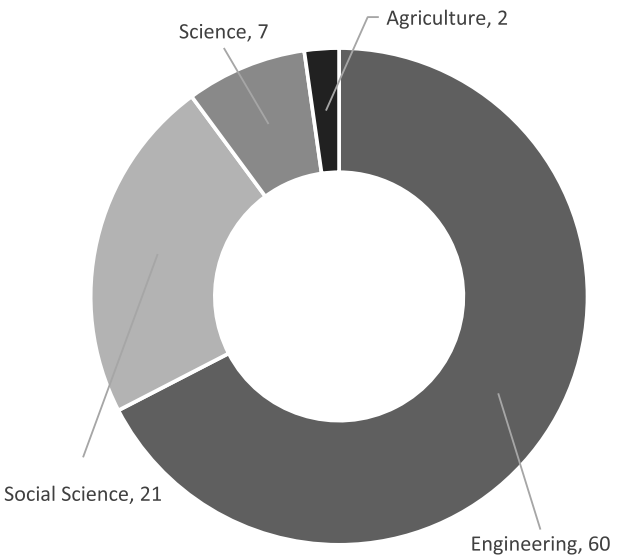

Fig. 3. Disciplinary affiliation. Source: Authors.

such. We thus decided to categorize articles first as empirical or non-empirical, then further as quantitative or qualitative.

The majority of the articles are thus empirical, quantitative research (69%, n = 62). The subcategory *quantitative* here includes economic models, energy scenarios, energy models, input/output analyses, cost (-benefit) analyses, lifecycle assessments, geoinformatics and other tools. The majority of these quantitative articles combine multiple methods. The most common category is energy models 36% (n = 32), followed by cost analyses 27% (n = 24). The calculation of energy generation costs, helps quantifying cost effectiveness of RE deployment. The combination of these two categories energy models and cost analyses occurs in 20% of the sample (n = 18) [18,29,30,33,38,39,41,45,54,56,58,60,68–70,77,85,102].

Other dominant quantitative methods are economic models (10%, n = 9 [22,25,42,43,48,59,78,80,99] and lifecycle assessments (10%, n = 9) [23,44,46,65,92,97,100,101,105]. These are followed by energy scenarios (9%, n = 8) [28,34,46,48,53,61,79,82] and geoinformatics (7%, n = 6) [21,25–27,43,91].

Articles using *qualitative methods* are, with 9% (n = 8), clearly underrepresented compared to the quantitative set. All eight qualitative articles [17,19,32,50,51,89,104,106] use interviews, some supplemented by ethnography. The main topics of investigation are energy access, impacts on living, governance and investments on a national level as well as a special focus on social acceptance. All the articles identify technological and institutional challenges related to these topics.

We categorized 22% (n = 20) of the articles as *review articles* [20,31,36,40,57,63,64,66,72,74,76,81,84,86,90,93,94,96,98,103], because they did not employ any discernible empirical method, neither quantitative nor

qualitative. Although we termed them "review," none of these articles put forward a method for how they analyzed and presented past research. To be fair, only a few articles claim to do a literature review. Even more surprising, many articles do not even take a critical position to past research. Only three articles take this perspective throughout [63,81,103], and six partly. Many articles, however, rather naïvely present the results of past research as facts. Only two articles report on past studies and provide an overview table [48, 63]. However, none of the articles is a systematic review, providing information about search terms, language, databases used, time frame or sampling as we would expect from non-empirical research articles [14].

In summary, most authors employ quantitative methods, especially energy models, economic models and cost analyses (see Fig. 4). Qualitative methods are rarely applied, reflecting the low representation of social scientists in the sample. Articles with no empirical evidence are numerous, and literature reviews are unsystematic, lack structure and transparency. Surprisingly, across all articles only a few authors base their work on a theoretical framework. While the advantage of quantitative research lies in testing hypothesis and quantifying relationships, often aiming to develop future scenarios and projections, qualitative research is needed when deep insights into social phenomena shall be derived, such as "opinions, attitudes, perceptions and understandings of people and groups in different contexts" [14]. Literature reviews are used to assess the current body of literature and identify research gaps [14]. Applied to our review sample, the majority of articles are concerned with the quantification of energy data, whereas articles that examine the underlying behavioral patterns and attitudes, which are closely intertwined with an energy system, are widely neglected.

3.3. Technological focus

Here we look at the renewable energy technology (RET) the articles focus on. A majority of the articles, 57% (n = 51), report on a mix of at least two technologies from solar power (50%, n = 45), bioenergy (44%, n = 40), wind energy (41%, n = 37), hydropower (14%, n = 13), or geothermal energy (8%, n = 7). Since solar, bio and wind energy predominate, we look at them in more detail (see Fig. 5).

Solar power is the most studied RET, often in a mix with others. The diversity is large. Some articles model it in regard to its potential for RE supply as one option among other RETs, others deal specifically with site conditions and the potential for the technology, and yet others examine the conditions under which solar home systems are actually used. In 72% (n = 38) of the articles, the solar technology examined is photovoltaics (PV). Solar thermal energy and concentrated solar power have

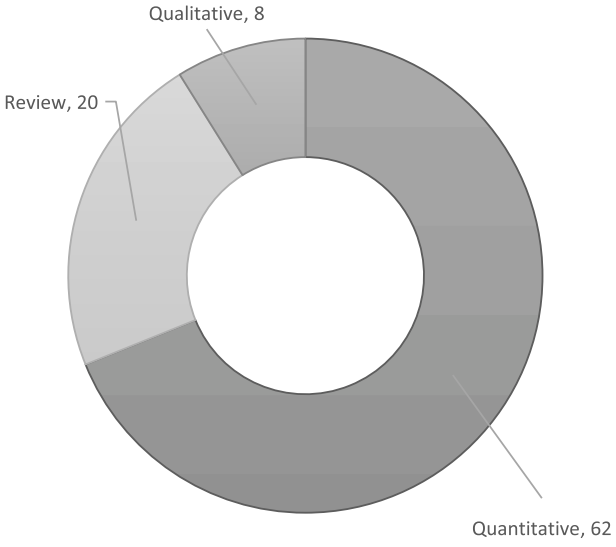

Fig. 4. Research methods affiliation. Source: Authors.

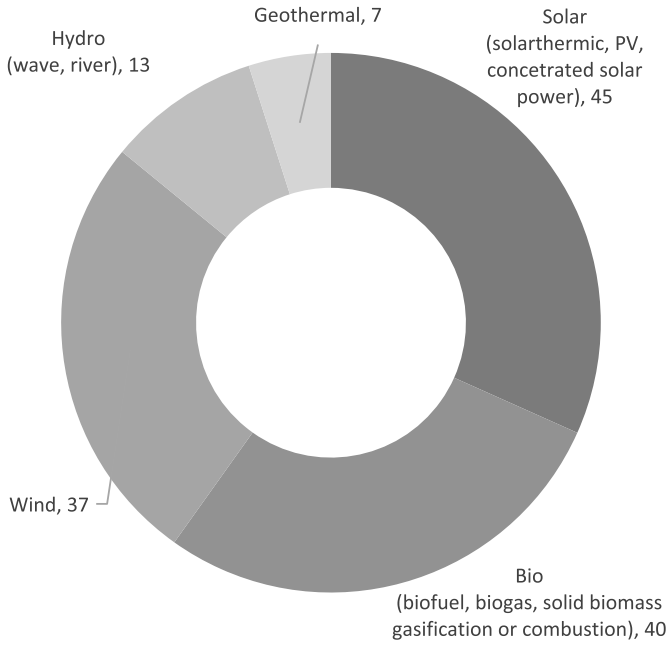

Fig. 5. RET. Source: Authors.

been of little research interest, each appearing in only 4% (n = 4) of the articles.

Only 10% (n = 9) of the articles investigate exclusively solar power. Seven of these are based on quantitative methods and follow mainly a technological approach: investigating solar radiation predictions for the optimization of PV systems, often involving system dimensioning [24, 26,34,35,46] and mapping of solar energy resources [91]. We also found one study on cost assessment of concentrated solar power [46] and one on PV used for desalination [45]. The two qualitative solar-related articles focus on factors important for the actual application of solar power [17,89].

Another eight percent (n = 7) of the articles in the sample investigate PV-diesel-hybrid solutions [18,37,43,56,60,68,85]. These articles identify how the energy needs of villages without a grid connection can be met, focusing primarily on techno-economic feasibility questions.

We found 44% (n = 40) of the sample addressing biofuels, biogas and/or solid biomass technologies. Biofuels, especially ethanol, dominate, followed by biogas and solid biomass technologies. As with articles addressing solar power, most of these articles address a mix of RE technologies.

In our sample, 27% (n = 24) of the articles investigate bioenergy only. Biofuels are by far most frequent (21%, n = 19). Articles about biogas and bioenergy (6%, n = 5) play a subordinate role. The biofuel articles have a strong focus on ethanol (n = 12). Diesel (n = 5) and oil (n = 2) are less often represented. The production of biomass and energy are clearly the most extensively studied aspects of bioenergy. Studies that address questions of biomass transport, trade or consumption are rare.

At this point, let us recognize that *negative environmental impacts* play a crucial role in the sustainability of bioenergy production [111]. In this respect, we consider all the articles on Asia, covering the cultivation of energy crops [53,63,65,72,75], with the exception of Ahmad and Tahar [47] to be rather naïve. This applies to articles covering the cultivation of energy crops, such as oil palm and jatropha in Asia, but also to those considering soybean and sugarcane in South America. Here, we found markedly one-sided views of the palm-oil-business, praising it for its commitment to sustainable development while rejecting environmental concerns raised by previous studies. Other bioenergy studies neglect environmental issues entirely.

Articles addressing biomass technologies in South America do not

take such a rosy-eyed approach. Several of the articles on this region place environmental impacts at the core of the investigation, such as life-cycle assessments, environmental footprints or the use of environmental and social indicators [79,81,83,90,92,101,106]. Nevertheless, we also found articles with only a cursory or one-sided consideration of environmental impacts [78,84,86,88,98].

We also found a large number of articles about wind energy (41%, n = 37). However, only seven percent (n = 8) investigate wind energy alone. These articles focus on local wind parameters such as wind speed and power density [27,49,73,95], the possibility of plug-in hybrid electric vehicles to regularize potential energy imbalances in the grid [102], and social resistance to wind projects [93].

Analyzed by where in the *energy value chain* the research directs its focus, our sample shows the greatest attention has been paid to energy production (73%, n = 66). Energy demand also attracts research interest (26%, n = 23), albeit strongly focused on energy load curves. The production of raw material (21%, n = 19), the storage of energy (19%, n = 17) and the management of the transmission grid (12%, n = 11) are also central to many articles. Articles about the transport of raw material, trade, or the consideration of the entire value chain are rare.

Analyzing the sample by *economic agents* shows that the majority of the articles that address them explicitly treat households (30%, n = 27) and economic sectors; transport (17%, n = 15), agriculture (12%, n = 11) and industry (9%, n = 10). The service sector (6%, n = 5) is underrepresented. Many of the articles address several sectors.

In summary, the majority of the articles address multiple RETs. Solar energy is the most common technology studied, followed by bioenergy and wind energy. Geothermal energy and hydropower receive far less attention. Numerous articles in the sample take into account only one energy type. Remarkably, despite the broad interest in solar power, the articles that focus on one energy type overwhelmingly choose as that type not solar power, but bioenergy.

3.4. Political perspective

In this section, we assess the political perspective of articles in our sample. The analysis includes policies and institutions. The focus of our assessment is the treatment by the articles in our sample of renewable energy policies in developing countries. Almost ¼ of the articles in our sample (24%, n = 22) discuss in varying degrees of detail the RE policy context. Here, we distinguished between analysis of single policies (e.g. feed-in-tariffs) or of a RE regulatory framework. We also identified articles (4%, n = 4) investigating the role of institutions (see Fig. 6).

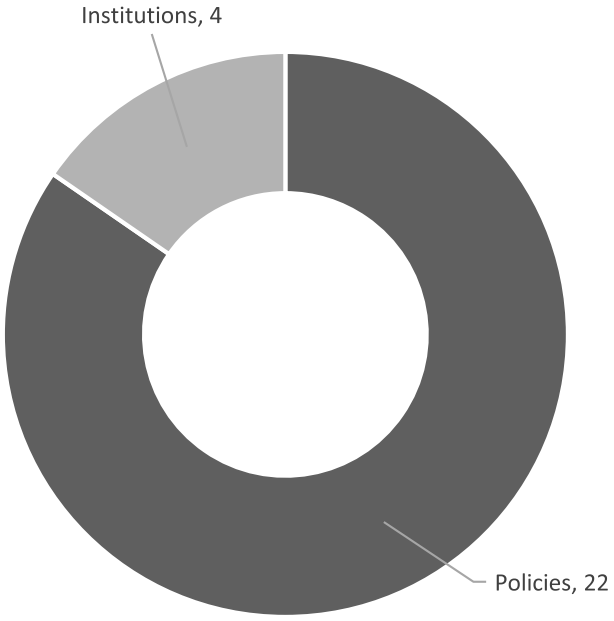

Fig. 6. Political perspective. Source: Authors.

In total, we identified 13 articles [19,40,46,47,51,63,64,66,72,75–77,104] that refer to feed-in-tariffs, and ten articles mentioning RE quotas [40,52,59,81,82,84,86,96,98,104]. Cursory inspection of the article lists shows that the categories are not exclusive. Similarly, other RE policies reported on are tax reductions, the clean development mechanism, and power purchase agreements. Only six articles [32,46,78,81,82,104] adopt a comprehensive policy perspective and consider the entire regulatory framework.

The range of analytical depth runs from a mere mentioning of policy recommendations in the concluding section to a more thorough analysis of specific aspects of RE policies, especially their economic, social and environmental impacts. Two examples serve to demonstrate. Pegels [40] discusses the economic impact of RE policies in South Africa on price levels, investments and costs. Garcez and Vianna [81] unpack the social implications of the Brazilian biodiesel program and critically assess legislative shortcomings in the social inclusion of farmer families. The authors further examine the program's implications for food security and criticize its failure to consider sustainability issues in agricultural practices.

How policy can serve as both a driver for and a barrier against widespread adoption of RE is another important perspective in the article set. For example, Ahlborg and Hammar [19] identify support from governmental policies, donors and governmental agencies as key influences driving the energy transition. Palit [64] singles out enabling policies in Asia such as rural electrification programs, 'Small Power Purchase Agreements' or the creation of a Rural Electrification Board. Reddy [67] shifts the perspective from drivers to barriers by identifying a lack of regulation in grid access or economic compensation for energy supply as main obstacles for wind farm developers.

One further aspect within the political dimension of RE adoption are both informal and formal institutions. These embody the structures and rules that support or limit the promotion of RE [112] within the local governance context. Four articles discuss the role of institutions as a potential driver but also a barrier to successful RE deployment [19,36,93,104]. These authors report that respecting the local institutions is prerequisite to introducing RE; the authors further highlight how acceptance of new technologies hinges on their being embedded in local socio-cultural practices.

However, we found only one article within the entire sample that adopts a genuine governance perspective in its methodology. Sovacool [104] applies a polycentric approach to a thorough and comprehensive analysis of political processes, an analysis that accounts for a multiplicity of actors with overlapping jurisdictions and scales of operation (e.g. local/national). His approach highlights how the energy transition depends on a central state as the key driver of change. But this approach equally demonstrates that the energy transition relies on various more actors to be included in the process [104]. His, however, is the only research in our set to apply a model derived from political science.

In summary, our review of political perspectives demonstrates that RE policy approaches have attracted significant research interest, and the literature has succeeded in touching on numerous issues. Yet, the analytical scope of the analyses is lacking. The role of political institutions is hardly examined, and only one article applies a political science-based model. Nevertheless, these articles convey valuable insights on how institutions may foster or hinder RE deployment.

3.5. Socio-cultural context

A low carbon energy supply cannot be achieved solely through technological advances. We need findings from research on social processes to help us understand the dynamics and drivers behind the acceptance, adoption and rejection of RETs [113,114]. We identified articles in the subcategories as shown in Fig. 7.

Of particular importance in the adoption of RETs are public and

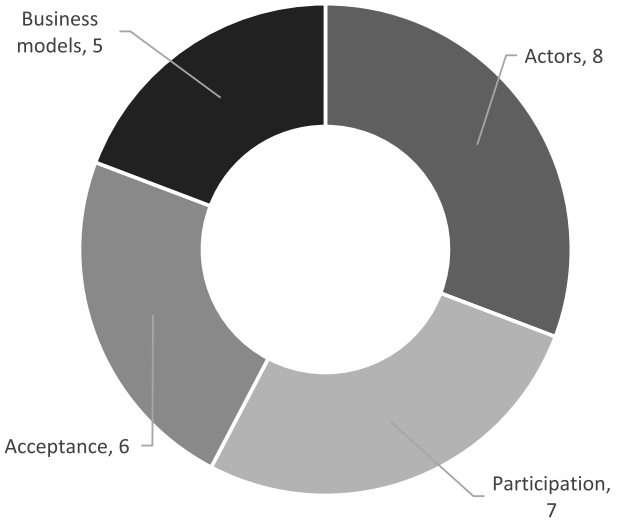

Fig. 7. Socio-cultural context. Source: Authors.

private *actors*. Their goals for the energy transition and the roles they play in the process shape the ongoing events and outcomes. Although many articles point to the responsibility of state actors for shaping policy regulations, the articles treat these actors as static preconditions, meaning the studies largely ignore the roles these actors play.

Only eight articles look closer at the roles actors play in the energy transition process [36,40,51,64,89,93,94,104]. Some of these follow an integrated approach, outlining how state actors can integrate private actors and civil society groups into the transition process. Others investigate local initiatives, revealing barriers for participation in RE projects arising through inadequate project planning. Better planning is needed for better integration of private actors like banks, suppliers, and private agencies. Here, project planners play a crucial role, as too often through insufficient communication with both public and private local actors, wrong assumptions have undermined projects. NGOs, international development agencies and donors are also mentioned as actors in the transition process, mainly for their role in implementing RE projects. But the interplay among actors, how their different objectives and strategies influence outcomes, is peripheral to most of the articles.

Empowerment and the ability of people to make decisions are crucial for transition processes [115,116]. Seven articles in the sample study *participation* processes [36,40,64,89,94,104,106]. We found different approaches in the articles regarding the degrees of participation. First, we found articles claiming usability test of renewable technologies as a form of participation. Second, we found articles calling for the inclusion of users, rural committees and local representatives into the transition processes. Third, some of the authors emphasize transparency, public participation, deliberation periods, and polycentric approaches with the active collaboration of various interest groups in decision-making and planning processes. One article summarizes the process as an "ever--evolving interchange in which all participants play an active role in a dynamic manner" [89].

As far as the *acceptance* of RETs is concerned, human-centered factors such as specific conditions, behavior and lifestyles need to be taken into account [115,117]. Six articles address aspects of acceptance [17,36,47,89,93,94], together identifying these seven conditions for acceptance: transparent communication and information, participatory processes, inclusion in the decision-making processes, familiarity with the RE technology, suitability of the technology to local needs, respect for the cultural heritage, and adequate compensation for land use rights.

The fit of RETs in the socio-cultural context depends on the *business models* chosen. Business models or elements of them are mentioned in five articles [50,64,70,77,106,118], but only two of these actually use the term "business model". Absent, however, is research into business model elements like customer segments, value propositions or revenue models, concepts associated with the term "business model" [118]. Most articles discuss whether energy production follows the logic of the profit-oriented private sector or the logic of the public sector. Concepts are proposed that combine private and public supply, community-based models for rural electrification with cooperatives or village energy committees with a mix of central and decentralized units or sub-contractors for maintenance and billing. With regard to revenue models, electricity flat rate and maintenance services, prepayment meters and net metering with the possibility to sell surplus electricity to the electricity company are mentioned. Financing possibilities are seen in (micro-) financing by consumers, service fees and leasing. For rural areas, a combination with income-generating activities, e.g. milk processing, is also discussed.

In summary, socio cultural context is the category that receives the least attention from researchers in our sample. Articles do address the importance of public and private actors; however, they do not explore actor networks in the depth needed to advance the energy transition. Nor are business models adequately researched, even though they play an important role in the deployment of RETs. Participation processes receive differing degrees of attention; collectively, the articles identify a number of conditions considered crucial for RE acceptance: transparent communication and information, participatory processes, inclusion in decision-making processes, familiarity with the technology, suitability to local needs and practices, respect for the cultural heritage, and adequate compensation for land use rights.

