DIFFUSION OF RENEWABLE ENERGY TECHNOLOGIES (RET) RESEARCH: PAST, PRESENT AND FUTURE

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ABSTRACT:

Many RET projects fail to achieve continuity, replication, commercialization and sustainable markets even when pilot projects demonstrate high potential and great interest from the potential users. Many RET diffusion studies try to explain the dynamics of the diffusion process and provide answers as to why successful demonstration and high consumer interest do not metamorphose into viable and sustainable RET commercialization.

A tendency to focus on specific technologies in precise geographical locations creates a wide variation in RET diffusion studies (Nagamatsu et al, 2006). However, deeper analysis of the variations reveals many common issues in methodology, findings, conclusions and recommendations that can be generalised to RET diffusion.

By reviewing published papers on diffusion of RET published between before 2013, this paper attempts to identify general patterns in RET diffusion studies, which can be used worldwide in the process of increasing the uptake of renewable energy technologies by trying to map out in a quite comprehensive manner what has been done and studied in this field over the last two decades in a more general fashion.

***Keywords**: Renewable energy Technologies, Diffusion of innovation, Energy Technology Systems, Barriers and incentives*

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Introduction

Efforts to promote Renewable energy technologies (RET), and the increasing acceptance, adoption, technological maturity and efficiency of renewable energy sources has not resulted in the expected diffusion of RET (Theodorou, Florides & Tassou, 2010). Few RET projects are able to capture sustainable markets, and they generally lag behind other technologies in terms of commercialization (Balachandra et al, 2008). Research interest in diffusion of RET has been growing over the last few years to try and address this problem; but diffusion is still a neglected area among energy researchers.

D'Agostino et al (2008) conducted a content analysis on 2,502 papers written by 5,318 authors published between 1999 and 2008 in three leading energy studies journals. They did not identified diffusion as one of the thematic areas whose further investigation could enhance the energy studies field and increase their policy-relevance. By 2003, only 280 out of a total of 5,200 publications in the field of diffusion of innovations, were related to energy; a clear indication of the low priority of diffusion in energy studies.

However, a better understanding of the systemic processes by which RET diffusion occurs is useful, both conceptually and to inform policymaking. This paper provide an overview of existing literature on RET diffusion, with a view that understanding diffusion will generate and support new and effective ways of institutionalizing RETs. The first part of this paper examines contextual factors influencing the emergence and development of RET. The second section will focus on the definition of diffusion of RETs. This will be followed by a discussion of key issues emerging around diffusion of RET in the literature.

Background and Context

RET diffusion studies, which originate from broader diffusion of innovation studies tracing their origin in the USA in the 1930s, identify four main elements of diffusion: the innovation, the communication channel, time, and the social system in which the innovation occurs (Rogers, 2003). These elements inform the most common questions in diffusion research that include: how earlier adopters defer from later adopters, how innovation characteristics affect adoption, and the S-shaped diffusion curve (Jacobsson & Johnson, 2000).

Diffusion research has generated findings with regards to: adopter categories and their characteristics (Sidiras & Kouhios, 2004) and the S-shaped adopter categories; perceived attributes of innovations (Bhatia, 1990); effects of opinion leaders, innovation characteristics, spatial distance, networks and different communication channels on adoption(Bhatia, 1990; Dennis et al, 1990); and the stages of the innovation process. Diffusion studies also aimed to predict the rate of adoption of new innovations. Such findings have motivated academic, policy-making and private sector interest; helping to promote global appeal for diffusion of innovation studies in many diverse fields.

Energy scholars only began to engage in diffusion studies in the 1970s when faced with a looming energy crisis **(**Fouquet, 2010). Today, renewed interest in diffusion of RET is fanned by the realization the growing use of fossil fuels is damaging the environment (Jacobsson & Lauber, 2006). However, RET diffusion research has been criticised for its pro-innovation bias, lack of interest in innovation rejections and discontinuance, failure to investigate "why" questions that could explain motivations for innovation adoptions, tendency to investigate the individual rather than the broader system, and failure to see the innovations in the eyes of the targeted populations (Jacobsson & Johnson, 2000; Kumar et al, 2003; Madlener & Vögtli, 2008). RET diffusion is also typified by a craving for government support as a prerequisite for adoption; and emphasis of the institutional context (McEachern & Hanson, 2008) at the expense of the individual. Diffusion of RET, being a change-oriented activity, evolves within a complex framework of political, economic and social changes occurring at the global, national and local levels.