3.6. Development aspects

A broad body of literature has examined links between energy access and progress in terms of "development" in its widest social, political, and economic context [119,120]. Energy access in the form of electrification is widely assumed to be key to a successful "development" trajectory [121–123]. However, there are empirical findings that energy access does not always lead to an increase in income or an alleviation of poverty [124].

Against this backdrop, we analyzed our sample articles by their treatment of questions related to developing countries. We first identified categories from the conventional quantitative metrics of economic development, such as GDP growth, financial ratios, and poverty lines [125]. Here, we tagged 36 (40%) articles. We also found the power dimension addressed as a sub-category and analyzed findings from four articles (4%) investigating donor presence and aid dependency.

To extend our analysis beyond quantitative economics, we identified people-oriented categories, such as capacity, gender and knowledge

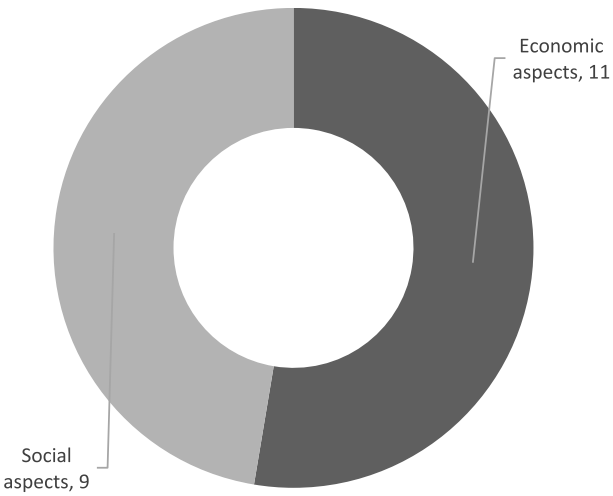

Fig. 8. Development aspects. Source: Authors.

[126]. Only 21 articles (23%) address these issues. In addition, as a sub-category, we identified articles addressing the divide between rural and urban areas. Here, we tagged 14 articles (16%). Of these 14 articles, 11 articles address economic aspects, nine articles address social aspects (see Fig. 8).

Because many articles in our sample address issues at least tangentially related to "development," we restrict a more detailed analysis to the 14 articles that fall into three or more of the above-mentioned categories and sub-categories. These we regard as offering a more thorough and comprehensive perspective on the broad theme of development [17,19,31,36,40,50,51,64,67,81,89,93,104,106] in their geographic regions.

Concerning *economic aspects* of development, authors within the sample discuss RE deployment as a driver for growth and development. First of all, the domestic RE sector is said to create jobs [104], yet this promise may backfire if jobs do not materialize. In that case, opposition can ensue, as the further marginalization of already economically weak groups through RE projects prompts opposition and protests against RE plants [93].

Still, there is consensus in the sample that by bringing energy to the most vulnerable people in society, RE represents a powerful solution to pressing social problems. It can help alleviate poverty and improve living standards [50,64,104]. But even Palit and Chaurey [64] who report a correlation between RE deployment and economic growth do not claim the relation to be cause-and-effect. If such relation is ignored, the risks mentioned in Ref. [93] can arise.

An important finding to emerge from the sample is the identification of numerous financial barriers to successful RE deployment. Inadequate financing is expressed as a key concern and takes many forms, from the absence of international investors [51], to the lack of financial resources [19,50,64], to the high costs of renewables technologies [31,67], which are often burdened by high import duties [17,51]. Since all of these barriers make it difficult to develop viable RE projects in countries of the Global South [50], some articles in our sample conclude that projects must rely on donors and development aid, which in turn then creates dependencies [19,36,51].

Looking at the *social aspects* of development sheds light on human-centered dimensions and the necessity to embed technologies within the experience and capabilities of each local community. This means that energy planning must recognize and adapt to people's realities and respect local knowledge systems and people's capacities to adapt [36]. In that regard, lack of knowledge and awareness within communities is frequently reported as a reason for not adopting RETs [67,89] (see section 3.5).

A further reason is the lack of technological capabilities in rural areas. Different kinds of pitfalls and barriers are identified, such as lack of affordability, lack of adequate supply or of repair and maintenance skills and services. All are factors that can hamper RE development [17,19,50,64], as can limited capability for disseminating information and training about RETs [67]. This has made training and skill-building essential to ensure the long-term success of an RE project [64,81]. Murphy [36] underlines this by pointing to technical, organizational, and institutional capabilities that must be developed for a transition from fossil fuels to RETs to occur.

Looking at the impact of RE on gendered power dynamics shifts our perspective towards the unequal burden of conventional energy deployment. Past research has shown that women are proportionally more often charged with pumping water, or carrying firewood, and they are more affected by health factors related to the use of biomass for cooking [50,104]. In that regard, RE deployment may represent an increase in living standard especially for women.

In addition, we looked at the rural/urban context. Given the challenge of achieving universal energy access for people in remote areas, it is not surprising that most of the research in our sample focuses on challenges in rural areas, and only a few articles discuss RE in urban contexts.

In summary, our sample shows that the term "development" means different things to different authors. The numerous understandings of development vary in depth and scope by the chosen study design. It is generally assumed that RE deployment fosters development. Since the review sample covers research about the Global South, it includes several articles that investigate development aspects more deeply. These articles address RE's contribution to economic growth, its financing, requirements for successful implementation, local capabilities, gender inequalities and access to energy. We had expected more research into power relations in the energy system, since these relations define the political and socio-cultural context of any energy transition.

3.7. Regional differentiation

At this point, we would like to present a brief comparison between the three regions in our sample; we summarize these results in Table 2.

A first interesting finding is that only in the African sub-sample do studies take a general perspective on the entire continent [25,43,46]. We did not find such studies in the other sub-samples. Looking into the multi-country studies in Africa, it is striking that most of them tend to consolidate the countries under review rather than contrasting the conditions in them. One potential reason is that researchers perceive Africa as homogenous, while they are more aware of country differences in South America and Asia. This would be consistent with discourse in the public media that also tends to treat African countries as

Table 2
Findings of the review in their regional differentiation. Source: Authors. Rating: + (1–5 articles), ++ (6–10 articles), +++ (11–15 articles), ++++ (>15 articles).

	Africa	Asia	South America
Author's disciplinary affiliation			
Engineering	++++	++++	++++
Social Science	++	+	++
Science	+	+	+
Agriculture	–	+	–
Country affiliation of author's institution	+++	++++	++++
Level of analysis			
Single country study	++++	++++	++++
Multi-country study	+++	+	++
Theoretical framework	+	+	+
Research method			
Quantitative	++++	++++	++++
Energy models	+++	++	++
Cost analysis	+++	++	+
Energy model and cost analysis	++	++	+
Economic models	+	+	+
Geoinformatics	+	–	+
Energy scenarios	+	+	+
Qualitative	+	+	+
Review	+	++	++
Technological Focus			
Type of RET			
PV	++++	+++	+
PV only	++	–	+
Bioenergy	+	++++	++++
Bioenergy only	+	++	+++
Wind energy	++	+++	+++
Wind energy only	+	+	+
Positon in the value chain	++++	++++	++++
Sector	+++	+++	++++
Political perspective	++	++++	+++
Policies	+	++	++
Institutions	+	–	+
Socio-cultural context	+	+	++
Actors	+	+	+
Participation	+	+	+
Acceptance	+	+	+
Business models	–	+	+
Development aspects	+	+	+
Economic Aspects	+	+	+
Social Aspects	+	+	+

homogenous [127]. This means ignoring the large differences in culture, wealth and the natural environment between countries in Africa, a major shortcoming of past research.

The differences in technological focus in RE deployment between the regions (see Table 2) may be explained by the natural preconditions. Solar radiation in many African countries is strong, while biomass is abundant in South American and many South East Asian countries [8]. Hydropower and geothermal energy are options rarely considered in any of the three regions, possibly because of the high investments required for all but small-scale projects. The majority of the articles address a mix of RETs in which the authors usually typically take nations as their analytical unit, whether the study's focus be multi-country or single country. This may be rooted in the authors' orientation towards national RE policies and the relevance of these national targets for RE deployment. If, instead of the nation, smaller analytical units were chosen, regional differences could be considered. By understanding region-specific conditions, the technological focus could shift to individual RET installations.

The comparably minor relevance of political perspectives in the studies on African countries may be explained, as mentioned above, by the fact that Africa is mostly viewed as a single continent and its diversity is largely neglected. Studies that analyze political perspectives usually address national policy directions and decisions, and so are rarely found in the sub-sample on Africa.

Unfortunately, we cannot make any reliable conclusion as to whether there are differences between the three regions in terms of socio-cultural and developmental aspects. The sample includes too few publications per region in these subcategories.

3.8. Summary

Our literature review reveals the thinking that prevails in the research agenda on renewable energy in the Global South. Clearly, energy and economic models dominate the discourse. Much is known about diverse technological approaches to RE, about natural resources for RE and potential energy demands in the countries. The production of energy garners strong interest.

Compared to this focus on technologies, little research has investigated social and political processes or development aspects involved in an energy transition. The representation is surprisingly light considering our literature sample focuses exclusively on countries of the Global South. Nevertheless, we gain valuable insights into social and political themes through the qualitative social research in our sample set.

We found a great diversity in the articles, both in terms of the topics and the theoretical depth with which they are discussed. But we take from our sample the insight that technologically-driven projects and discussions alone will not lead to a sustainable energy supply. Questions about the political and social elements of development should be investigated systematically. The literature to date has looked at these superficially. Instead, we need to go deeper into question such as: Who are the actual drivers of a sustainable energy supply? Which actors are pursuing what goals? Are there conflicts of interest? How do power relations shape transition pathways? What kind of ideas, narratives and discourses inform energy concerns in the society? Which path dependencies shape the contemporary energy systems?

These are the questions to be asked if we are to gain insights into the potential for sustainable energy systems in the Global South.

4. Discussion: The energy transition debate as interpretive framework for the findings of the review

In the following, we look at our literature sample through the lens of energy transition research. This research has emerged over the past 10–15 years, as sustainability transitions themselves have become a worthy subject of study. A number of publications [1–3,128,129] have examined the multimodal shifts from fossil fuels to renewable sources through systematic analyses of socio-technical and socio-political change [130].

This interplay between diverse transition approaches and the parallel development of transition research has spawned efforts to grasp the complexity of transition processes. We find the meta-theoretical framework provided by Cherp et al. [112] to be helpful. They present energy transitions as a process not restricted to the change of individual technologies or resources, but rather a change in an entire energy system. To understand national energy transitions, we need to recognize three interweaving influences at work: the techno-economic, the socio-technical, and the political.

From the *techno-economic perspective*, the object of study is energy flows and markets. This perspective regards energy as an economic good, produced, traded and consumed by society like all other goods. Energy is modelled and analyzed using quantitative methods run for long-term scenarios under different assumptions. Cherp et al. [112] see a shortcoming of this perspective in the externalization of policies and normative objectives, rather than their integration into the economic analyses. Further, economic and societal path dependencies and aspects of technological innovation are not integrated into these approaches.

From the *socio-technical perspective*, the focus is on technological change, in particular, the emergence and diffusion of new technologies. This is contrasted with the techno-economic perspective, from which "energy systems are defined by energy flows, conversion processes and (…) coordinated through energy markets" [112]. From the socio-technical perspective, technology is not understood as a traded good, but as a social phenomenon, incorporating among other parts, shared knowledge, practices and networks. Technological innovations are considered both in their potential to overcome path dependencies and lock-ins, and their contribution to the emergence of same.

From the *political perspective*, the focus is on the "change in policies which affect energy systems" [112]. Here, three concepts from political science contribute to understanding a national energy transition. The first is of the *state*, where authors distinguish between a state-structural and a state-centric approach. A state-centric approach conceptualizes the state as an independent actor capable of acting in the national interest. A state-structural approach, in contrast, assumes the state's agency reflects competing national interest groups.

The second helpful concept from the political perspective is that of *institutions*, and particularly that of *institutional capacities*, "defined as patterns of interaction between the state and industry." These both enable and constrain energy transitions, so that "a state is not able to pursue any energy policy it desires." [112].

The third concept important to understanding a national energy transition is that of *international influence*. Here arise questions of how states interact, especially the question of policy convergence when numerous states work toward the same or similar energy goals.

To these three concepts, Cherp at al. add a fourth factor to understand the political process: *comprehensive policy change frameworks* that use non-linear system theory to conceptualize the interaction of actors in the transition process and better grasp the complexities involved.

We use this meta-theoretical framework of Cherp et al. as our analytical tool to classify our findings and identify the different disciplinary approaches more comprehensively. This permits us to recognize both areas of knowledge concentrations and important gaps in the research.

4.1. Techno-economic perspective in the sample

We can safely say that most of the articles in our sample examine renewable energy in developing countries from the growth-driven techno-economic perspective. The largest set of the sample consists of economic models, energy scenarios, energy models, input/output analyses, cost (-benefit) analyses, lifecycle assessments and geoinformatics (see section 3.2). The analytical variables representative of this perspective include energy resources, demand, and infrastructure [112].

We consider the resource side as already well researched, with numerous articles about PV radiation, biomass availability and wind speed parameters, especially regarding electricity generation and fuels for transportation. Feedback relations between REs and macroeconomic variables, as well as the potentials and costs to electrify villages have also been adequately introduced into the academic discourse.

On the demand side, we find different approaches. For example, the interaction between the parameters of CO2 emissions, economic growth, foreign direct investments, and RE consumption is modelled in different articles based on the Environmental Kuznets Curve hypothesis [42,48,80]. Another frequent approach investigates whether and at what costs the electricity needs of villages can be met.

However, the sample lacks an investigation or discussion of the productive use of energy by the industrial sector, especially by small-to-medium-sized enterprises (SMEs). The literature sample provides little insight into business potentials arising from REs on the supply side (e.g. energy companies and agribusinesses), nor does it shed light on the demands and development potentials of manufacturing companies.

Research into infrastructure systems is also underrepresented. Only a few articles de facto investigate the existing infrastructure, meaning the equipment and its operation. Most articles discuss off-grid solutions and do not regard integration into the existing grid-network as an option. Articles that do address the existing infrastructure often regard it as a barrier to the diffusion of RE technology, pointing to restricting factors like import dependencies and the associated challenges that come with integration into an existing infrastructure.

Largely absent from our literature sample is research into the state of the infrastructure and its future deployment under the increasing adoption of RE. Two exceptions are Szabó et al. [43] who compare electrification costs of distributed solar and diesel generation to grid extension and Caballero et al. [77] who analyze the business model of a grid-connected hybrid PV-wind energy system.

4.2. Socio-technical perspective in the sample

Few articles in our sample analyze energy transition processes from the socio-technical perspective. Important concepts to work with from this perspective are innovation systems, regimes and niches, and technology diffusion [112].

Regimes are understood as stable systems, carrying shared rules and routines. Here, technological innovations emerge following established pathways and along predictable trajectories. *Niches* are protected areas where "novelties" (innovations) can develop outside the influences of the current regime. Both entities play key roles in *innovation systems*, but research into their role in developing countries is surprisingly absent from our sample. This may be related to the dominance of the techno-economic perspective, or the externalities of innovation systems in Global North countries.

Our literature sample does treat technology diffusion by addressing global maturity of technologies and their application across core and peripheral locations. It includes articles that investigate the fit of renewable energy supply technologies to specific local preconditions. Examples include biogas digesters in the tropical climate of Costa Rica [87] or Ahmad and Tahar's [47] analysis of how different RETs might meet Malaysian energy needs, which considers technical maturity among the criteria for selecting the best renewable resource for electricity generation.

In this context, "maturity" means the commercial availability of proven technology, a concept that must be broadly understood when applied to a developing country. The availability of technologies determines any assessment of maturity, and such availability is affected by factors that include import dependencies, high prices, and low quality standards. Our sample includes authors who investigate the "non-maturity" of RETs for the needs of the local context, and see therein a factor that restricts the diffusion of RETs (see section 3.6).

The broader understanding of maturity needed in our context adds awareness of urban/rural diffusion differences. Transmission networks often do not extend to regions with RE resources, or the grid networks are too weak to integrate the new technology [51]. In any case, some technologies are not an option for many regions even though natural conditions might be optimal for RE installations. Maturity also denotes the availability of after-sales services like repair and maintenance. These are needed for a mature RE energy supply to develop, as RE technologies call for skilled operators and maintenance technicians. Such do not emerge out of thin air, so often do not exist in rural areas, meaning they, unfortunately, are not provided at all [17,36,64,106].

Interestingly, we find one article critical of the diffusion of RETs. Sarkodie and Strezov [42] claim the dominant supply-gap perspective is the wrong analytical approach. They emphasize that no conclusions can be drawn about the sustainability or effectiveness of renewable energy systems from the number of technologies implemented.

Some articles from the sample approach the innovation system from the macro-level, in particular by examining government programs intended to promote research and development. These programs aim at improving the transfer of technology from research institutions, and the articles address the question of how political decision-making can accelerate the development of RE supply. These studies recognize the significance of knowledge transfer and exchange in actor-networks, but do not go beyond simply describing their importance. We do not learn much about location-specific parameters, entrepreneurship, experiments, social and institutional innovations that influence technological change – all questions relevant from the socio-technical perspective (see section 3.5).

4.3. Political perspective in the sample

From the political perspective, three key concepts help us analyze our literature sample: first, state goals – the type of goals and influencing factors; second, political interests; and third, institutions and capacities [112].

What concerns the first category of state goals; most of the articles in our sample regard the state as the central actor behind energy transitions. In this understanding, states are able to define and impose renewable energy goals. Authors conceptualize the state as an autonomous actor capable of dictating energy policies according to the national interest. The state is thus regarded as the main agent in formulating, planning, enforcing and insuring compliance of RE policy [40,51,57,63,66].

Here, Cherp et al.'s differentiation between a state-centric and state-structural approach is helpful. The state-centric approach adopted by many authors reflects an assumption of centralized and consolidated state power. Under different governance settings, a state-structural conceptualization would be more helpful, as it recognizes state activity as an expression of competing interests. This conceptualization further allows analysis of factors that affect state goals, such as dependency on the cooperation of international aid agencies in the nation's development [19].

The structural conceptualization is also helpful in identifying the second category. Political interests exercised by different societal groups such as parties, lobbying networks or voters [112]. In our sample, authors do refer to particular actors from the private sector or civil society that are incorporated into political processes [19,63,104]. However, we found an absence of articles addressing systematically other groups that affect energy policy, such as political parties, social movements, or voter preferences. A systematic analysis from the state-structural perspective would permit tracing policy outcomes to the influences of competing actors pursuing their particular interests.

The third category – institutions (see sections 3.4 and 3.6) and capacities – cannot be fairly considered without referring to international relations, which sheds light on how international processes shape domestic energy policy. A frequently mentioned example is the clean development mechanism that shapes the development and

implementation of RE projects and hence patterns and structures of the domestic energy supply [40,63].

In general, the role of international development agencies within RE policy is rarely discussed. Ahlborg and Hammar [19] highlight the ambiguous role of international actors within domestic RE policy. Some strings are always attached. When international actors provide the bulk of the energy budget, they expect to exercise influence over national energy policy. This can produce skepticism among domestic policy makers wary of the donors' push for privatization. Donor administrative demands, whether for reports or meetings, make the transition process unnecessarily burdensome. However, discussing the international dimension of domestic energy supply raises questions of global power relations, around which our sample sidesteps, both on global and local scales.

4.4. Summary

Seen through the meta-theoretical framework of Cherp et al. [112], we were able to determine the dominant perspectives in our review sample and to identify the research gaps. Fig. 9 shows a summary of the results.

Our sample is dominated by research from the techno-economic perspective. Using energy and economic models, the potentials of RETs for energy supply and the energy demand of societies are analyzed. Largely ignored is the industrial application or the productive use of RETs by local actors in the economy, such as SMEs. Possibilities for energy access are mostly sought in off-grid solutions, with few analyses of network expansions.

Looking at the socio-technical dimensions of energy transition, the general importance of actors is acknowledged, but knowledge transfer and exchange through actor networks has not received detailed attention. The consideration of technological novelties is rare, although technology diffusion is investigated in its suitability to local preconditions.

Numerous articles in the sample discuss issues from the political perspective. They mainly follow a state-centric approach, understanding the state as an autonomous force driving the energy transition. Articles addressing other policy related groups are scarce. In general, international processes influencing the domestic energy policies are discussed; however, the role of international development agencies in setting RE policy is largely ignored.

5. Conclusions

We conducted a critical review of 90 of the most highly cited peer-reviewed articles in English on renewable energy in the developing countries of Africa, Asia, and South America, 30 for each continent. We identified dominant trends and approaches in the research agendas, and then looked comprehensively at the dynamics of energy transitions to identify important research needs.

We openly acknowledge the limitations of systematic reviews and the bias that arises by focusing on citation histories and so excluding recently published articles, e.g. in the field of hydropower, geothermal power and hydrogen, or articles which might address some of our identified shortcomings. And though our results may serve merely to characterize a sample, a sample of the 30 most highly cited articles about a region does serve to highlight dominant modes of thought.

With this article, we contribute to the research on renewable energy transitions in the Global South in four ways. First, we identified the key research foci that dominate the scholarly discourse, regarding the six categories metadata, research design, technological focus, political perspective, socio-cultural context and development aspects. The journals *Renewable Energies, Energy Policy, Energy* and *Applied Energy* carry the bulk of the discourse. Two out of three voices in that discourse belong to engineers, with social scientists being the most vocal discipline in the remaining third. Research institutions from Africa, Asia and South Africa drive the publications in their respective regions. Quantitative methods, especially energy models, economic models and cost analyses dominate the scientific approach. Qualitative methods are rarely applied. Articles with no empirical contribution are numerous.

The majority of the articles address multiple RETs. Solar energy is the most common technology studied, followed by bioenergy and wind energy. Numerous articles in the sample take into account only one energy type. RE policy approaches have attracted significant research interest and the literature has succeeded in touching on numerous issues, such as economic, social and environmental aspects. How institutions can promote or hinder the use of RE is also investigated. The socio-cultural context is the category that receives the least attention from researchers in our sample. Articles do address the importance of public and private actors in rather general ways. Participation processes receive differing degrees of attention; collectively, the articles identify a number of conditions considered crucial for RE acceptance.

Second, in addition to pinning down these dominant research strands in our sample, we identified the following understudied fields and shortcomings: Unfortunately, the literature reviews in the sample are

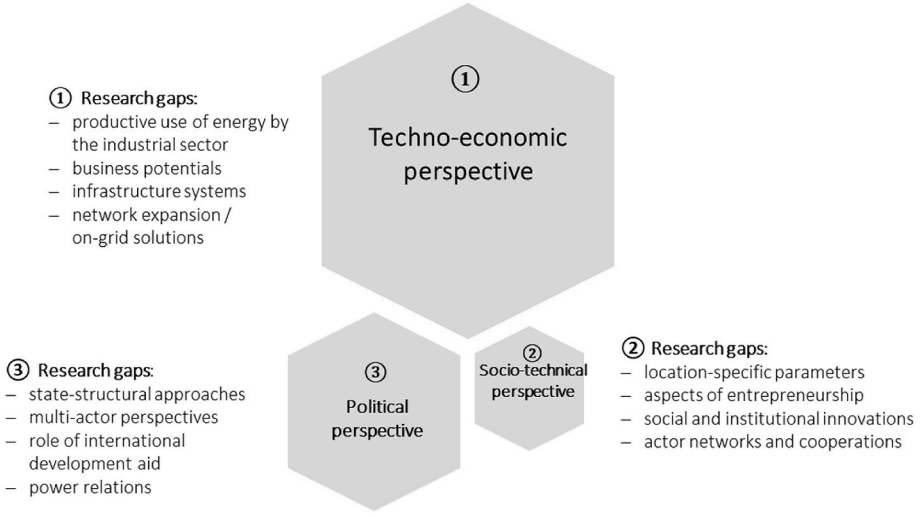

Fig. 9. Research gaps in the reviewed sample; Source: Authors; The size of the hexagons indicate the distribution of the reviewed articles in the three perspectives, as developed by Cherp et al. [112].

unsystematic, they lack structure and transparency. Across all articles, only a few authors base their work on a theoretical framework, why there is an urgent need to improve the theoretical validity of research on RE in the Global South. Within the scientific community, human-centered approaches on RE merit greater consideration. With regard to RET, articles on geothermal energy and hydropower receive only little attention. The RE policy analysis yet lacks an analytical perspective. The role of political institutions is rarely examined. Within the socio-cultural realm, articles address the importance of public and private actors, however, deeper insights into actor roles and actor networks, which are crucial to advance the energy transitions, are missing. Business models are equally understudied.

Third, when we applied the meta-theoretical framework developed by Cherp et al. [112]we were able to position our findings in the ongoing energy transition debate. This analytical approach allowed us to identify existing research gaps in the dominant scientific discourse (see Fig. 9). Within the techno-economic perspective, which is overrepresented in our sample, we identified research gaps regarding the productive use of energy by the industrial sector, business potentials, infrastructure system design and potentials for network expansion and on-grid solutions. From the political perspective, research gaps exist with regard to state-structural approaches, multi-actor perspectives, the role of international development aid and power relations. Concerning the least represented perspective in our sample, the socio-technical, research gaps are in the realm of location-specific parameters, aspects of entrepreneurship, social and institutional innovations, as well as actor networks and cooperation. Perhaps our most important finding is that established concepts are often inadequate to meet the challenge of decarbonizing energy systems in the Global South.

Fourth, to find viable solutions, particularly about RE in the Global South, we recommend research in the following five directions:

5.1. Socio-technical imaginaries

The concept of *socio-technical imaginaries* can assist our understanding of the current research agenda. Used to examine "how energy interventions are being imagined and constructed by key actors in the sector" [131], the concept has helped authors advance technological change processes that fit the expectations and realities of the local population. Socio-technical imaginaries may compete, as they correspond to "particular practices of future making" [132], and represent how "the imagination of desirable visions of the future" interacts with "ideas about the role of technology and innovations in society" [133]. Recently authors also investigated "energy cultures" and their role in transition processes [134].

One of our main findings is that the dominant RET imaginary in our sample is that of a "top-down technologically-driven framework" [131]. This is an external imaginary, and does not include public discourse, knowledge production, or ideas surrounding the transition processes. Such often clash with indigenous imaginaries, making energy transitions problematic and risky when driven by ideas imposed by the international aid community [135]. In recently published research, the concept is operationalized to shed light on how (competing) imaginaries between differing groups shape pathways for RE transitions in the Global South [133,135–137].

We found little attention given to how imaginaries develop, interact, and work to shape the future. Yet this is especially important in a socio-cultural context. The collective understandings underlying an energy transition need to be understood. Further research into socio-technical imaginaries operating in an energy transition can investigate how narratives, ideas and beliefs drive, delimit or hinder energy transitions.

5.2. Power in energy systems

Western predominance leading to financial, political and technological impositions has spurred discussions about power relations and energy justice. Authors in our sample are mostly silent on the role of power within the energy system [49,130]. Power asymmetries, of particular importance in the given context because of North-South hierarchies, shape decisions over energy sources, questions of participation, ownership and affordability [138]. Further research from last years shows, how the perspective on power hierarchies helps to understand national energy transitions embedded in global power relations [139–141].

Additionally, these matters have raised questions about energy justice. Yet, the debate centers around countries in the Global North, with authors questioning the extent to which the analytical frameworks of justice need to be adopted to realities in the Global South, as these embed Eurocentric notions [142,143]. The avenues for further research are open here, both for theoretical work to extend existing frameworks to non-Western realities and for empirical studies to better understand power and energy justice in the Global South.

5.3. Social innovations

The energy transition debates often focus on targets, numbers, and technical considerations [4,129], underscoring the dominant technology-driven view of innovation in the discourse. Unfortunately, little light has been shed on the interplay of diverse actors, their roles and functions within innovation processes, the framework conditions they act under and at the same time challenge, their strategies of knowledge acquisition, and their networks of social capital, e.g. Refs. [144,145].

To understand innovations leading to new energy systems, we need to understand the drivers of innovation, including social innovations in energy transitions and the new ways of organizing and governing sustainable energy systems [115]. Research on social innovations that co-evolve with, result from or contribute to technological novelties is therefore promising to advance transition processes, e.g. studies on energy cooperatives [146,147]. Hoppe and de Vries see in social innovation, "innovation that is social in its means and which contributes to low carbon energy transition, civic empowerment, and social goals pertaining to the wellbeing of communities" [115]. Such an understanding of innovation opens avenues for research that go beyond market mechanisms and technology applications.

5.4. Business factors

Much needed is further research into the role of business and the energy consumption of companies. Companies play an important role in an energy transition. First, they are engaged at every step of the value chain, from the innovation processes behind new technologies, to the production of technical infrastructure, through resource exploitation and energy production, to the marketing and distribution of energy. Second, they are active in the service sector, responsible for all the support services from billing to after-sales service and maintenance.

All these activities make up an energy market, and to play a competitive role therein, actors have to devise suitable business models. These are rarely considered in our sample. Consider that the energy consumption of companies is an important demand factor, and then think how economic actors influence regulations, pricing, acceptance and the public discourse about energy [129]. From these reflections, but also on the fact that we find little other research on this topic [148–151], we conclude that business factors in the nexus of the Global South are underresearched. Further research into phenomena like prosumerism in the Global South [152–154], which is considered positive in the western context [155–157] could provide insights on the opportunities of companies in the energy transition. Deeper insights into companies are needed – about their goals, capabilities to influence, needs and potentials for achieving a sustainable energy transition.

5.5. Spatial dimensions

Our investigation leaves open the question of where energy transitions actually take place, which socio-spatial dynamics are in place, and how they influence or are altered by transition processes. Innovations emerge in different places, but are linked with each other, within and across different spatial scales, e.g. local/regional/national/global. The integration of different spatial scales would make it possible to uncover the interdependencies and relationships between actors that decisively shape the transition processes. This would permit analysis of how the constellations of actors, firms and entrepreneurs engage in various types of cooperation and knowledge exchange, and what willingness to experiment and take risks the different agents bring to the process [120, 158–160].

Besides happening across different spatial scales, energy transitions are related to specific local conditions. These represent the prerequisites for actors to develop new technologies and lifestyles, and to test policies that support sustainable transitions, such as local cultures, institutional settings, policy frameworks, actor networks, availability of capital, ability to diffuse novelties and regional economic restructuring [120, 159]. Research on the geography of sustainable transitions would explore similarities and differences of transitions across locations [129].

Declaration of competing interest

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

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Appendix A. Review Protocol

Table A 1
Systematic review – Protocol of the selection process of the sample. Source: Authors

Identification	**Web of Science Core Collection** Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI–S, CPCI-SSH, BKCI–S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years Search date: April 21,21 April 2020 ***Search queries for*** ***Africa:*** #1 (TS=(Renewable Energ* AND Africa)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) #2 (TS=(Renewable Energ* AND (Algeria OR Egypt OR Libya OR Mauritania OR Morocco OR Sudan OR Tunisia OR Cameroon OR "Central African Republic" OR Chad OR Congo OR Equatorial Guinea OR Gabon OR "Sao Tome and Prinicipe" OR Burundi OR Comoros OR "Democratic Republic of the Congo" OR Djibouti OR Eritrea OR Ethiopia OR Kenya OR Madagascar OR Rwanda OR Somalia OR "South Sudan" OR Uganda OR "United Republic of Tanzania" OR "South* Africa" OR Angola OR Botswana OR Eswatini OR Lesotho OR Malawi OR Mauritius OR Mozambique OR Namibia OR South Africa OR Zambia OR Zimbabwe OR Benin OR "Burkina Faso" OR "Cabo Verde" OR "Côte d'Ivoire" OR Gambia OR Ghana OR Guinea OR "Guinea- Bissau" OR Liberia OR Mali OR Niger OR Nigeria OR Senegal OR "Sierra Leone" OR Togo))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) ***Asia:*** #3 (TS=(Renewable Energ* AND Asia)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) #4 (TS=(Renewable Energ* AND (Brunei Darussalam OR Cambodia OR China OR "Democratic People's Republic of Korea" OR Fiji OR Indonesia OR Kiribati OR Lao OR Malaysia OR Mongolia OR Myanmar OR "Papua New Guinea" OR Philippines OR "Republic of Korea" OR Samoa OR Solomon Islands OR Taiwan OR Thailand OR Timor-Leste OR Vanuatu OR Vietnam OR Afghanistan OR Bangladesh OR Bhutan OR India OR Iran OR Maldives OR Nepal OR Pakistan OR "Sri Lanka" OR Bahrain OR Iraq OR Israel OR Jordan OR Kuwait OR Lebanon OR Oman OR Qatar OR "Saudi Arabia" OR Palestine OR Syria* OR Turkey OR "United Arab Emirates" OR Yemen OR Armenia OR Azerbaijan OR Belarus OR Georgia OR Kazakhstan OR Kyrgyzstan OR "Republic of Moldova" OR Russia* OR Tajikistan OR Turkmenistan OR Ukraine OR Uzbekistan))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) ***South Amercia:*** #5 (TS=(Renewable Energ* AND "Latin America")) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) #6 (TS=(Renewable Energ* AND "South America")) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) #7 (TS=(Renewable Energ* AND (Bahamas OR Barbados OR Belize OR Guyana OR Jamaica OR Suriname OR "Trinidad and Tobago" OR Mexico OR "Costa Rica" OR Cuba OR "Dominican Republic" OR "El Salvador" OR Guatemala OR Haiti OR Honduras OR Mexico OR Nicaragua OR Panama OR Argentina OR Bolivia OR Brazil OR Chile OR Colombia OR Ecuador OR Paraguay OR Peru OR Uruguay OR Venezuela))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) **Records identified though database**: Africa, combination #1, #2 (n = 1912) Asia, combination #3, #4 (n = 7583) South America, combination #5, #6, #7 (n = 1525)	
Screening	***Limitation to* 30 most *cited articles per region***	
	Exclusion criteria (1) False results of the search query (term "Renewable Energ*" is not part of title, abstract, or keywords). (2) Articles about developed countries. (3) Articles with a global scope (no focus on developing countries in Africa, Asia and South America) (4) Articles with no serious focus on RE (RE only mentioned in title, keywords and abstract, with no further exploration in the article).	***Screening*** Articles pertaining to two regions or more are integrated in the region where they achieve a higher ranking in terms of citation order. Subsequent most cited articles have replaced the excluded articles. Records excluded in consecutive order of the no. of citations: Africa (n = 15) Asia (n = 62) South America (n = 33)
Sample	***Articles (n = 90)*** ***Africa:*** [17–46] ***Asia:*** [47–76] ***South America:*** [77–106]	

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What Drives Senegalese SMEs to Adopt Renewable Energy Technologies? Applying an Extended UTAUT2 Model to a Developing Economy

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Abstract: Renewable energy technology (RET) can help small and medium enterprises (SMEs) in developing economies to both meet the need for a stable energy supply and contribute to the fight against climate change. In Senegal, SMEs have the opportunity through RET to become electricity prosumers. Whether it works as such in Senegalese SMEs is one of the questions we were able to address through qualitative interviews with 23 SMEs and 13 experts. Using qualitative content analysis, we examined what factors promote the adoption of RET by these SMEs. We also examined how well the established Unified Theory of Acceptance and Use of Technology model (UTAUT2) can serve as a guiding framework for this type of investigation. We find that effort expectancy is generally underestimated. Performance expectancy, when high, may influence the adoption process positively, while social influence does not seem to play a role. Both SMEs and experts point to customer service and government support for SMEs adopting RET as important facilitating conditions. The cost of RET is another factor influencing the adoption of these technologies. However, we regard the UTAUT2 as only partially helpful for the Senegalese context, due to the informal sector economy in Senegal. This leads us to add the factors knowledge, communication channels and entrepreneurial orientation. Moreover, we question the unequivocally positive notion of prosumerism for African contexts, as the idea draws its motivating power from a Western mindset.

Keywords: renewable energy; small and medium-sized enterprises (SMEs); unified theory of acceptance and use of technology 2 (UTAUT2); entrepreneurship; individual entrepreneurial orientation (IEO); informal sector economy; sub-Saharan Africa

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1. Introduction

Small and medium-sized enterprises (SMEs) around the world play a significant role in the development of national economies. In Senegal, 95 percent of all enterprises are SMEs. They account for 20 percent of the GDP, around 30 percent of domestic valued added and about 40 percent of all employees [1]. In other economies in Africa and in the Global South generally, SMEs play an equally important role: 90 percent of the enterprises in the private sector of the Global South are SMEs [2]. The prominence of SMEs has led to increasing research into entrepreneurship, considered one of the most promising approaches to economic development and poverty reduction in Africa [3,4].

SMEs in Africa face serious challenges, including a lack of access to financial resources, government assistance, human capital, and infrastructure [4]. However, the lack of a stable energy supply could be the most daunting [5]. In a 2012 survey on the effects of power outages on firms in Senegal [6], 57 percent of the participating SMEs identified

electricity as a major concern for their enterprise, while 55 percent said that the risk of power outages factors into their investment decisions.

Renewable energies (RE) as a distributed form of energy production could provide these enterprises with a stable source of energy. Renewables would also create opportunities for new business models for the SMEs, e.g., running RE-powered charging stations for mobile phones [7]. Moreover, from a macro perspective, a shift to renewable energies represents a preemptive strategy to mitigate climate change, especially in developing economies where rapidly growing energy demands would otherwise be met by burning hydrocarbons.

It thus becomes of interest to understand what factors influence SMEs, in our case in Senegal, to adopt RE and energy efficiency (EE) technologies. We are specifically interested in the decisions made by business operators who turn to RE technology for a stable energy supply. These enterprises make decisions to use, or not use, RE in the context of a business model that uses energy simply as infrastructure. Other SMEs might adopt RE technology as the foundation for a sustainable business model, as in the low-carbon charging service just mentioned [7]. However, we are interested in the thinking of the entrepreneur who needs a stable source of electricity to run an SME.

Most academic research on entrepreneurship has focused on developed economies [3], so the research into African entrepreneurship is limited. Devine and Kiggundu [4] conducted a systematic review of the existing literature and identified three lines of research, each with their respective focuses. One line of research has explored entrepreneurship in marginalized groups (e.g., women and youth), investigating education, work behavior and displacement. A second line has investigated the entrepreneurial firm, looking at forms of organization (SMEs and family business), capitalization (financial and social), social entrepreneurship and the informal economy. A third line has examined macro-socioeconomic conditions, addressing government assistance and policy concerns, poverty, corruption and internationalization.

Most of these studies, however, lack grounding in theory and are restricted to quantitative approaches. Scant research attention has been paid to the thinking of the entrepreneurs who are presented with opportunities to integrate renewable energies into their business operations [8]. Insight into how entrepreneurs in Africa make their decisions to adopt RE in their firms—or not—is sorely needed, but missing from the literature.

We seek to fill this gap by adopting a human-centered approach that focuses on the economic actors—the individual entrepreneurs—and the opportunities they have to adopt RE in their businesses. We base our approach on the theories of entrepreneurial action, looking into the processes by which opportunities for the adoption of RE technologies are formed and exploited. We use the framework of the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2), but extend it with insights from the Diffusion of Innovation Theory (DOI) [9].

Our central research question is: What considerations motivate Senegalese entrepreneurs to adopt RE in the operation of their SMEs? More specifically, we ask:

(1) Which dimensions of the UTAUT2 matter for RE adoption in Senegalese SMEs?
(2) What other influencing factors play a role in the Senegalese context?

To explore these questions, we conducted 36 qualitative interviews with entrepreneurs and energy market experts in Senegal, which we then analyzed for insights.

Our research provides an opportunity to advance knowledge of RE adoption factors in three ways. First, it fills a research gap about entrepreneurial opportunities to adopt RE technology in Senegal. Second, it uses UTAUT2 in a qualitative research design, a rarity as most UTAUT2-centered studies to date have used a quantitative design. Third, it investigates the UTAUT2 framework in the context of SMEs in sub-Saharan Africa, a first in the literature.

We proceed by outlining our research methods and then introducing the analytical framework built from the theories of entrepreneurial action and the UTAUT2 model. Within this framework, we present our results, followed by a discussion of our findings and our conclusions.

2. Materials and Methods

2.1. Research Method

To investigate the considerations that motivate Senegalese entrepreneurs to adopt RE in the operation of their SMEs, we conducted a qualitative interview study focusing on two different groups: Senegalese SMEs and experts in the Senegalese energy sector. We conducted 23 interviews from the first group and 13 interviews from the second. Table 1 lists the sectors and areas of expertise represented by the 36 interviewees.

Table 1. Profile of interviewees; source: authors.

Sector	Interviewee
Accommodation and Food Service Activities	SME 1, SME 2, SME 5, SME 7, SME 16, SME 17, SME 18, SME 20
Information and Communication	SME 6, SME 14, SME 15; SME 23
Agriculture, Livestock and Fishing	SME 3, SME 8, SME 12, SME 21
Wholesale and Retail Trade	SME 9, SME 10, SME 13, SME 22
Construction	SME 11
Other Services	SME 19
Intl. Development Cooperation	Expert 1, Expert 13
Environmental Consultant	Expert 2
Public Institutions	Expert 3, Expert 5, Expert 6, Expert 8, Expert 9
Senegalese RE Industry	Expert 4, Expert 7
Academia	Expert 10
Finance	Expert 11, Expert 12

As shown by this table, our study is not restricted to one industry, but includes SMEs across a wide range of economic activities. The SMEs operate in the cities of Dakar and Saint-Louis. The first is the capital and the largest and most populous city in Senegal, while the second is one of the country's larger cities.