Defining the Diffusion of RET

Technology diffusion is casually defined as the increasing acceptance and adoption of a new technology. However, academic definitional debates tend to move beyond acceptance and adoption, although these concepts are often used to operationalize the diffusion variable. Rogers (2003) defines diffusion as a "process by which an innovation is communicated through certain channels over a period of time among the members of a social system"; putting more emphasis on the communication, time and the characteristics of the social system. Drinkwaard et al (2010) contend that diffusion is about people's motivation to keep tackling barriers that impede the functioning of their system through "local de-bottlenecking activities", emphasising the notion of technologies evolving through continuous adjustments to the point where they truly meet people's needs.

However, Uphoff et al (1998) argue that diffusion of RET will only be assumed to occur when recipient communities mobilise resources to promote self-reliance and self-sufficiency with regard to RET; leading to increased technology adoption and utilization, diversified applications to other problem areas, and enhanced local capabilities and problem-solving strategies arising from learning and better control over their situations and futures. When people disadvantaged by the conventional energy system are enabled to share in the decisions, implementation and benefits of the emerging RET system and motivated to express their views, mobilise their own resources and enforce their demands on the emerging energy systems (Korten, 1980).

Nature of RET Diffusion

Many RET deployment programmes concentrate on methods and processes of pushing technologies instead of developing structures so that markets develop in tandem with local social dynamics and capabilities of existing actors (Srinivasan, 2005). Societies and their organizations differ, and therefore different approaches should be employed in the deployment processes (Taylor & Bogach 1997). Different approaches between various types of stakeholders helps to clarify barriers to adoption, and to exploit other approaches; because people are always rooted in their past behaviours (Dijkema et al, 2006). By interacting with targeted communities and ensuring local community ownership of the RET, deployment causes little disruption of the social structure; building know-how within the local community and encouraging new learning (Shum & Watanabe, 2007).

New institutions emerge from existing institutions through a process of adaptation (Radulovic, 2005). By trying to import foreign institutional frameworks to support the deployment of RET, vendors tend to block the creation of sustainable markets even for positively piloted projects (Balachandra et al, 2008). Radulovic (2005) questions the over-emphasis of a technology-push approach that is premised on finding ways of diffusing RET. He recommends a technology-pull approach that focuses on how best community needs can be met using available RETs. Taylor (2008) also contrasts between technology-push strategies that fund the supply of new knowledge; and demand-pull strategies that create demand for new technologies.

Demonstration projects are often used to overcome doubts and uncertainties associated with new RETs. However, what they reveal is usually of more interest to RET advocates and policy makers and not those of the target community (Velayudhan, 2003). Demonstrations aimed at discovering suitable market opportunities are less successful in achieving diffusion than projects that target a particular application and concentrate resources on it (Brown & Hendry, 2009).

To boost RET diffusion, several approaches have been suggested including: upgrading 'potential adopters' to 'techno-entrepreneurs' by integrating the processes of market transformation and entrepreneurship development (Balachandra et al, 2008); for use of Strategic Niche Markets (SNM) where new technologies are provisionally protected from market forces (Drinkwaard et al, 2010); using the innovation value-added chain (IVC) framework to evaluate the impact of a RET on the various stakeholders and players in the production and diffusion processes (Shum & Watanabe, 2007).

The Dynamics of RET Diffusion

In trying to explain the diffusion of RET, Dieperink et al (2004) try to integrate different partial explanations into one conceptual framework by combining secondary analysis of earlier studies; focusing on the techno-economic characteristics of the RET and the decision-making process of the potential adaptors affected by their characteristics and the networks in which they operate. Rehman et al (2010) use the Strategic Niche Management (SNM) framework to explore the development of value chains resulting from socio-technical transitions to RET. They recommend RET customization and innovative financing to cater for the needs of end users.

Stephens et al (2008) propose a Socio-Political Evaluation of Energy Deployment, (SPEED), framework "to integrate the analysis of regulatory, legal, political, economic, and social factors" that influence RET deployment decisions, helping to show the interconnected components of energy systems and the socio-political influences on energy technology deployment. Wang et al. (2009) use Multi-criteria decision analysis (MCDA) to explore decision making processes at various stages in the dissemination and uptake of RET based on technical, economic, environmental and social criteria.