To complement the insights gleaned from these SMEs, we conducted interviews with 13 experts from the Senegalese energy sector. Our choice of experts in this study follows the recommendations of Döringer [10], who states "experts are considered knowledgeable in a particular subject and are identified by virtue of their specific knowledge, their community position, or their status" [10] (p. 1). Experts possess competencies by which they help shape the processes in their respective field, in contrast to laypersons who may have knowledge but lack the power that community position or status confers.

Table 1 illustrates that our sample includes experts who structure or help shape the relevance of RE in Senegal, based on their knowledge and possibilities for action. Our expert sample is not restricted to one area, but encompasses intersecting disciplines, with expertise in the public institutions of Senegal especially well represented.

In designing the interviews, we took into account the fact that RE technology is still not widely used in Senegal, so we needed to allow latitude for the interviewees. This led us to choose a semi-structured design. We also recognized that the two groups would work from different perspectives, so we developed guidelines for the respective interview partners, SMEs or experts. The guidelines were derived from the literature on barriers, success factors and capacity-building needs for RE implementation in the Global South, with a focus on sub-Saharan Africa. Accordingly, success factors are primarily stakeholder engagement at various levels [11,12], a high degree of ownership that can be fostered with local experts [13,14], sociocultural embedding to meet local needs [12,14], and adapted marketing and communication structures to promote the technologies and manage expectations [11,15].

Barriers are identified in terms of financial resources, such as high upfront costs and access to finance [13,14,16,17], and in the socio-cultural context, such as insufficient knowledge about RE technologies, lack of maintenance and misalignment of business

models [12,15,18–21]. However, shortcomings are also identified in political efforts, which are often seen as insufficient in terms of policy transparency, administrative procedures, lack of government support, and lack of cooperation and coordination among stakeholders [11,15–17,19,20,22,23].

Capacity building needs are particularly seen in education and training on RE in financial institutions [15], the lack of trained local staff for maintenance and repair services [15,19,24,25], and missing collaborations with national universities to access and integrate their knowledge [23].

The resulting interview design with its semi-structured, guideline-based approach allowed us to explore the perspectives of the interviewees without influencing them with ideas that we, as researchers, had already worked out [26].

All interview partners were first contacted by phone or email, which was followed in fall/winter 2019 by face-to-face interviews at the workplace of the SMEs and experts. In 2020, owing to the pandemic, we conducted additional expert interviews by phone. The interviews were conducted in French, English or German according to the preference of the interviewee. They were recorded, transcribed and then analyzed with the program MaxQDA [27]. To evaluate the transcripts, identify themes and quantify the qualitative data for comparison, we used qualitative content analysis, as developed by Mayring [28]. Coding of the transcribed interview material was conducted according to an extended UTAUT2 model, which we present in the following section.

2.2. Analytic Framework

To analyze the data from our study, we reviewed existing models and theories on technology acceptance and decided to use the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) as our theoretical framework because it offered the best fit to our research questions. However, we recognized the need to adapt the theory to Senegalese entrepreneurs, so we created new categories to extend its range to include dynamics in Senegalese SMEs. We explain the development of our framework in the following.

2.2.1. Models of Technology Acceptance

Since our study aims to better understand how entrepreneurs evaluate potential investments in RE technologies, models of technology acceptance are obvious candidates to frame the analysis of our interview data. Generally, there are two types of these models: models that capture decision-making processes of organizations, and models that focus on the decision-making processes of individuals. The latter seem best suited to our SMEs in that their decision-making processes most closely resemble those of individuals. The entrepreneur often decides without consulting others, the decision-making processes are mostly informal, and the entrepreneur bears the direct consequences of the decision, including, of course, the financial impact.

This is not the case for most employees in the context of organizational decision-making [29]. On the other hand, entrepreneurial decisions are not fully comparable to everyday individual decisions, because an entrepreneurial decision carries consequences that have to be considered and weighed carefully. A decision to employ renewable energy technology is hardly a spur-of-the moment choice, but one that needs time and most likely some cost–benefit analysis, if for no other reason than to obtain financing.

Table 2 presents a number of models frequently employed to analyze individual decision-making about technology adoption. The header row lists the models, while the data rows summarize the variables included in each. All of these models have been used either in the context of renewable energies, in developing economies, or for analyzing entrepreneurial decision-making, albeit not necessarily for the combination of all three.

Table 2. Overview of models and theories on technology acceptance; source: authors.

Model/Theory	Theory of Planned Behavior (TPB)	Technology Acceptance Model (TAM and TAM2)	Diffusion of Innovation (DOI) Theory	Unified Theory of Acceptance and Use of Technology (UTAUT and UTAUT2)	Entrepreneurial Event Model (EEM)
Dependent variables		Behavioral intention to use Actual use	Innovation adoption	Behavioral intention to use Usage behavior	
Independent variables	Attitude Personal norms Perceived behavioral control (PBC)	TAM: External variables Perceived Usefulness Perceived ease of use Attitude towards using TAM2: Subjective norm Voluntariness, and image Job relevance Output quality Result demonstrability Perceived usefulness Perceived ease of use	Innovation itself Communication channels Time Social system	UTAUT: Performance expectancy Effort expectancy Social influence Facilitating conditions (Moderating variables: gender, age, experience, and voluntariness of use) UTAUT2 adds: Hedonic motivation Price value Habit	Perceived desirability (Attitude, Social norms) Perceived feasibility (cf. PBC) Volitional element (propensity to act)

Before looking at the models in more detail, we would like to stress one point. All these models are used far more frequently in quantitative studies than in qualitative designs. In the sample reviewed by Williams et al. (2015) [30], research on UTAUT was used in 155 survey studies while only 12 studies used interviews and four case studies and none of the studies used qualitative data analysis methods.

Moreover, the models are by no means independent of each other. A common starting point of many of the theories in this field is the Theory of Reasoned Action (TRA) together with the Theory of Planned Behavior (TPB) [31] that emerged from it. The TPB has broader scope than technology adoption and has been used to explain a wide variety of behaviors not necessarily technology related.

Additionally, building on the Theory of Reasoned Action is the Technology Acceptance Model (TAM) [32]. TAM has been described as "… the most influential and commonly employed theory for describing an individual's acceptance of information systems" [33] (p. 752).

The Diffusion of Innovation (DOI) Theory also has broader scope than technology adoption, as it considers all innovations, not just technological ones. Nonetheless, it is widely applied to studies of the adoption of new technologies.

The Entrepreneurial Event Model (EEM) [34] also draws heavily on the TPB. Its construct perceived desirability uses attitude and social norms, two variables from the TPB [35], and its construct perceived feasibility mirrors Perceived Behavioral Control (PBC) in the TPB.

The Theory of Planned Behavior, the Diffusion of Innovation Theory, and the Technology Acceptance Model are combined in the Unified Theory of Acceptance and Use of Technology (UTAUT) [36]. The initial UTAUT looked primarily at employee decisions [29,37] and included the influencing factors performance expectancy, effort expectancy, social influence, and facilitating conditions. It developed further into UTAUT2 to capture consumer decisions [29] and added the factors hedonic motivation, price value, and habit. As such, it has been widely adopted in studies on technology adoption [38] and served as our starting framework.

Table 3 shows how the influencing factors from UTAUT2 have been operationalized in studies on decision-making about RE and EE technologies. Most of the studies were carried out in developing economies, which attests to the applicability of UTAUT2 to our study.

Table 3. UTAUT and UTAUT2 constructs: influencing factors; source: authors.

Construct	Definitions According to Venkatesh et al. (2003) (Original UTAUT) and Venkatesh et al. (2012) (UTAUT2)	Operationalization in the RE and EE Context
Performance expectancy	" […] degree to which an individual believes that using the system will help him or her to attain gains in job performance." [36] (p. 447)	Reduction in dependence on power grid [39] Energy savings [38] Cost savings [38] Output increase [38] Safety [39] Helps to keep an eye on energy and water consumption [40] Helps to reduce electricity consumption [41]
Effort expectancy	" […] degree of ease associated with the use of the system." [36] (p. 450)	Ease of obtaining information [38] User friendliness [38] Ease of use [38,39,41] Ease of understanding [41] Ease of installation [39] Ease of maintenance [39] Compatibility with existing appliances [39] Ease of learning to use [38,40]
Social influence	"[…] degree to which an individual perceives that important others believe he or she should use the new system." [36] (p. 451)	People who are important to the user think she/he should use it [38,39,41,42] People who have an influence on the user think that the technology is a cool innovation [40] Prestige of people who already use it is high [38] Media (traditional, social) encourage it [42] Government approves of the technology [38,42] Community encourages it [42] Positive experience by neighbors [39] Would not use it because I heard of theft of these systems [42] Would use it if friends used it [42]
Facilitating conditions	"[…] degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system." [36] (p. 453)	Own resources [38,42] Own equipment [41] Own knowledge [38,40,42] Fits into lifestyle [42] Compatibility with existing systems [38] Instructions and support available [38,42] Heavily rely on after-sales service for maintenance [42]
Hedonic motivation	" […] the fun or pleasure derived from using a technology […] [29] (p. 161)	Fun [40,41] Interesting [40] Entertaining [41] Exciting experience [39] User will be happy doing it [39] Satisfying to be among the first [39]
Price Value	"[…] consumers' cognitive tradeoff between the perceived benefits of the applications and the monetary cost for using them […] [29] (p. 161)	Reasonably priced [40,42] Value for money [42] Good investment [42] Cost-effective [39] Affordable [39,42] Less expensive than conventional electricity consumption [42] Economically viable due to government incentives [39]
Habit	"[…] the extent to which people tend to perform behaviors automatically because of learning […] [29] (p. 161)	Currently using similar technology (app) [40,41] Already actively monitoring water and energy consumption [40,41]

Most operationalizations of the UTAUT2 variables are consistent across the studies listed in Table 3. They also align with the definitions by Venkatesh and his co-authors in the original publications on the two models [29,36]. However, we noted discrepancies in some variables: Compatibility with existing systems appears as an item for measuring effort expectancy [39] as well as for measuring facilitating conditions [38] in the original publication by Venkatesh et al. 2003 [36]. Additionally, the operationalization of facilitating conditions with references to the user's own resources [38] comes as a surprise, because the original definition by Venkatesh refers to conditions external to the user. Compatibility with one's lifestyle appears as a construct for habit in [41], but also for facilitating conditions [42].

2.2.2. Extensions of the UTAUT2 Model

In the literature on the creation and diffusion of innovations in low-income countries, the UTAUT facilitating conditions have been identified as a major source of influence [43]. They have been shown by research not only to influence the intention to adopt technology (i.e., "Behavioral Intention" in Table 2) but also to have a direct effect on the actual use of that technology ("Use Behavior" in Table 2) [30].

However, past research has also pointed to the important differences that exist between developed and developing countries in innovation diffusion. In their comprehensive literature review of innovation diffusion in low-income countries, Zanello et al. [43] found that it depends heavily on knowledge diffusion. The lack of skills that would have been acquired were stronger educational systems in place often becomes a barrier for the diffusion of innovation.

Knowledge diffusion itself rests on communication, but in economies dominated by the informal sector, where few large firms operate and SMEs predominate, communication opportunities are limited. Exchange of work knowledge between employees is rare, employee mobility is limited, and communication problems arise between innovation owners from developed countries and innovation adopters from developing countries. Communication is further limited by underdeveloped road infrastructures, which hamper the movement of skilled people and new products.

These considerations lead us to add two more constructs to the UTAUT2 model: knowledge and communication channels from the DOI theory [9]. These build the basis for an entrepreneur to create opportunities for the adoption of new technologies in a firm, and we cannot take them as givens in the context of Senegalese entrepreneurs. Indeed, we are convinced they strongly influence Senegalese entrepreneurs making adoption decisions about RE technologies. We explain in the following our rationale.

In Rogers DOI [9], the stage of knowledge is the first phase of the innovation-diffusion process, followed by the phases of persuasion, decision, implementation and confirmation. Knowledge is crucial, because at the beginning of the process, individuals engage with innovations for the first time. Information-seeking and -processing activities enable individuals to form an attitude towards the innovation. The concept of knowledge that Rogers [9] develops goes beyond simple awareness of the innovation to include the individual's interpretation of information, including knowledge of the proper use of the innovation and the functioning principles underlying its operation.

These considerations come under the knowledge dimension in our study, through which we seek to gain insights about what Senegalese entrepreneurs actually know or believe about RE. Dependent on this, entrepreneurs build their assumptions and attitudes in their decision-making processes, which we then address through the UTAUT2 categories.

What makes possible the growth of knowledge is an individual's access to information, important at all stages of innovation diffusion [9] and related to existing communication channels. According to Rogers [9], communication might range from interpersonal to mass media channels; it can be passive (information about an innovation) or active (information that motivates one to actively engage in an innovation); and it can be disseminated by different sources ranging from government to private firms to NGOs. Rogers points to the importance of interpersonal networks as a communication channel

in the innovation-diffusion process, since "the interpersonally communicated experience of near peers can substitute, in part, for the individual's personal experience with an innovation (…)" [9] (p. 203).

Due to the importance of communication channels, we include them as a separate dimension in our study. We put a particular focus on the organization of entrepreneurs in networks as "near-peer" communication, since the use of RE technologies in Senegalese firms is still not widespread. By sharing information with others, entrepreneurs can obtain valuable information that they can evaluate for their own business context.

Our extended UTAUT2 model thus consists of the nine dimensions shown in Figure 1: knowledge, communication channels, performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value and habit. UTAUT and DOI have been combined in a previous study on energy-related technologies [44], while knowledge has been introduced as an additional factor for the adoption of solar PV in a developing country context [42].

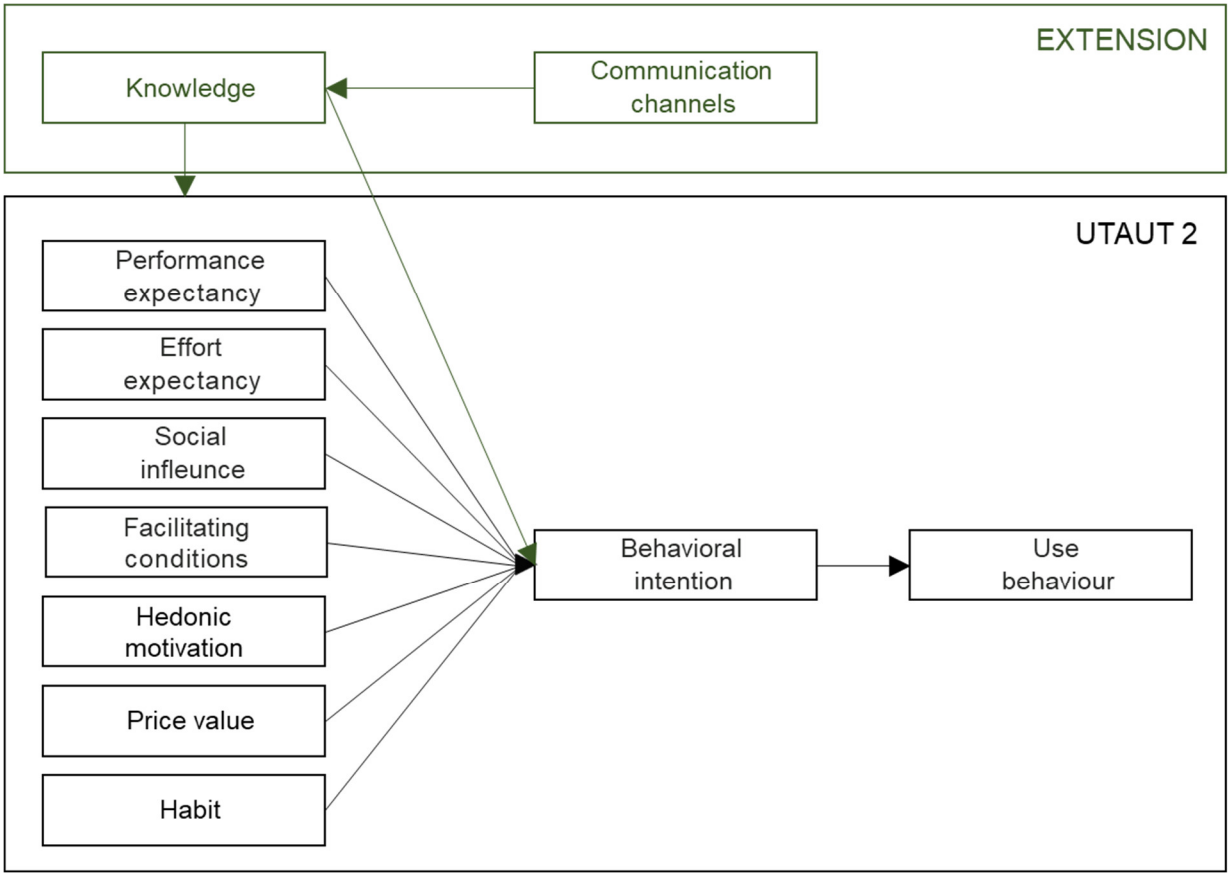

Figure 1. Extended UATUT 2 model; source: authors.

3. Results

In this section, we present and discuss the findings from our empirical study by the nine influencing dimensions shown in Figure 1. We display the results from both the perspective of the SMEs and that of the experts. We find that knowledge, communication channels and facilitating conditions are central for the adoption of RE technologies in Senegalese SMEs.

3.1. Knowledge

The majority of SMEs stated that they had knowledge of RE and EE technologies. Only three admitted having insufficient or no knowledge. However, the positive self-estimation of the majority should be viewed from an insider's perspective:

> "The people watch TV and that's how they know. But from a practical point of view, they don't know anything. What it takes to get it, how it's going to last. There's all this information out there, that people don't have a clue about." (SME 6). All interview quotes in this study were translated from French into English by the authors).

This assessment is echoed by another SME explaining "Of course, we try little things. For example for biogas, we watch videos on YouTube and try to see how it goes." (SME 21). Furthermore, almost all SMEs are interested in trainings fostering knowledge about RE and EE technologies.

A similar picture emerges when we look at the way in which the SMEs deal with the issue of energy in general. We find that they have little information about the energy contract options offered by Senelec (Société Nationale d'Electricité du Sénégal), the state-owned national electricity utility; which has a monopoly for transmission and distribution). More than a third (8/23) of the SMEs have no information at all about the existence of differentiated electricity tariffs, such as business tariffs. One SME admits "I can't say for the moment because I didn't really engage with that [electricity tariff]." (SME 14).

How experts view the knowledge level of SMEs in their country sheds light on the real level of knowledge SMEs operate from when evaluating RE and EE technologies. One expert expresses a general consensus about their competence, saying:

> "They don't know. And when they do know, they don't have the ability to do. But if they know, they say 'Okay, now that we know, how are we going to do it? With what means?'" (Expert 3)

Another expert identifies the information deficit as the major constraint to RE adoption:

> "You know what the problem is? It's the information. Can you believe it? When the persons are not informed, they can't choose. And in general, small and medium enterprises or microenterprises are not informed about the possibility of producing their own energy in a renewable way. You have to demonstrate this. People need to see what you're talking about. You want to do solar, make your business run on solar? Do a pilot project with solar and people will see it. 'Is that it? Yes, I want to it.' Because then they know what you're talking about." (Expert 4)

The lack of skills in business management and entrepreneurship is also recognized as a limitation to seizing the opportunities that lie in adopting RE and EE technologies (Expert 5). The SMEs' level of information on current framework conditions is noted as lacking; for example, Expert 8 points to the possibility to generate electricity for self-consumption with plants with installed capacity ≤50 kVA, which has been regulated in the Electricity Act 1998 (Law no. 98-29) [45]. However, none of the SMEs in our sample was aware of this possibility.

To address these information deficits, the organizations of three experts work directly in knowledge diffusion. They offer training on topics that include environmental and climate challenges; project planning and financing; EE measures such as efficient lighting; and best practices for firms that want to implement RE measures. In addition, the experts mentioned other organizations in Dakar offering support, such as the Bureau de mise à niveau, the institution responsible for implementing and monitoring corporate modernization plans., which has an energy efficiency department, the National Rural Electrification Agency and the ECOWAS Center for Renewable Energy.

To summarize: information and knowledge are acknowledged by both SMEs and experts as important barriers to RE adoption.

3.2. Communication Channels

A dismal picture emerges when viewing communication channels accessible to Senegalese SMEs. We have already noted how policy support exists for RE deployment, but none of the SMEs know about it. Several organizations exist to provide support for integrating RE into a business, but none of the SMEs are aware of them. Contract options with

business tariffs are available from Senelec, yet few SMEs know about them. Information distribution through mass media plays at best a minor role. Only one SME actively uses YouTube to gain information for its business.

Networking organizations, an essential communication channel between firms, do not seem to be a crucial part of the entrepreneurial activities in Senegal, according to the majority of the SMEs interviewed. Only two SMEs reported that they were members of their respective industry association. However, questions related to energy are not yet discussed in these associations. The exchange in informal settings with former classmates or other firms is more common. However, this does not automatically lead to promising collaborations:

> "We talk about this with our colleagues, with our network, but we just talk. (...) We discuss the problems of electricity but it is a discussion only. There is no progress, (...) how do we find the solutions?" (SME 8)

Few companies make strategic use of networks going beyond these loose exchanges; in our study, two strategic network actors have taken on the role of institutional entrepreneurs, being integrated into networks with links to the national governance level. SME 9 sees benefits from joining forces with firms whose competencies differ from its own, identifying diversity of knowledge as a success factor, increasing its own human capital. Both network actors pursue strategic goals, such as influencing the Senegalese government to request financial support from the Green Climate Fund of the United Nations or encouraging the government and other donors to favor solar energy over hybrid power plants. Besides these activities, however, nine of the 23 SMEs are not involved in any energy network activity at all.

The experts in our sample know only a little about the networks of companies that consume energy, but they do have insight into the networks of Senegalese entrepreneurs that offer renewable energy solutions. They note that networking is also still developing in the industry of RE technology suppliers, not just among RE adopters, who have mostly been on their own. Only in 2020 were two new associations founded. However, two experts express doubts about the ability of these and other networks or interest groups to influence national policy-making. Two reasons are given. First, there is no existing lobby considered capable of contributing quality ideas sufficient to influence decision makers. Second, decision makers are not interested in consulting with experts outside their established advisory group.

To sum up: mass media communication channels are insufficiently built out, if they exist at all, to reach the entrepreneurs. Networks, which can be an important communication channel, are clearly underdeveloped and do not contribute in Senegal to the diffusion of accurate practical knowledge about RE.

3.3. Performance Expectancy

All interviewees see benefits in the use of RE and EE technologies. The SMEs in our sample identified benefits in three domains. First, cost reduction, in the words of one SME:

> "All I can tell you is that all we expect is to pay less, that's all we expect from energy. When we talk about energy, we think cheaper." (SME 8)

The second benefit derives from re-investing the money saved on energy into other business activities. One business owner explains:

> "If we reduce that cost [electricity], there is a part of that cost that will be reused in the form of savings for other investment purposes to develop the business, especially we can invest that amount of money in the purchase of other materials we need." (SME 19)

The third expected benefit is that RE serves as back-up during low tension/power outages. In the words of one SME, "It allows me to keep the light on even though there is actually a load reduction." (SME 5)

Overall, the SMEs have a very positive perception of RE and EE technologies. The experts agree with the SME's expectations, but also predict another opportunity for the future where the firms themselves become energy suppliers and thus develop new ventures. Interestingly, only one of the SMEs in our sample mentioned this opportunity, imagining an approach based on the French model:

> "So it's something that could work if, I wouldn't say copy, but take the model of France with EDF so that the population, if they want, can invest for their own consumption and inject in case of surplus production." (SME 10)

Performance expectancy is clearly a positive factor that can promote the use of RE among SMEs in Senegal.

3.4. Effort Expectancy

Only one SME provided a considered opinion on effort expectancy, expressing skepticism with regard to the use of RE technologies, considering the feasibility of implementation under the restrictions of an urban environment, such as the availability of space and potential energy losses along the supply cables. None of the other SMEs commented on the expected effort to deploy RE. Rather, their view is quite naïve. They overlook the efforts needed to adopt RE technologies into their firms. This becomes evident particularly in their estimation of photovoltaic systems where a notion of plug-and-play simplicity prevails. In the words of one SME: "If it were me, I would take the solar. It's very reliable now and you pay less. Once you buy the equipment, it's over." (SME 16). No thought is given to what the use of the sun will mean to his firm, nor to requirements such as installation, maintenance, or compatibility with existing appliances.

Effort expectancy, on the whole, does not seem to be a barrier for RE adoption, but not because of justifiable confidence. It is more likely that the rosy expectations belong to the prevailing knowledge deficit about RE.

3.5. Social Influence

When we look for the factor of social influence in our sample, we find little evidence that it plays a role in adoption decisions. Three SMEs expressed an awareness of climate change and the need for the decarbonization of the energy system:

> "I'm in this because when we talk about solar energy, I think it goes straight to the heart of the matter, there's no waste, only the greenhouse effect. We don't use anything that also harms the environment." (SME 9)

However, the reasons lie rather in individual values instead of a collective social influence or norm. The experts have little to say about social influence other than pointing to the importance of an environmental consciousness for the engagement in renewable energies:

> "Internally, they [the SMEs] don't have the staff dedicated to that. It just takes an environmental consciousness on the part of the entrepreneur to conduct environmental activities." (Expert 3)

Therefore, overall, social influence apparently does not act as a supporting factor for introducing RE into Senegalese SMEs.

3.6. Fascilitating Conditions

Among the SMEs in our sample, none expressed a positive opinion of existing facilitating conditions. Instead, they identified three mechanisms of state support needed to facilitate integration of RE and EE technologies into their firms.

First, the SMEs claim financial support is needed to invest in clean energy solutions. Only one SME, however, specified a need for support in the banking sector, where SMEs are not yet considered credit worthy. A second facilitating condition, mentioned by another SME, is a Feed-In Tariff (FIT) mechanism. This would enable SMEs to inject their

surplus into the energy grid, as is common in Europe. A third facilitating factor was named by two SMEs, who see the possibility to stimulate competition through a liberalization of the energy market, which would give SMEs the opportunity to freely choose their energy supplier. Unfortunately, only these four already mentioned SMEs formulated concrete ideas; the others simply expressed general criticism of the state.

A far more detailed picture emerges from the expert statements, which offer different perspectives on the state's role in fostering RE technologies. On the one hand, experts described the state as very committed, due to the budget it spends on the energy transition, despite the urgent policy fields of poverty and health. In addition, various initiatives and agencies operate in RE in Senegal, some of which receive state funding. A major step towards reducing investment costs in RE was achieved in 2020, as import duties on energy technologies were abolished. Moreover, microcredit securitization has also been established to meet financing barriers. In this respect, however, more commitment from the state is called for, so that the specific needs of SMEs can be better addressed. One of the experts further explains:

> "There is no problem for the demand of financing, because in Senegal microfinance is widely developed. There are many savings and credit cooperatives. On that side, there is no problem. The funds are there. But the problem is at the SME level." (Expert 5)

On the other hand, fundamental concerns about the transparency of political goals, regulations and (donor) coordination exist. One expert points out that governmental or official development cooperation organizations often do not know the full details of the laws in effect. This is also reflected in our sample. Some experts call for a legal framework for grid-injections, while others claim that the regulation already exists, but its implementation is still unclear.

In addition to addressing the role of the state, SMEs and experts point to the limited maintenance and service offers and the guarantees given by suppliers as challenging:

> "There are quite a few businesses today where people sell solar panels. Do they know how to do it? Do they know how to teach you? That's something else. Can they install it? I'm not sure. But they sell solar panels." (Expert 4)

However, no facilitating conditions to overcome this barrier were named. Providers of technology, service and maintenance are mostly concentrated in the city of Dakar or other urban centers, which leads to distributional constraints. For customers, this creates uncertainty about support, and for providers it means great effort to reach customers in a satisfactory manner. One business owner contends:

> "…above all, the problem for Africans is maintenance continuity. And this kind of energy requires maintenance and renewing the equipment all the time. Because when they install the equipment, it's not that the equipment is going to last ten years." (SME 6)

A lack of the after-sales maintenance and support that might encourage technology adoption stems from conditions in the country:

> "Companies that are based in Dakar, or in Saint-Louis, they actually find it difficult to work throughout the country because they are quickly confronted with logistics problems. They will also be faced with problems of maintenance and upkeep, and after-sales service, because they often need to have after-sales service relays at the local level. They do not necessarily have the financial and human resources to ensure these after-sales service." (Expert 12)

In summary, SMEs tend to be vague about the need for government support and other facilitating conditions, and they sometimes call for support that experts believe already exists. This points again to the knowledge and communication deficits that play a central role in our findings. Policies intended to facilitate the adoption of RE technology only work if the intended beneficiaries know about them and how to make use of them.

3.7. Hedonic Motivation

In the interviews with SMEs and experts in our sample, pleasure derived from the new technology was not mentioned at all.

3.8. Price Value

Judgements by the SME and experts on the "price value" of RE—the trade-off between the perceived benefits of its application and the monetary cost of using the technology—coincide very well. Due to the costly importation of most technological components, it is not surprising that the question of price dominates all other considerations of many SMEs and experts. As one expert notes:

> "A large solar panel to operate, for example, or an electric dryer where you can dry mangoes or bananas, it is very expensive and a company can't afford it." (Expert 3)

Moreover, both experts and SMEs are very critical of the quality of the products:

> "You can buy a solar thing that costs nothing at all, it comes from China, you install it and after three months it is defective. Sometimes even after a week. We need people who can guarantee that when you put that [PV panel] on, you have quite some time without needing to do anything." (SME 16)

3.9. Habits

Senegalese SMEs have little experience with the productive use of renewable energy, and this is reflected in our sample, precluding us from making any claims about habits. There are no learned RE behaviors, because, as the experts in our study emphasize, RE is still a novel idea in Senegal. Without long experience with the technology, companies cannot turn to legacy knowledge and routines.

However, the experts note two other factors affecting RE adoption in Senegal. First, one expert cites the outcomes of trainings on RE and a public campaign by Senelec for EE measures—both of which have already been implemented with little success—to claim that Senegalese citizens are not willing to change their energy behaviors. A second claims the Senegalese "do not act pro-actively, as it is not in the habits of the Senegalese". Both observations highlight the significance of cultural constraints that limit RE adoption.

4. Discussion

Academic interest in African entrepreneurship has increased in recent years, but one area had remained unexplored until this study, namely, the factors influencing decisions of SME entrepreneurs on whether or not to adopt RE technologies. To investigate these influencing factors, we conducted a qualitative interview study that included 36 interviews, both with Senegalese SMEs (23) and experts from the Senegalese energy sector (13). We used the UTAUT2 model as an analytic framework but extended it by two factors we find critical for understanding our study group—knowledge and communication channels (Figure 1).

The reader should keep in mind that the UTAUT2 model was developed for and focused on actors in developed economies. Caution must be exercised when applying the model to the decisions made by Senegalese entrepreneurs. This was a primary motive for our choosing a qualitative interview study design with its open explorative approach. By allowing SMEs and experts to voice their own unfiltered views without trying to fit them into the parameters of a quantitative study, we were able to gain valuable insights into the thinking of Senegalese entrepreneurs about RE technologies.

As our study uses an extended UTAUT2 model, it necessarily addresses both the suitability of the model for understanding Senegalese entrepreneurship as well as the suitability of the prosumerism idea to the Senegalese context. In Europe, prosumers have profited greatly from the solar energy boom. The idea of producing energy both for yourself to use and to sell to others would seem to have appeal to any entrepreneur. However,

does it in Senegal? Can it serve as motivation for RE adoption in a country where the informal sector makes up the major portion of the economy?

The informal sector plays an important role not only in Senegal, but also in developing economies worldwide, where it accounts for up to 60 percent of a nation's GDP [46]. In Senegal, the informal sector contributes 41.6 percent to the nation's GDP, according to the International Labor Organization (ILO) [47]. Basing their results on 2018 data, the ILO estimates that informal employment accounts for 90 percent of total employment in Senegal with more than 70 percent of this taking place in informal sector SMEs.

Past research has already pointed to the importance of providing energy to enterprises in the informal sector and in informal settlements as a means to improve productivity and living conditions in cities in the Global South [48]. However, the characteristics of the informal economy—the fact that it is not regulated by governments, it is not taxed, it can only grow to a certain size, and it depends on middlemen to connect entrepreneurs to their customers—mean that entrepreneurs in that economy are driven more by necessity than opportunity [4].

4.1. Dimensions of the UTAUT2 Influencing RE Technology Adoption by Senegalese SMEs

Table 4 presents the nine dimensions of our extended UTAUT2 model, with bulleted items under each dimension noting important observations and relevant SMEs from our sample listed to the right. Looking first at the standard UTAUT2 dimensions, we see extensive commentary from our interviewees on the dimensions of performance expectancy, facilitating conditions, and price value. Performance expectancies are high, but commentary on facilitating conditions is largely negative, with the SMEs unanimous in their general criticism of the government. Commentary on price value is also negative, focusing on high investment costs and low product quality.

Table 4. Extended UTAUT2 in the sample; source: authors.

Dimension	SMEs
Knowledge (extended model)	
Insufficient knowledge of RET	5, 8, 21
Sufficient knowledge of RET	1–4, 6–20, 22–23
Interest in trainings on RET	1–14, 16–23
No knowledge of business electricity tariffs	7, 9, 14–15, 17, 19–21
Communication channels (extended model)	
Use of mass media channels	21
Organization in informal networks	8–10, 17–19
Organization in strategic networks	3, 9
No organization in networks	1, 5–6, 11–12, 14, 20–22
Performance Expectancy (UTAUT2)	
Cost reduction in general	2–3, 6–8, 15–17, 20, 22
Re-investment of savings in other business activities	3, 11–12, 19, 23
Back-up option during low tension/power outages	5, 7, 12, 19, 23
Effort Expectancy (UTAUT2)	
General skepticism	1
Unreflective high expectancy	16
Social influence (UTAUT2)	
Awareness of climate change	2, 9–10
Facilitating conditions (UTAUT2)	
General criticism of governmental support	1–23 (all)
Needed: support (banking sector, feed-in tariffs, liberalization of the energy market)	8–10, 21
Needed: maintenance, after-sales services and guarantees	4, 6, 8, 16
Hedonic motivation (UTAUT2)	none
Price value (UTAUT2)	
Criticism of high investment costs	3–5, 7, 10–11, 15–16, 19, 22
Skepticism of product quality	4, 8, 16
Habits (UTAUT2)	none

Our study did not distinguish between formal and informal SMEs, as that was not our research focus. However, given the preponderance in Senegal of informal sector entrepreneurs whose decisions are driven more by necessity than by opportunity, it is not surprising that for many of our SMEs, investment costs are a formidable adoption barrier.

On the other hand, it may seem surprising that social influence does not play a greater positive role among our SMEs. Other studies that have applied the UTAUT or UTAUT2 to RE adoption in economies of the Global South suggest the importance of social influences in encouraging potential adopters to investigate and evaluate the technology and to share their knowledge about it [38,42,49]. While we did find that our SME entrepreneurs were generally aware of climate change challenges, we did not find the kind of social influences at work that would promote RE adoption.

Along the UTAUT2 dimension of effort expectancy, there is commentary from only two SMEs, and that commentary, both in its sparseness and in its content, reveals another adoption barrier in the two extreme views expressed. Both hinder realistic RE adoption: SME 1 vastly overstates the effort, while SME 10 vastly understates it.

Regarding habits, we only obtain the meta-perspective of the experts who note that RE is still a new idea in Senegal, and so habitualized experiences are missing from SME practices. Nor did any of the SMEs in our study express any expectations of pleasure to be derived from the use of RE technology, meaning no evidence of hedonic motivation was found.

We find that the entrepreneurs in our sample tend to view RE adoption from the perspective of constraining factors rather than recognizing entrepreneurial opportunities. They attribute the responsibility for creating support programs and other enabling factors to the government and seem to overlook their own entrepreneurial responsibility to create opportunities.

However, we also find that government policies designed to assist RE adoption, including financial incentives and microfinancing opportunities, exist in Senegal, but knowledge of these instruments and how to use them is lacking among the Senegalese SMEs we interviewed. This underscores limitations both in the available communication channels and in the engagement that entrepreneurs have with those channels. The necessities of day-to-day business take the full attention of our SMEs, and so they do not actively engage with new innovations or what in the West would be called strategic planning. Even the limited networking activities that exist do so to serve primarily social purposes; only two of our 23 SMEs engage in what would be called strategic networking.

From our study context, we find that UATUT2 is not yet sufficiently appropriate to meet the reality of decision making by SMEs in Senegal. As revealed through our extensions, important indicators are missing that cover above all awareness-raising and low-tech learning. We still know little about entrepreneurial behavior and its dynamics, directly linked to the characteristics of informal firms, which remains an understudied context in entrepreneurship studies [46]. The problems of applying the UTAUT2 model in Senegal lead us to our second research question.

4.2. Additional Influencing Factors in the Senegalese Context

While in developed economies entrepreneurs supposedly have sufficient knowledge and access to communication channels to acquire new knowledge and thus be able to evaluate technological innovations, we cannot de facto assume the same conditions exist for Senegalese entrepreneurs. From this recognition and based on Rogers DOI [9], we added to our analytical framework the dimensions of knowledge and communication channels that are shown in Table 3.

Our results show that knowledge is crucial at two levels of the decision-making process. First, in the awareness-forming phase, entrepreneurs must first learn that they can use RE technology to become prosumers. Without awareness of this opportunity, entrepreneurs cannot evaluate and interpret the technological innovations for their own purposes and cannot decide rationally for or against the use of RE. However, knowledge is

needed beyond this critical phase of awareness of an entrepreneurial opportunity. Our findings show knowledge is needed to form the intent to act and to carry it out. For example, the entrepreneurs need information about the complexity of the technologies, local markets, after-sales service, best practices and financing options.

The readiness of entrepreneurs to exploit external knowledge, to recognize and evaluate the advances of technological innovations, and to transfer what they learn to the context of their firms depends on the formal and informal information channels the entrepreneurs use and actively shape. Zanello et al. [43] found internal factors of the firms, such as education and managerial skills, highly influential on the creation and diffusion of innovation in countries in the Global South. The human capital of the entrepreneur, i.e., his or her networking capabilities and knowledge about appropriate RE options, are seen as a particularly supportive mechanism for the adoption of RE technologies. However, we found lower levels of knowledge and networking activities in our sample, which is why this effect does not emerge.

As fruitful as the dimensions in our extended model are in understanding the factors influencing the decision-making of Senegalese entrepreneurs, we are convinced that the scope of investigations in the Global South should be widened to include additional factors that help us better understand the attitudes and considerations of informal sector entrepreneurs in the African context. Specifically, we find the concept of individual entrepreneurial orientation (IEO) fruitful, itself derived from the concept of entrepreneurial orientation (EO) developed and extended for the organizational level of firms [50]. Numerous studies that have applied EO to investigate an organization's strategic choices have concluded that "entrepreneurial orientation reflects an overall posture consisting of deep-rooted beliefs and values associated with a tendency to be simultaneously proactive, risk taking and innovative" [50] (p. 98). Outside organizational contexts, studies that take the three behavioral factors of proactivity, risk-taking and innovativeness at the individual level to explain entrepreneurial decision and actions are rare. The few studies that have used IEO to investigate developing economies include Musara and Nieuwenhuizen [46] in South Africa, Goktan and Gupta [50] with a multi-country study in the US, Hong Kong, India, and Turkey and Fatima and Bilal [51] in Pakistan.

As we have already shown, integrating the DOI dimensions of knowledge and communication channels contributes significantly to the understanding of entrepreneurship in Senegal. We think it would be helpful to add the IEO factors of proactivity, risk-taking and innovativeness to better understand the decision-making processes of SMEs in the formal and informal economies of Senegal. With this combination of the UTAUT2 model and relevant aspects from DOI and IEO, the factors influencing the adoption or non-adoption of RE into the businesses realities of Senegalese entrepreneurs could be better understood.

5. Conclusions

From the answers to our research questions, we can draw implications for firms in the RET context as well as for central and regional governments. We conclude there are opportunities, both to address the internal capabilities of the entrepreneurs and to provide external support to enable entrepreneurs to make a valid decision about the adoption of RET.

With regard to the internal factors, we would like to emphasize the importance of promoting the attitude and skills that allow entrepreneurs to engage with new technologies in their own context. These include networking capabilities and vehicles for knowledge diffusion. Here, we see a mandate for external support by knowledge carriers and brokers such as Senegalese universities and RET suppliers to cooperate more closely and to establish networks of SMEs. These activities should meet the needs of the Senegalese SME community and address the needs of both formal and informal firms. By exchanging information on RET between heterogeneous actors, the knowledge available in the country could be better disseminated.

In addition, more attention should be paid to improving communication channels. Existing information and support mechanisms must be developed and presented in such a way that they reach out to their intended recipients and they should be able to access them via simple structures. It is noteworthy, for example, that there is a gap between the needs for government support expressed by entrepreneurs in our interviews and the structures already put in place by the government that already at least partially meet those needs. Additionally, there are uncertainties with regard to the quality of and the prices asked for PV systems. These uncertainties could be reduced by RET suppliers who provide the SMEs with transparent information and offers.

5.1. Addressing Senegal's RE Policy from Two Strategic Points

Given the ongoing efforts of the Senegalese government to promote RE in general, we would like to address policy from two strategic points. First we would like to come back to the role of the informal sector. Knowing that in Senegal 95 percent of all enterprises are SMEs and 70 percent of the informal employment takes place in informal enterprises, we see informal firms as important promoters of the energy transition. Even if individual SMEs are not the largest consumers, they are enormously dependent on a stable and affordable energy supply. To empower these firms, which make up almost half of Senegal's GDP, measures are needed that target the needs of the entrepreneurs in the informal sector to make existing policies accessible for them and promote them in their role as one of the stakeholders in the energy transition.

Second, we ask why the adoption of RE technologies by SMEs, i.e., their transformation into prosumers of electricity, does not receive more support from the Senegalese government—especially since SMEs form the backbone of the country's economy. Governmental efforts seem to focus either on the incumbent state-owned energy supplier, Senelec, or on the electrification of small rural communities, which do not have access to the public grid. SMEs in cities like Dakar or St. Louis that have access to the grid are left behind, without support in their transition to prosumers.

This finding can serve as an impetus to question the unreservedly positive Western notion of prosumers [52–55] and to look into perceptions of the prosumer phenomenon in an African context. A survey of energy experts in Africa [56] revealed that among several energy trends—including the growing importance of renewables, introducing competition to the electricity market, and distributing energy resources—the trend of consumers becoming prosumers came in dead last in all categories: deemed least popular in the electricity sectors, least recognized by policy makers and least beneficial for the country. The survey also revealed that prosumerism enjoys conspicuously less regulatory support in African countries.

We cannot answer from our interview study whether it is a deliberate decision by policy makers and regulators in Senegal not to actively support SMEs in becoming prosumers. However, a World Bank report provides indications on power sector reform in countries of the Global South and characterizes the implications of prosumers for grid operators, utilities, and regulators as follows: "The advent of prosumers […] able to deploy decentralized generation, storage, or demand–response solutions complicates the task of planning, which affects both generation expansion and grid development […] [57] (p. 135). Add to this the fact that Senelec is already struggling to keep the grid stable with limited amounts of renewable power and very few prosumers, and it does not take much imagination to understand possible reservations among Senegalese policymakers about prosumerism in the electricity sector. However, distributed generation by prosumers can also help to reduce the stress on the grid and the necessity to invest in its extension [58].

Besides the technical problems of integrating prosumers into grid management, there are also social and financial reasons for Senelec to be wary about rising numbers of prosumers. Generally, prosumers are more affluent than the average electricity consumer and the takeoff reduction by the former increases the burden of fixed grid costs that is distributed on the latter under a volumetric grid tariff [52–54]. Thus, for example German

RE legislation with its historically generous FIT for prosumers has been criticized as "[…] regressive, redistributing income shares from the distribution's bottom to its top." [59] (p. 1342). Additionally, in an African context, becoming a prosumer involves some investment, so it is usually not the poorest stratum of society that embraces this new opportunity. Thus, a study from South Africa finds that "[…] while disruptive technologies offer potential opportunities to develop infrastructure that is more responsive to environmental and social imperatives, they also threaten critical revenue from South Africa's wealthy consumers that cross-subsidizes electricity services for the poor and other essential municipal public services." [60] Therefore, trying to keep relatively wealthy entrepreneurs in the grid can be rational for Senelec and the government from a social justice perspective.

Not only policy makers but also researchers seem to marginalize prosumerism in the African context. Studies looking into prosumerism in sub-Saharan Africa are extremely scarce and they tend to overlook social issues while conveniently focusing only on technical questions [61]. The same applies for developing countries in other regions, e.g., Asia [62]. A rare exception is the Study by Khan [63].

Summarizing the above discussion on prosumers, one should not draw overly simple conclusions, as a variety of actors with different and potentially conflicting interests and goals are involved in the socio-technical arrangements of energy systems. While SMEs have a legitimate interest in becoming at least partially independent from the unpredictable and perceivably expensive public grid, and while an increased share of renewables is positive from an overall environmental perspective, in the short term, it is understandable that the interests of Senelec and the government in keeping relatively affluent entrepreneurs in the energy system and not overstretching their capacity for grid management would prevail.

5.2. Suggestions for Future Research

With regard to these findings, we suggest six avenues for further research*:*

- In the largely understudied context of RE adoption by African SMEs, further qualitative studies should be conducted in other sub-Saharan settings. More research is needed on how African entrepreneurs perceive specific influencing factors to allow a more meaningful picture of the decision making of these entrepreneurs to emerge. Once we have a better understanding of these factors, quantitative studies could follow to determine their specific influencing variables.
- Additionally, research should pay special attention to the specific conditions of informal firms. Given the importance of the informal sector for African economies, this field should be considered by more scientists in the future.
- Valuable insights could be derived from studying SMEs that have already adopted RE technology. These insights could reveal the factors underlying affirmative RE adoption decisions.
- Given that entrepreneurial skills are important for the entrepreneur's attitude and engagement with innovation, these skills and their contribution to behavioral intent should be better explored on a region-specific basis, e.g., by using the IEO factors.
- The dominance of Western models in the entrepreneurship literature leaves room for further research to test whether the models, which have so far proven suitable in developed economies, can also be applied in countries of the Global South. A critical examination of the influencing factors is urgently needed and should be further developed to understand the processes within nonwestern contexts.
- Likewise, the nearly unequivocally positive notion of electricity prosumerism and partial independence from the grid should be revisited in an African context. Examining policy makers' and utilities' representatives' views on prosumerism would increase our understanding of their decision-making processes.

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Original research article

Renewable energy transition in Senegal? Exploring the dynamics of emerging paths to a sustainable energy system☆

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ABSTRACT

Research into the transition of energy systems has attracted considerable attention in recent years from a wide range of disciplines and perspectives. From evolutionary economic geography (EEG), scholars have emphasized the processes underlying the formation of new energy paths in energy system transitions. These processes have been well studied in Global North countries, but insights into the processes shaping the energy transition in sub-Saharan Africa are still limited. This study provides a contribution to fill that gap by exploring the emerging energy paths in Senegal through the lens of EEG, using the framework of regional path creation processes to analyze qualitative interview data from 17 experts in the Senegalese energy sector. Senegal is an instructive country to study, as its energy sector is undergoing substantial reform that has accelerated the deployment of large-scale renewable energy projects in recent years. The study uncovers three parallel evolving energy paths stemming from path transplantation, indigenous path creation, and path upgrading. Each path differs greatly in its legitimation and in the role of institutions as enablers. These results not only contribute to the ongoing scientific debate; but also provide insights for development agencies, national and regional institutions, NGOs and private actors involved in the Senegalese energy system.

1. Introduction

A key step toward meeting international climate goals is decarbonization of the energy sector, one of the United Nations Sustainable Development Goals and part of the international community's commitment to affordable, reliable, and sustainable modern energy available worldwide. To meet these goals, ever larger investment volumes have funded a wide range of global initiatives and joint international efforts, the result of which has been accelerated growth rates of renewable energies (RE) in countries of the Global South.

Although Africa's renewable power generation capacity almost doubled from 27.33 GW in 2010 to 48.44 GW in 2019 [1], its ever growing energy demand has not been significantly alleviated by RE. Data from the International Energy Agency shows sub-Saharan Africa (SSA) to have the lowest electrification rate in the world: 48 % in 2019, while the global average for the same year was 90 % [2]. This means for sustainable energy transitions to succeed in SSA, we must understand the embedded political and socio-cultural processes, namely, the societal transitions that require sustainability-oriented reconfigurations [3,4].

A sizable research community has pursued this understanding, shedding light on how complex political, economic, and social systems are intertwined with the processes leading to decarbonization of an energy system. But most of these transition studies have focused on disruptive processes and the emergence of technological innovations [5]. The processes of path creation, such as the co-evolution of industries and knowledge, the role of institutions, and multi-scalar knowledge bases – these have received scant attention.

These processes do, however, form a central area of research in economic geography [6–9]. The related literature on path creation can shed light on the paths toward energy system decarbonization that are emerging in Senegal. Senegal is an informative country to study, as little is known about the dynamics of the Senegalese energy sector, even though the country is undergoing a reform process in the sector and the

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deployment of large-scale RE projects has accelerated in recent years.

What we do know about Senegal has come from one dimensional investigations. Van den Bold [10] recently examined the electricity sector reforms in Senegal with regard to private sector investments. Diouf and Miezan [11] analyzed shortcomings in the biogas program initiated by the government of Senegal and the concession-led model of rural electrification. Apfel and Herbes [12] investigated in their interview study the decision-making processes of Senegalese SMEs whether to adopt RE, and Cissokho [13] explored in his article the productivity effects of power outages on small and medium enterprises. Others have examined Senegal in multi-country studies concerning RE policies [14], business experiences of sustainable energy SMEs [15], rural electrification initiatives [16], systems for village-scale solar power supply [17] or sociotechnical imaginaries for solar power [18]. However, studies applying a multi-dimensional approach are missing.

This study aims to contribute to energy research by drawing on Cherp et al.'s [3] understanding that energy transitions are processes that change the entire system and are not limited to changes in individual technologies or resources. From the "framework of regional path creation processes" developed by MacKinnon et al. [5], the study takes five key elements as a basis for analysis: (i) regional and extra-regional assets, (ii) actors, (iii) mechanisms of path creation, (iv) market construction, and (v) institutional environments. Together, these provide an answer to our central research question:

> *What new energy paths are emerging in Senegal that go beyond the greening of the energy mix?*

To date, little is known about the dynamics that lead to the creation of new energy paths in SSA, particularly in West African countries. The results of this study are therefore not only interesting for the scientific debate on energy transitions in SSA, but also for practitioners of development agencies, national and regional institutions, NGOs and private actors involved in the Senegalese energy system.

This paper proceeds as follows: Section 2 outlines the study's analytical approach; Section 3 explains the research methodology used – expert interviews, qualitative data analysis and document analysis; Section 4 presents results of the study; Section 5 discusses those results, and Section 6 offers conclusions.

2. Analytical approach

2.1. Academic interest in sustainability transitions and path creation

Much of the academic interest in sustainability transitions has focused on disruptive processes and technological innovation; the results of these studies and their underlying analytical approaches have been summarized in prominent literature reviews. Cherp et al. [3] present a meta-theoretical framework highlighting the interdependence of three perspectives – techno-economic, socio-technical, and political; the researchers emphasize that none of the perspectives are subordinate to any other. Köhler et al. [19], in a comprehensive literature review, outline nine research strands ranging from power and politics to organizations and industries, with ethical aspects also considered. In developing their own meta-theoretical framework for the energy transition, Sovacool et al. [20] point out that few of the theories used in existing research adopt multidimensional perspectives that would allow multiscale assessments. Rather, many would "anchor their analysis on a single dimension of analysis: agency, or the 'micro' role of actors; meaning, or the 'meso' attributes of discourses, visions, and narratives; and structures, or the 'macro' role of system level constraints." [20].

Scholars studying the geography of sustainability transitions take a more integrative approach to understanding transition processes [21]. Through the lens of evolutionary economic geography are seen the endogenous dynamics of economic change [22]. Boschma and Martin [23] specify this as a process "by which the economic landscape - the spatial organization of economic production, circulation, exchange, distribution and consumption - is transformed from within over time" [23].

Insights from historical path dependencies can shed some light on this future economic development, and recent research argues the underlying aspects of path creation processes are the important determinants in sustainability transitions. These aspects are embedded in specific spatial patterns, as the co-evolution of industries and knowledge, interpath dynamics, the role of institutions, and multi-scalar knowledge bases [6–9,24].

In the scientific debate, there is no consistent use of terminology regarding the varied types of path creation or path development. The understandings of *creation* or *development* do not differ fundamentally but rather the difference is how the terms are adopted [8]. In this article, I adopt *path creation*. This choice stems from the seminal article on 'Path dependence and regional economic evolution' by Martin and Sunley [25]. Here, paths arise out of five forces: indigenous creation; heterogeneity and diversity; transplantation; diversification into related industries; and upgrading of existing industries. This understanding of *path creation* is broad enough to be applicable to the Global South, in contrast to other frameworks that embed the exigencies of the Global North and so may not be suitable in a Global South context.

2.2. MacKinnon et al.'s framework on regional path creation processes as analytical tool

MacKinnon et al. [5] expand and deepen the concept of path creation through their integrative theoretical framework on regional path creation processes. They incorporate insights from established research strands in fields other than evolutionary economic geography, including transition research, sociological and institutional perspectives, global production networks, and geographic political economy. This integration provides a view of path creation processes that can capture the interplay across economic, political, social, and environmental systems.

The framework focuses on the interplay of five key elements: regional and extra-regional assets, key actors, institutional environments, market construction, and mechanisms of path creation. Table 1 summarizes the five elements and their underlying understandings. Fig. 1 depicts the interaction of the elements, showing that none is privileged in its contribution to path creation. This neutrality offers the possibility of uncovering the underlying interactions, power relations, and opportunities in a region where new path creation processes are taking shape.

With MacKinnon et al.'s dynamic understanding of regional boundaries as "open and porous" [5], regions are embedded in multiscale processes. This understanding is crucial for analyzing the emerging paths of energy transitions in countries of the Global South, as the shaping factors go beyond inherent capabilities of these countries. For this reason, the framework has proven itself invaluable in addressing questions about the energy transition in Senegal.

Perhaps it takes a scholar focusing on the Global South to recognize the framework's potential to shed light on the dynamics and processes there, as a data query of Scopus, conducted on November 8, 2021, revealed that studies have yet to apply the concept to that region. Among the 88 studies citing MacKinnon et al. [5], almost all applied the framework to path creation dynamics in North America and Europe, with a bias toward Scandinavian countries. The few exceptions are studies on China, Taiwan, Singapore and Namibia. There is no evidence in Scopus that the framework has ever been used for the analysis of energy transitions in SSA.

3. Research methodology

The empirical basis of this paper draws on two sources. The first and most significant source is primary data collected through qualitative interviews with experts in the Senegalese energy sector. The interviews were conducted face-to-face during two visits to Senegal in 2019,

Table 1
Key elements of MacKinnon et al.'s framework and their contexts.

Key elements	Specific types	Definition and understanding
Regional and extraregional assets	Regional assets: - natural resources - infrastructural and material assets - industrial assets (technology and firm competencies) - human assets (labor skills, costs, knowledge) - institutional endowments (rules, routines, norms) Extraregional assets: - industrial assets (technology) - human assets (knowledge, skills)	- Regional assets are "… products of the broader regional environment, which are utilized by firms and non-firm actors for specific purposes" (p. 122) - Extraregional assets have"… linkages to exogenous assets and resources through wider extraregional networks, particularly in its early stages (…) these can often play a particularly important role for peripheral and latecomer regions, potentially enabling them to jump ahead by creating more technologically advanced growth paths." (p. 122)
Actors	- Innovative entrepreneurs - Institutional entrepreneurs - Path advocates	- Innovative entrepreneurship fosters the rearrangement from existing and the generation of new paths. That implies "(…) individuals that exploit these [future] opportunities, requiring new forms of market and technological knowledge" (p. 123). - "Institutional entrepreneurship involves challenges to existing rules and norms, and attempts to institutionalize alternative rules and practices (…) in support of particular path creation agendas" (p. 123). This is linked to power relations and different objectives of the actors and understood as a process of change rather than as a reaction to a trigger. - Path advocates have leadership skills that enable them to influence other actors across organizational boundaries. This is seen as strategic place-renewing leadership, a hybrid of public and private, influencing decision-making processes in such a way that economic change can emerge. This relates to path "legitimation and empowerment" (p. 123) through advocates' ability to influence established structures and networks.
Mechanisms of path creation	- Path diversification - Path transplantation - Indigenous path creation	Path creation processes are a coupling of actors with regional and extra regional assets. "Rather than regarding them [path creation mechanisms] as ontologically 'pure' and separate entities, they should be viewed in relational terms as partial overlapping" (p. 123). The reference is made only to diversification, transplantation and indigenous creation, as identified as the most prevalent in research. However their referencing work of 25 [25] also entails heterogeneity and diversity as well as upgrading of existing industries.
Market construction		"… markets are (re)constructed out of existing relations rather than created afresh, emphasizing that this process is shaped by unequal power relations and struggles between actors" (p.124). Regional markets need to expand to national and international markets to generate scale effects and achieve a critical mass.
Institutional environments		"Multiscalar institutional environments enable and constrain their [actors] actions and strategies" (p. 125). These embed the rules and norms that influence the actors, which include political contestation and compliance with industry standards and investment rules. "… the legitimation of an emerging path requires a critical mass of actors who can form packs of entrepreneurs, working through industry associations and other collective agencies" (p. 125)

Source: Author.

followed by telephone interviews and video calls in 2020 to accommodate COVID-19. Depending on the preferences of the interviewees, the language was French, English or German.

The interviews were based on semi-structured guidelines focusing on six themes: actors and their roles in shaping the energy sector; regulatory frameworks driving the energy sector reform; changes in the energy sector due to renewable energies; knowledge, skills and capacities existing in the Senegalese economy; international financing and its role in developing the energy sector; and visions about Senegal's energy future.

The interviews sampled 17 experts identified as having competencies that shape the Senegalese energy sector, based on their knowledge and potential to foster change and development. Experts were chosen based on Döringer's definition: "experts are considered knowledgeable in a particular subject and are identified by virtue of their specific knowledge, their community position, or their status" [26]. Table 2 provides an overview of the interviewees according to their area of expertise.

With the permission of the interviewees, the interviews were recorded and then transcribed. The material was analyzed using the software MaxQDA [27]. Qualitative Content Analysis, as developed by Mayring [28] was used to evaluate the transcripts. The coding categories corresponded to the five key elements in MacKinnon et al.'s framework, which represents a deductive approach.

The secondary source of data used to complement the experts' insights included policy and technical documents, and press releases related to the energy transition in Senegal. These were reviewed for regulatory actions, objectives, and results claimed. The information obtained provided context for the evaluation of the interview material. So the reader can better understand the energy context in Senegal, the next section provides a brief introduction to its dynamics.

4. Mapping the energy transition paths in Senegal

Senegal was chosen as a case study because its energy sector is undergoing multiple changes, while facing structural and socio-cultural challenges that will affect its future development. To understand the processes of change in the energy sector, this article does not focus on individual energy technologies, infrastructures, or investigate the role of individual energy sources [3]. This article thus differs from other research in the context of energy in the Global South, which mostly focuses on a specific energy source, such as electricity or biogas, or on individual technologies, such as photovoltaics. Nor does the article study specific economic sectors or analyze individual case studies. The interview study conducted, with its semi-structured, guideline-based approach, allows the perspectives of the interviewees to be explored with regard to all facets of the energy sector, without limiting them to

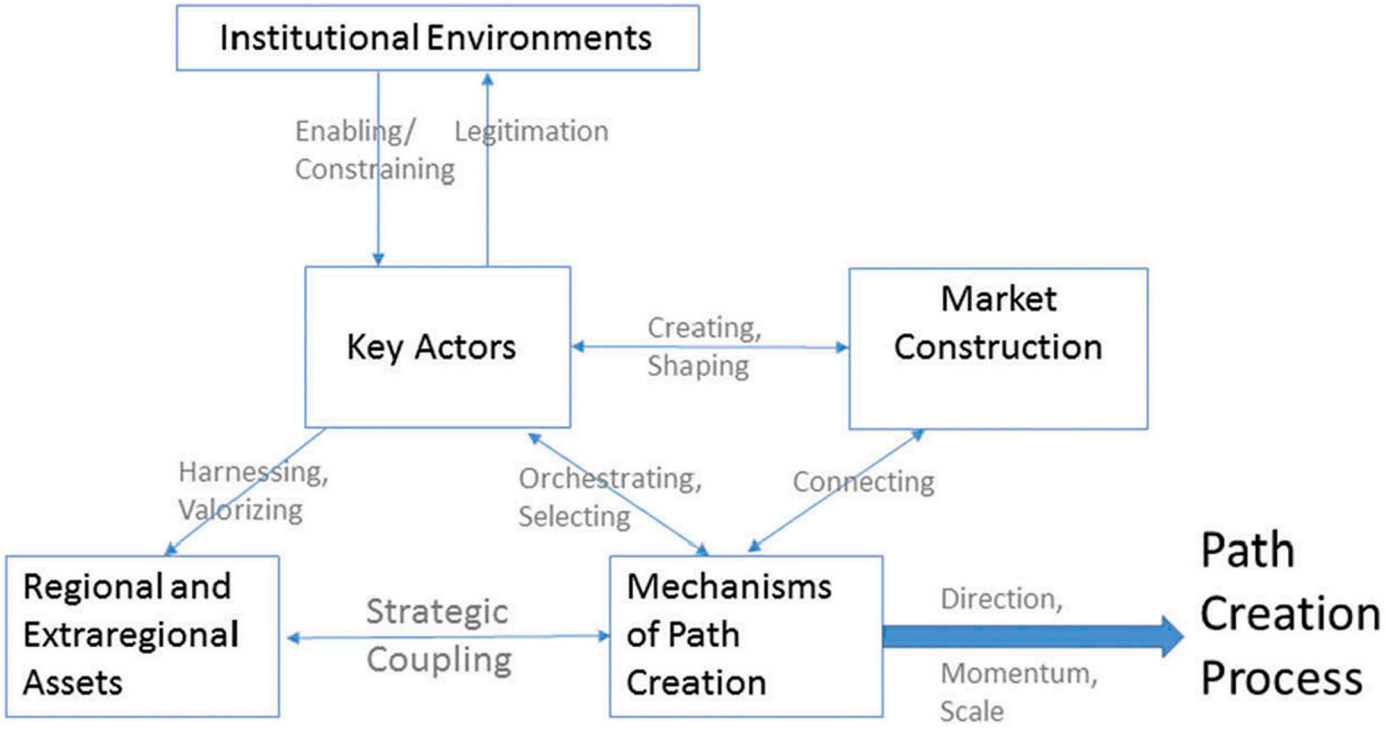

Fig. 1. Integrative framework on regional path creation processes.
Source: [5].

Table 2
Profile of interviewees.

Area of expertise	Interviewee (expert # in citations)
International development cooperation	1, 17
Environmental consultant	2
Public institutions of Senegal	3, 6, 7, 9, 11
Senegalese RE industry	4, 8
Academia	12
NGOs	5, 14
Electricity concessionaire	10
Finance	13, 15, 16

Source: Author.

one technology or energy source given [29]. In this way, influences on complex and profound systemic transitions can be identified on the national level. This involves a certain complexity, but enables such a whole-system analysis, as the realities of the energy transition are aligned with national laws and regulations [3], see Fig. 2.

The sector's key characteristics can be summarized in three points. First, the sector has shifted in recent years toward RE. In 2011, Senegal conducted a pilot study in cooperation with the International Renewable Energy Agency (IRENA) to assess the country's potential for deployment of RE technologies. Since then, the country has steadily increased its installed capacity of renewable energies. From 2000 to 2019, it increased from 28 MW to 209 MW [1], mainly due to the realization of large-scale projects, such as the solar parks of Bokhol (20 MW) and Méouane (30 MW) and the Taïba Ndiaye wind park (50 MW by 2019, with a planned final capacity of 158 MW). While this step toward RE was being taken, oil and gas fields were discovered in Senegal in 2014–2016, the exploitation of which was started in 2020, which will diversify the energy mix.

In terms of RE, the total primary energy supply in 2019 shows that the shares of solar (1 %) and wind (0,4 %) are still very low. Oil is the main primary energy source (61 %), followed by biomass (27 %) and coal (11 %) [30]. The contribution of gas is minimal (0,3 %). These figures are predicted to change in favor of gas instead of oil and coal, which is stated in the latest "Policy letter of energy sector development" [31]. As for energy consumption in Senegal consisted in 2019 of oil (41 %), biomass[1] (36 %), electricity (15 %) and coal (8 %) [30]. Major energy consumers in Senegal are households (40 %), the transport sector (33 %) and the industrial sector (18 %) [30].

Second, the energy reality in Senegal is bleak and its future does not yet look favorable. Energy costs in Senegal are among the highest in the world [33]. Energy riots in 2009 and 2011 broke out in the greater Dakar area after prolonged and repeated power outages [34,35]. Protests broke out again in 2019 in response to Senelec's 10 % electricity price increase. These large-scale civil demonstrations give voice to the massive dissatisfaction of the Senegalese people with their energy supply. Constrained by high prices and low reliability, the Senegalese energy supply is a roadblock to the economic development of the country's people and companies [12,13,36]. Moreover, weaknesses in the energy supply lead to inequalities in energy access between urban and rural areas, as evidenced by the wide disparity between the respective electricity access rates in 2018 of 92 % and 44 % [37].

Third, to overcome these problems, the government is committed to reforming the energy sector and solving the structural problems of the national utility Senelec (Société nationale d'électricité du Sénégal). Over the years, new energy regulations have been adopted, and Senelec has undertaken strategic planning to better meet the country's energy needs [33]. Fig. 2 depicts the timeline of national energy programs and energy sector reforms. The reforms aim to attract private capital, which is

[1] Biomass is used almost exclusively by households to meet their primary energy needs [32]. A national biogas program PNB-SN was initiated by the Senegalese government to counteract deforestation for firewood and provide families with clean energy. However, the program failed due too poorly implementation of state policies and access to finance in rural areas [11]. However industrial biogas plants are rare. These are found, for example, at slaughterhouses or the Dakar sewage treatment plant. Senegal's bioenergy potential has not yet been fully tapped.

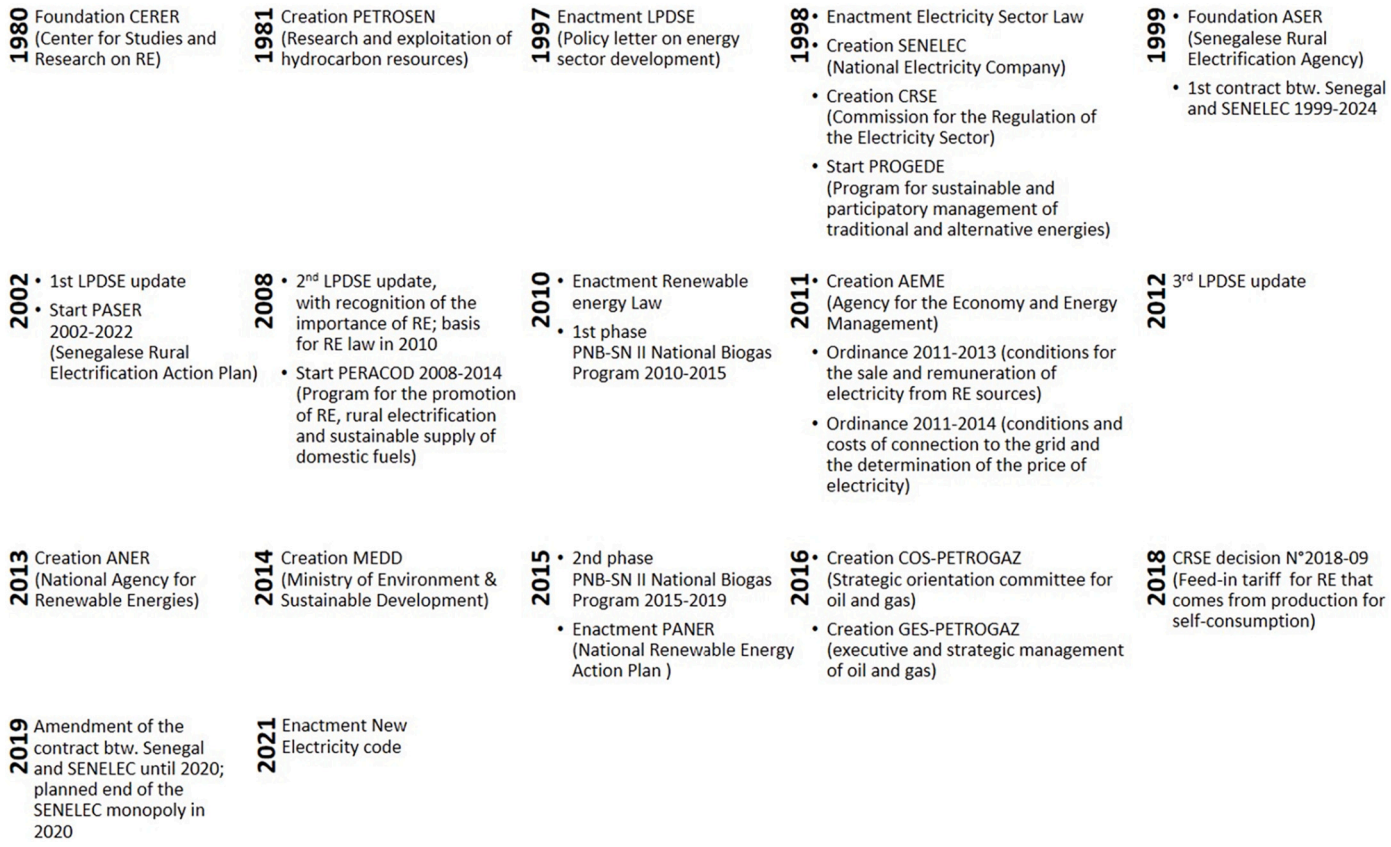

Fig. 2. Timeline of the energy sector reforms and national energy programs. Source: Author.

urgently needed to overcome the country's dependence on expensive oil imports and a huge investment backlog.

These three characteristics define the Senegalese energy context from which development paths emerge together with opportunities to Senegal to benefit from these developments. Applying the five key elements from MacKinnon et al.'s framework, we look first at regional and extraregional assets (Section 4.1), then actors (Section 4.2), then institutional environments (Section 4.3), then market mechanisms (Section 4.4) and, finally, mechanisms of path creation (Section 4.5).

4.1. Regional and extraregional assets: rich natural resources but weak local capacities

Throughout the country, Senegal has great potential for RE that can contribute to power generation. Solar and wind energy offer the greatest potential, while the conditions for biomass and hydropower are less favorable. Solar resources are estimated at an annual PV output per unit of 1600–1800 kWh/kWp/year for 80 % of the country. The potential of wind differs regionally, but in the 10 % windiest areas in Senegal reaches a wind power density of 6.61 m/s or 260 W/m^2. The potentials have already been exploited with large-scale projects via Independent Power Producers (IPPs), with the first solar parks commissioned in 2016 and 2017 [38]. It is also important to note that oil and gas fields were first discovered in Senegal in 2014. Their exploitation was to begin in 2020.

While the strong efforts to reform the energy sector reflect the government's will to push the energy transition and take advantage of the country's natural resources, one of the sources in this study (Expert 2) stresses that regional capacity in terms of human and financial resources cannot keep pace with the reform processes in the sector. No co-evolution of the Senegalese economy along the value chain has been stimulated, such as in operation, maintenance, repair and transport, which was found in another study on South Africa [39]. A number of the interviewees (Experts 5, 8, 11, 12, and 15) describe constraints in Senegal that limit local banks and financing options, which was also shown in the in the South African case [39]. But the experts are equally vocal about companies lacking skills in business management and entrepreneurship (Experts 5, 7, 11, 14 17). To meet this challenge, Senegal's universities have a central role to play, and so, since 2015, they have offered an “Interuniversity Master of Renewable Energies” (MIER - Master Interuniversitaire d'Energies Renouvelables). This is a university-level degree program initiated by German Cooperation for International Cooperation (GIZ); it provides applied education in RE and energy efficiency, while also strengthening entrepreneurial skills [40].

4.2. Actors: the who's who of the energy transition in Senegal

While the Senegalese energy sector has for decades been characterized by the dominance of the Ministry of Energy and the state-owned power utility Senelec, reforms of the sector have been carried out with multi-actor involvement and under the strong influence of bi- and multinational institutions. This has brought numerous new actors into the Senegalese energy sector, leading to a mix of “who's who” in the transition process. Together, they are key to creating an enabling environment for private capital investment that can unlock the country's energy potential. The actors in this mix are involved both in the sector reforms and the associated large-scale projects, working in a way that displays the emergence of a public-private governance system.

On the one hand, there are the state actors responsible for the legal and regulatory frameworks and their implementation. These include the Ministry of Petrol and Energy, the Regulatory Commission of the Electricity Sector (CRSE-Commission de régulation du secteur électrique),

the Senegalese Agency for Rural Electrification (ASER-Agence Sénégalaise d'Electrification rurale), the National Agency for Renewable Energy (ANER), and Senelec. The objectives of these public actors are to ensure energy security and universal energy access, develop an energy mix with at least 15 % renewables by 2025, liberalize the energy sector to attract IPPs, improve competitiveness, and reduce costs. These objectives a specified in the Letter of Energy Sector Development Policy (LPSDE). The public sector is crucial to mobilize large investments in the renewable sector in sub-Saharan Africa and, in particular, to attract private financing [41], which is also evident in Senegal. However, in her study on the electricity sector reforms in Senegal, van den Bold [10] points out the difficulties that arise for the state from this role. The reforms implemented by the state in order to mobilize private capital, which is being channeled into utility-scaled RE IPPs, increasingly reduce the state's control of the electricity sector and its role as a key actor.

The reforms of the energy sector, especially in the electricity sector, have led to a number of non-state and hybrid actors – international donors, development finance institutions and private investors – which are actively influencing and shaping the transition. Among these are the French Development Agency (AfD) and the French Proparco, GIZ and the German Development Bank (KfW), and the United States Agency for International Development (US AID). Engaged in financing are also the World Bank Group, the European Investment Bank, and the African Development Bank etc., all of which are actively working in the sector to make possible large investments, mainly from Global North countries. Together, these actors realize IPPs that are a combination of public and private investors, with complex structures, often a mix of private funds and public debt [10,42]. Frequent changes in international shareholdings are common [43] with interests oriented toward short-term financial gains and rent-seeking, without relevance to the long-term success and sustainability of the company [44].

Here we see established and strong institutions serving in the role of path advocates. Through loans, grants and technical support, they bring together the interests of private investors and help reshape the institutional environments to support increased use of renewable energies. One of the experts calls this process a "policy dialogue" and explains how institutional clout can sometimes help to overcome the challenges of private investors:

> "*When we have a project in mind and we want to push it to the finishing line (…) we can use our influence and our relationships to get around [the limitations] and overcome the [challenges] of our clients.*"
>
> (Expert 16)

The Senegalese actors engaged in the transition include the Ministry of Petrol and Energy, the national agencies and Senelec, yet other national actors seem sidelined, though one might have expected the country's universities at least to act as knowledge carriers and information brokers. But as Expert 12, a well established senior scientist in RE, reveals, scientists have not been included in presidential energy meetings. Not only scientists, but also local providers of renewable energy technology seem sidelined in the transition process.

Networks and associations do exist, but their actual influence is not evident, nor is the achievement of their goals. Little information beyond general descriptions of the organizations was publically available for this article. In 2015, the Business Council of Renewable Energies of Senegal (COPERES - Conseil Patronal des Energies Renouvelables du Sénégal) was founded [45,46] and in 2019/2020, the Association of Renewable Energy Professions (REPER - Réseau des Professionnels des EnR du Sénégal), was established to bring together private firms active in the renewable energy business (Expert 17, [47]). The aforementioned senior scientist sees these networks as still developing, and thus their ability to influence current policy-making is limited.

> "*What we really need in this country are key players who are able to influence public policy. (…) That is to say strong conjunctions of civil society organizations, NGOs, who are there and capable of lobbying (…) giving inputs and ideas. (…) Policies in general are decided in ministerial cabinets. So it's the minister, his office, and his technicians who decide.*"
>
> (Expert 12)

Beyond established institutional actors and emerging networks and associations, entrepreneurs also serve as actors in the RE sector. They act as institutional and innovative change agents, trying to influence the government to make further commitments to renewable energy and to experiment with new technologies and techniques, some of which must be acquired abroad. Finally, while all companies in Senegal face high energy prices and all businesses suffer from the lack of reliable power, it seems they have no role as actors in the current energy transition.

4.3. Institutional environments: fuzzy arrangements and energy strategies

As pointed out in Section 4.2, the reform steps taken so far in the energy sector have been made largely through the participation of strong transnational institutions. All the experts interviewed indicated that the institutional arrangements that evolved through the reform process are followed with caution, especially with regard to the reforms of the electricity sector. This becomes apparent in three main respects.

First, the concept of using private-sector Independent Power Producers (IPPs) for power generation is questioned. In 2018, Senelec's share amounted to 52 % of total capacity, followed by 39 % from IPPs, with 9 % imported [48]. The electricity generated by the IPPs is sold to Senelec via power purchase agreements (PPA). However, these PPAs are based on long-term contracts lasting 20–30 years raising questions about the sustainability of such agreements:

> "*It is true that the authorities are doing everything they can to get electricity, but at a very high cost. (…) But, electricity generation is not profitable, and in 10 to 15 years we might have so much debt that we won't be able to pay it (…). We are going into debt to get electricity.*"
>
> (Expert 2)

Second, the complexity inherent in the energy sector is worsened by a nontransparent governmental strategy. Several stakeholders expressed concern in the interviews about access to the government's energy strategy, or even questioned the existence of a holistic policy vision. To one interviewee, the "*Senegalese are not very clear about their goals and needs*" (Expert 1). This lack of vision impacts engagement with international actors, which means that those in control of the financing are also the ones who set the conditions for the institutional and policy framework needed for their goals [10]:

> "*We don't have our own plan and then it's also about interests. We are doing this [RE] because donors or foreign states are developing various projects. We ourselves have little visibility, (…) which doesn't allow us to take a step back before we set out. Moreover, it is a race against time because we have to develop. Who will blame the government for not stepping on the brakes and saying wait and see. (…). But for me, the origin of the whole [problem] is planning. We should actually plan what we want, regardless of which government is in power. We plan, we decide what we want to do, we decide how we want to do it, and then we say okay now they [international actors] can come and help us.*"
>
> (Expert 8)

Third, policy implementation needs improvement. While the experts acknowledge the legal regulations already set in place for reforms of the sector, they also see strategic gaps that impede the actual process. Or, as one expert says: "*Although there has been a law for over five years that allows anyone to sell electricity, (…), no one knows how to do it*". (Expert 17). Such lack of clarity about the rights of private actors or how the sale of energy is regulated can lead to tensions in the transition processes [49] and also hinder them, as national utilities such as Senelec in the Senegalese case, lose their monopoly control over the supply side of energy [43]. Some experts (6, 12) question the implementation strength of state agencies and their performance, as well as policy outcomes.

Purportedly, there is no monitoring of the authorities and the policy frameworks. Instead, the government continues to push ahead with reforms without regard for the effectiveness of measures already taken or, if necessary, the need for policy adjustments.

One expert offers this impression of Senegalese energy policy and implementation:

> "*I think that the policies are not bad because they are generally developed by experts in the sector with a fair amount of consensus. (…) Often the implementation can be more or less complicated, depending on whether we go in the direction that suits the state of Senegal or not. The decision makers are always politicians, who often have to deal with clientelism. They don't always make the right decisions. Maybe that's the case in all countries, there's always a bit of clientelism in the decisions they make. But, sometimes it is necessary to have the courage to hurt some a little bit in order to correct and realign things. In my opinion, the leadership of the energy sector is still weak because (…) outside the ministry there is nothing and nobody. What I think is missing is, for example, an extremely strong energy directorate with all kinds of competencies that is really the strategic element of decision making for the direction of the sector. That can really initiate the policies, make the necessary orientations, make the necessary studies, and present these views to the politicians for approval.*"
>
> (Expert 4)

4.4. Market construction: from large scale projects to rural electrification

The findings reported in Sections 4.2 and 4.3 make evident power asymmetries in the energy market. The expert pool reports that a market for international large-scale projects has indeed developed for wind and solar parks, but it is stimulated and coordinated predominantly by international actors. They, not Senegalese, take the key roles of providing policy and technical advice, financing, de-risking projects via management and mitigation of risks, constructing and operating RE projects.

The active players have created coordinated structures as an enabling environment for their business interests. Monthly meetings of the TFP group[2] serve to exchange information on the development processes of projects and future intentions. "*We have all the parties including occasionally the MCC [The Millennium Challenge Corporation] will come and gives us a presentation as to what they're doing. We get members of the Ministry of Energy, we get members of the Ministry of Finance*." (Expert 13). This leads to commitments of the Senegalese government, such as the exemption of RE technologies from import taxes and duties, measures that increase the attractiveness of Senegal for investors: "*And if they [the Senegalese government] don't [offer these exemptions] it is not feasible economically and financially to move ahead with the project*". (Expert 13).

Another interviewee states that the purchase of the electricity produced by IPPs is not a problem. Senelec buys the electricity through PPAs, and "*we [institution of the interviewee] force the state of Senegal to give a guarantee to cover the risk*" (Expert 15). These large scale RE IPPs are perceived positively insofar as they increase the share of renewables in the energy mix and help to stabilize the underserved electricity market. But they do little to provide participation opportunities for Senegalese companies. Moreover, financing asymmetries work against local companies, impeding their ability to participate in the PPA market. A development also observed by Baker in South Africa, where the market was supposed to be aligned with the national interest, but smaller national players could not compete with global players [44]. One interviewee explains these inequalities in competition for funding for Senegalese projects as follows:

> "*So for a renewable energy project, it's important to invest capital. A company here that doesn't have access to 20 million euros, or that has access to an interest rate of 10% will lose out compared to a company in the United States, Germany, France, or elsewhere that is able to get 20 million euros at an interest rate of 1%.*"
>
> (Expert 8)

Another interviewee explains how large-scale projects "killed" the local industry:

> "*Scaling Solar*[3] *convinced the Senegalese government that they could sell kilowatt-hours at a price that no one could produce. And the state of Senegal has set the purchase price for the kilowatt-hour at the price offered by Scaling Solar. This means that I cannot sell at my cost-covering price. (…). Because they [Scaling Solar] have access to public funds without any consequences. (…) Those who come with the money are the ones who will carry out the projects. (…) That's what's going on here. That's why I said it killed the industry. (…) A policy has to be win-win. Today, projects like Scaling Solar are only a benefit to actors from the Global North. We consume and you produce. That's the pattern we've always had.*"
>
> (Expert 4)

Some experts (4, 7, 8) point to the need for new measures to regulate the implementation of large-scale RE projects. They contend the government should ensure that a portion of the market is reserved for local Senegalese companies to facilitate their entry into the market. Such an approach has been taken in South Africa, for example, where the renewable energy procurement program was designed so that 30 % of the evaluation of project bids is in favor of local benefits such as "job creation, participation of historically disadvantaged people, protection of local content, rural development, community ownership and skills development" [44]. However, the success of taking these factors into account and actually implementing such sustainable development approaches is seen critically. South Africa is also seeing an increase in foreign investors with their short-term financial goals, which are affecting local content [44].

A different picture emerges when we turn from large-scale RE projects to mini-grids and stand-alone systems. Here opportunities for local companies can be found in feed-in models, in the sale of surplus electricity to Senelec, and in the ongoing electrification process in rural areas. To open the market for RE projects, however, further government involvement is still considered necessary. One interviewee cites the example of European countries.

> "*They have developed the technology, the know-how and the construction techniques. A banking environment was set up to support and validate bankable projects and a whole ecosystem was developed and set up. Today, in countries like ours, the ecosystem is limited to the State.*"
>
> (Expert 4)

However, the same interviewee questions whether a critical mass of entrepreneurs and consumers exists for the development of a national renewable market. Another interviewee emphasizes the limited entrepreneurial capabilities of the Senegalese in the market: "*Actually the market is here. The problem is how to capture that market. And most of the companies that are there, they don't have that reflex*" (Expert 5). Assuming that this market could emerge and surplus energy be fed into the grid in the sense of prosumerism, then grid management capabilities surface:

[2] The group brings together all technical and financial bilateral and multilateral partners working in Senegal. The purpose of the TFP is to consult with each other, harmonize interventions and adopt common positions in the dialogue with the government [50]. The energy sector is organized as a thematic group.

[3] Scaling Solar was launched in 2015 by the World Bank Group to unlock private investment in the emerging market of solar power. The aim is to bring "together a suite of World Bank Group services under a single engagement aimed at creating viable markets for solar power in each client country." [51].

"*We need to be able to control the network. We need metering stations everywhere. (…) There are small producers in the network that we cannot absorb. So this is a technical problem that needs to be resolved.*"

(Expert 8)

In short, it is clear that universal electricity access remains a challenge for Senegal. After years of slow progress in providing energy access to rural areas, in 2015, the country was divided into ten concession zones as part of the National Rural Electrification Programme (PNER Programme National d'Électrification Rurale), intending to attract foreign investors through a tendering process [52]. However only six concessions could be awarded. Senelec ultimately has had to accept the remaining four. A principal reason for limited concessionaire interest is that tendered contracts require compliance to high quality standards, but prohibit recovery of associated costs from customers. Additionally, the planning basis on which the concessions were developed are considered unrealistic. The forecasts of consumption are actually lower than predicted when the contracts were issued, which has led to tension between concessionaires and customers (Expert 10).

The concessionaires are ready to work with IPPs to fulfill the concessions (Expert 10), so there are opportunities for Senegalese companies to participate in rural electrification. A Local Rural Electrification Initiative (ERIL Rurale d'Initiative Locale) has been established to build mini-grids for village-level projects in areas that do not fall into a concession zone. Within the framework of the ERIL program, tenders are invited for the construction of mini-grids [52].

The conventional energy market is also reforming in Senegal due to the recent discovery of oil and gas reserves. The importance of these discoveries is reflected in the renaming of the former Ministry of Energy and the Development of Renewable Energy (MEDER) to now the Ministry of Petroleum and Energy (MPE). Including gas-to-power and especially gas-to industry solutions into the national energy strategies would not only help further diversify energy supplies, but also lead to the maximum benefit of gas for the domestic market [53]. Senegal's president Macky Sall points to the role that natural gas found in Africa can play in the development of industry, in Senegal and throughout Africa [54]. He also voiced criticism at COP 26 in Glasgow that many countries, particularly the EU and the US have decided to stop investing in undeveloped fossil fuels, not associated with carbon capture technology, arguing that these decisions would affect the right to development of African countries and would further increase climate injustices [55].

The interviewees have a mix of feelings toward these developments. On the one hand, they hope for participation by Senegalese companies, as the government seems to want to ensure that local actors get their piece of the pie along the value-chain:

"*Everyone knows that it is the multinationals that are the leaders in the exploration and production of oil in the upstream. But nevertheless, there is also what we call the petroleum business and there are many Senegalese companies that can position themselves in that.*"

(Expert 7)

But given the barriers encountered by local companies to participation in the RE sector, one has to question whether the project structures for the extraction and use of the fossil resources will allow local companies such access.

On the other hand, there is concern that this new focus on domestic fossil fuels will block the further transition of the energy system to renewables (Expert 5). Another interviewee sees a tendency for gas to be pushed by the government, and renewables projects to take lower priority in energy policy (Expert 13). RE projects will nevertheless be implemented if they are attractive. Yet another interviewee does not see any contradictions between fossils and renewables:

"*While the government actually was making plans to develop renewable or sustainable energy, the government was already investing and had the information on the possibility of discovering all these resources. But I've never seen a scenario whereby renewable energy would be downgraded because of discovering gas or oil.*"

(Expert 16)

4.5. Mechanisms of path creation: multiple emerging paths

From the perspectives offered by Sections 4.1 through 4.4, we can identify three parallel emerging paths in the Senegalese energy sector. The first arises through the dominance of large-scale projects under the influence of transnational key actors who are actively engaged in creating an enabling an environment for their own goals along the whole value chain. This exemplifies the concept of *path transplantation*. The knowledge of the international actors is formed and aggregated outside the realm of Senegalese actors; that knowledge base is then translated to the Senegalese context and adapted for project execution. Our experts report that the knowledge remains with the transnational actors who bring together finance, technologies and companies from the Global North, via their own structures. Still, these large scale projects realized through path transplantation are expected to contribute substantially to meeting the energy goals set by the Senegalese government – the share of renewable energy in the electricity mix to reach 20 % by 2020 and 23 % by 2030 [56]. The share of renewables in 2019 remained at 15 % [32], but as soon as the Taïba Ndiaye wind park is connected to the grid in the mid 2020s, the share will immediately jump to reach already the target level set for 2030.

The second emerging path in the Senegalese energy sector arises from the mini-grids and stand-alone solutions, markets not yet penetrated by foreign investors. These give local companies an opportunity to shape the market according to their capabilities, the needs of the population, and local conditions. Here, the operative concept is *indigenous path creation*, which can occur independently of the demands and activities of large-scale projects. Both indigenous and endogenous, this process has not yet found much support from the Senegalese government, and so depends principally on the ability of Senegalese RE companies to capture these markets.

The third emerging path is in the fossil energy sector, where *path upgrading* is the operative concept. The use of in-country oil and gas resources drives the reconfiguration of this market. The actors can bundle the existing competences in this field to shift toward self-sufficiency. Since the Senegalese government intends to include local companies along the entire value chain, new knowledge will be generated. If this proves true, it will mean the engagement of Senegalese knowledge brokers, principally universities and vocational colleges, in innovating technologies. This engagement will deliver numerous benefits to domestic companies from service and maintenance to technical infrastructure, resource exploitation, and energy generation and distribution.

5. Discussion

This study examined the transition dynamics at work in the energy sector in Senegal, seeking through qualitative interviews with Senegalese energy experts to identify and characterize newly emerging energy paths in what is taken as a representative country of sub-Saharan Africa (SSA). Through MacKinnon et al.'s [5] framework of regional path creation, three emerging paths could be identified, each evolving in a different sector of the energy system, at its own pace, and on its own scale. I discuss these dynamics from two perspectives offered by the framework: the role of institutions both as enabler for the emergence of new paths and as legitimator for their validity. Finally, the fit and limitations of the framework for economies in the Global South are addressed.

5.1. Institutions and their role as path enabler

The importance of understanding the role of institutions in new path creation processes has been recognized in recent EEG literature [6,7,57]. To extend this understanding to new paths emerging in Senegal, let us take a closer look at how the institutions and paths have evolved together and the institutional role in the path building dynamics. As highlighted by Gong and Hassink [6], institutions should be understood in two ways: how they shape the development of paths; and how they are influenced by the collective and individual actors in the field.

The three emerging paths in Senegal evolve in different institutional contexts. As the findings of Section 4.2 show, many powerful transnational actors are engaged in the field of large-scale RE projects, and these actors strongly influence Senegal's RE trajectories and their institutions. These actors from firms, agencies and finance institutions are proactively driving liberalization of the electricity market to enable investments in large-scale projects, leading to new regulations in Senegal (see Fig. 2). This form of international leadership incorporates all the forms of MacKinnon et al.'s [5] types of agency: innovative entrepreneurship by actors who see the market opportunities for their technologies, institutional entrepreneurship by actors who gradually transform established environments to prepare them for a new market, and path advocacy by actors who can influence decision-making processes. Although these large-scale projects bring new knowledge into Senegal, on which development of the RE sector rests, the dependency on foreign actors and direct investments introduces the risk of a lock-in to the transnational RE networks [58].

In contrast to this prime example of agency in the path transplantation processes of large-scale RE projects, in the indigenous path creation processes by small-scale RE providers, influencing agents are largely missing. Whereas the international actors rely on knowledge acquired over years of experience with RE technologies, the Senegalese actors still depend on receiving this knowledge from outside the region. It must then be adapted to intra-regional knowledge-bases. Our interviews with Senegalese RE providers uncovered their frustration with attempts to enter the large-scale path; this was discussed more than small-scale project opportunities. Although these entrepreneurs see opportunity along the emerging indigenous path, they lack the crucial support of institutional entrepreneurs and path advocates in the path creation process. Nor has local academia filled the role of knowledge broker to disseminate expertise that could contribute to indigenous path creation. The mobilization of intra and extra-regional knowledge bases via formal and informal linkages as suggested by Chen and Hassink [24] is hardly identifiable. Rather, the emerging networks are still seen as too weak to be effective lobbyists.

Indigenous path creation could find critical support from formal state institutions in Senegal. These could actively shape the emerging paths by, for example, helping to reshape the banking sector to achieve better access to finance, or designing tenders so that domestic companies can participate, a recommendation also made by our interviewees. They were not, however, able to say whether or not the absence of such support for domestic companies is a deliberate decision by policy makers and regulators in Senegal.

The third emerging path – path upgrading – seems to have had its trajectories mapped out since the discovery of the oil and gas fields in Senegal. This path, however, is expected to phase out, which is also reflected in political decisions, such as that of the European Investment Bank to no longer invest in fossil fuel projects [59]. As this paper did not focus on Senegalese conventional energy companies, no in-depth evaluation on the influence of these companies and their lobbying on this path upgrading can be made. The interviewees of this study could not provide insights into the dynamics of this path; rather, relevant processes seem to be decided behind closed doors. Due to this lack of transparency, no further insights could be gained through secondary resources or the exchange with Senegalese colleagues.

5.2. Differentiated legitimation for different paths

How a path acquires legitimation in a socioeconomic context is another promising approach to understanding the emergence of new technologies and industries [5,60,61]. New paths need institutions and actors to pave the way. Narratives are needed to justify the normative, social, and regulatory legitimation of these new paths [60]. In Senegal, legitimation processes are particularly interesting, as all three emerging paths differ in their legitimation. As MacKinnon et al. [61] argue, these processes underlie temporality and differ in space, which becomes evident in Senegal.

The first case, *path transplantation* via large-scale projects, is locally legitimated through international credibility. Strategic coupling of the available natural resources with technologies considered as environmentally friendly in the world lead to the development of this RE path. The global emphasis on the importance of renewables for climate change, Senegal's emission reduction targets, and the need for energy security provide legitimation for the massive involvement of foreign actors in the planning, financing, realization, and operation of large-scale RE projects. Within the legitimation of this path, we can detect "shared cultural beliefs, values and norms (…) of actors that support a new technology or innovation, incorporating technology developers, lobby groups, environmental organizations, policy-makers and politicians, and potential end users" [61]. Even though some interviewees question the implementation of large-scale projects, none question their necessity for the state's energy future, even if they bring in new financial energy dependencies. These large-scale projects promise not only the greening of the country's energy mix, but also a future with a secure electricity supply for any consumer connected to the grid.

The second case identified in this study, *indigenous path creation* via mini-grids and stand-alone solutions, supposedly has strong normative legitimation: energy access for all. This legitimation is clearly reflected at the international level in SDG 7, but sufficient legitimation at the national level in Senegal does not seem to have developed, particularly compared to the large-scale RE projects. Since the approach taken so far for promoting rural electrification through the award of concessions has not produced the desired results, attempts are being made to accelerate electrification through small-scale PV projects. The legitimation of the original approach lay in the reduced costs for rural electrification on the Senegalese side, costs shifted to the concessionaires [52]. The legitimation of the small-scale solar projects seems to lie in their perceived role as stopgaps. So far, no legitimation for these projects has occurred at the national level, although given their adaptability to local conditions, their scalability to individual customer needs, and their operation by Senegalese companies, these projects should be seen as more than that.

For the indigenous path to evolve, an articulation of visions for further development is needed, one that sadly could not be found in this research. Nor could an assemblage of actors be identified who are engaged in valorizing regional or extra-regional assets supportive for this path. Despite this current lack of legitimation, some interviewees thought initiatives could be seen starting at the regional level to transform the role of PV projects as stopgaps into an opportunity for new path creation, e.g. with diagnostics of potentials and initial contacts with local leaders. It remains to be seen whether Senegalese actors at the regional level – in particular political representatives and entrepreneurs offering solar solutions – will be able to establish the legitimation of this path and so forge a way forward toward universal energy access in Senegal.

The third emerging path, *upgrading* the fossil sector, finds legitimation at the national level through reduced energy costs and increased energy security, two factors mentioned by all the interviewees. A further legitimation process affects this path, namely, the integration of national companies in the value chain. This effect outweighs the international vision of decarbonizing the energy sector that legitimated the implementation of large-scale RE projects independent of the involvement by Senegalese companies. However, the potential of Senegalese

entrepreneurs to develop the fossil fuel value chain seems to be regarded differently at the national level than their potential to engage in RE path creation processes.

5.3. Theoretical implications

In this article the framework of MacKinnon et al. was used as conceptual approach for examining the processes shaping the Senegalese energy transitions and has proven to be very useful of uncovering the most important influencing factors in the five key elements of regional and extraregional assets, actors, institutional environments, market construction and mechanisms of path creation.

The reader should keep in mind that this framework was developed in the context of developed economies, why caution must be paid when applying it to a Global South context. Based on the experiences and results of this study, influencing parameters can be derived that are further relevant for an application in the Global South in the energy context and contribute to an extension of the framework. I would like to address two important aspects in particular. First, the liberalization of the energy sectors in countries of sub-Saharan Africa follows the familiar pattern of neoliberalism, whereby foreign capital and key players, invest in the countries, determine to a large extend the regulations and are replacing public services in the energy sector [62]. In the framework, this overarching role of international finance and its intertwined structures with powerful stakeholders groups is jammed between regional and extraregional assets, actors and institutional environments, as outlined in my research. This falls short in the realm of Global South economies. I therefore argue that insights from the growing number of publications on the financing mechanisms for renewable energies in Global South countries [10,43,44,49,63] should be thoroughly reviewed and taken into account as another key element when applied to contexts similar to those in this study.

Second, the question of justice in transition processes is becoming an integral part of social science research agendas [19,20,64–66]. Although energy justice was not in the scope of this paper, the findings show injustices in all three dimensions – distributional, procedural and recognition – which is evident in all three emerging paths. The question of (in) justice, however, plays a role in all path creation processes, as injustices are never eliminated, but are rather (re-) distributed through the emergence of new paths. Thereby, power asymmetries are a crucial factor in energy path creation as they influence decisions on energy sources, issues of participation, ownership and affordability [67]. So far "unequal power relations and struggles between actors" [5, p. 125] are limited to shaping the market creation in MacKinnon et al.'s framework. But, the integration of justice as another fixed key element in the framework can contribute significantly to the understanding of path-finding processes, as it integrates a social dimension, that is currently missing.

6. Conclusions

Prompted by recent papers in evolutionary economic geography (EEG) showing how path creation processes can contribute to understanding sustainability transitions [6–9,24], this study sought to identify new sustainable development paths emerging in Senegal that go beyond the greening of the energy mix. This meant investigating the energy sector as a whole rather than focusing on a single dimension of its operation. This was possible because the framework of MacKinnon et al. [5] provides a balanced analytical approach that does not privilege any of the key sector elements influencing path creation processes, but rather embeds them in multiscale processes. This is crucial for application to a country of the global South.

Applying this framework to an explorative interview study with 17 experts of the Senegalese energy sector, I was able to determine three parallel emerging energy paths in Senegal. First, mechanisms of *path transplantation* paved the way for large-scale RE projects, which result in a greening of the energy mix. Second, there are indications that *indigenous path creation* is emerging in the realm of mini-grids and stand-alone solutions for electrification, which could enable the development of a pure renewable energy supply beyond the grid. Third, there is evidence for *path upgrading* with regard to the fossil energy sector. Further special focus was put on the role of institutions in the creation of new paths and the underlying legitimation of them. I argue that the three paths differ greatly in the influence exerted on institutions by actors, but also in the active engagement of institutions to shape and support the processes. Moreover, they differ fundamentally in their legitimation.

While this article has shown how current dynamics in Senegal shape path creation processes, it also demonstrates that such an integrative approach has its limitations. And though these findings may serve mainly to characterize the paths currently emerging in Senegal, they also highlight dominant structures along each path, as well as future opportunities to address Senegal's energy challenges. These findings contribute not only to the scientific debate on the role of path creation in energy transitions, but also to the needs of practitioners in development agencies, national and regional institutions, NGOs and private firms involved in shaping the Senegalese energy system.

Considering the findings already obtained in this study, several research avenues seem promising for further investigation. First, inter-path dynamics in regional contexts, as explored by Frangenheim et al. [68], may be relevant in the Senegalese case. Following their argument that paths in different markets with same scarce assets are strongly linked but are also characterized by a competitive relationship, it would be interesting to find out which linkages exist between the two RE paths and whether synergies could be actively leveraged by the authorities. It would also be interesting to investigate whether the strong involvement of international actors has exhausted the capacities of the national authorities, further increasing the power asymmetry already existing in financial resources and knowledge.

Investigating energy transitions in developing economies always raises questions about value capture, as growing markets present opportunities for domestic companies [69]. Since this is also one of the most pressing issues raised by the interviewees with respect to the RE sector, more attention should be paid to these questions. For example, what role do local companies play in current financing programs for RE projects at national and international levels? Questions about alternative ways of organizing and managing energy systems could be explored, such as the potential of energy cooperatives as a business opportunity for RE providers and citizens, given the fact that surplus energy can be monetized.

Data availability

The authors do not have permission to share data.

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Declaration of competing interest

The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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