West et al, (2010) use a cultural theory framework to explain how individuals' world views inform opinions and behaviour in relation to RET. Using econometric techniques, Masini and Menichetti (2010) examine structural and behavioural factors affecting RET investors' decisions and the relationship between RET investments and portfolio performance. Nagamatsu et al.'s (2006) framework reveals strong interaction with the institutional systems across which RETs diffuse in order to allow for continuous development of applications during the diffusion process.

Shum & Watanabe (2007) use the Innovation Value-Added framework to evaluate the impact of a new RET on the various stakeholders in the diffusion process. They recommend a deployment strategy that causes minimal disruption to the existing structures, boosts existing competences and expedites new learning.

Energy Technology Systems

Increased acceptance and adoption of RET is a necessary, but not a sufficient condition for diffusion (Mallet, 2007).Unless a complete transformation of the energy system is achieved, isolated cases of high adoptions in dispersed geographical areas may not result in diffusion. The RET System defers significantly from the conventional energy systems (Theocharis & Stamboulis, 2005) in which the existing-dominant energy technologies, the actors, rules, procedures and norms are all well-coordinated; forming one consistent system that is difficult to displace by the newer RETs (Drinkwaard et al, 2010). The existing energy system has to be transformed as a prerequisite for RET diffusion to occur (Masini & Menichetti, 2010). Transformation will however, be opposed by people with vested interests in the current energy system (Huang & Wu, 2004); implying that energy systems will only change very slowly, and in a very uncertain manner (Jacobsson & Johnson, 2000).

Huang & Wu (2004) propose a framework to examine energy systems based on the Technology Innovation System (TIS) perspective to examine the entire energy system so as to understand how different actors, networks, policies and functions phase out of the old system, while phasing into the emerging energy system. Using the TIS, they were able to analyse community networks and institutions; and the perceptions, competences and strategies of the vending firms. Using the same TIS, Suurs et al (2010) studied the dynamics of building a new energy system; concluding that systems are constructed over time, through cumulative causation in which system functions reinforce each other through repeated use in a recursive manner. Time enables emerging technologies to be refined gradually until they are able to compete with the conventional energy systems (Fouquet, 2010). The transition to fossil fuels was also a slow process driven by cheaper or better services innovations; and niche markets willing to pay more for these innovations.

Integrating supply- and demand-side perspectives, Theocharis and Stamboulis (2005), argue that policies for speeding RET diffusion should focus on systemic innovation processes. According to Dijkema et al (2006) three dimensions define the diffusion of new RET: the product, the entire socio-techno network of which a particular technology emerges; stakeholders' decision processes. Developing systems calls for building institutions to support RET markets to flourish through competition that maximizes efficiency (Nagamatsu et al, 2006). However, too much competition may compel vendors to sacrifice quality and reduce costs in order to be competitive (Radulovic (2005), eliminating expensive but better quality technologies. He recommends capturing the elite to override pre-existing institutions in addition to building institutions.

Barriers and Incentives to Diffusion

Major concerns in the discussion of RET diffusion, are the many barriers that RETs have to overcome before joining the mainstream; and the incentives provided to encourage the adoption process. Cooke et al (2007) observe huge variations in the importance of drivers and barriers to using RETs; and between RET dissemination projects. Lantz et al (2007) identify two types of incentives and barriers - those affecting the production of RET, and those affecting the utilization of RET. They include: lack of demand, availability, awareness, and lack of economic incentives (Garrett & Koontz, 2008); high capital and operating costs (Weis, Ilinca and Pinard, 2009); lack of information (Kounetas, et al, 2011; Drinkwaard et al (2010); systems focus on hydrocarbons, ignorance of the potential of RET markets, lack of funding for RET investment, and poor regulatory framework (Drinkwaard et al, 2010); credit risk (Martinot et al, 1993); technical performance of systems (Garret & Koonz, 2008); lack of component options and poor service levels (Thorne, 2008); costly and time consuming marketing campaigns (Diaz-Rainey & Ashton, 2008); forging sustainable and replicable business models (Dinica, 2006); poor assessment methods(Cooke et al, 2007); and poor regulatory models (Hekkert et al, 2007.

Moreover, networking, lesson-sharing and working links between RET businesses are very rare **(**Verbruggen et al, 2010). Lessons learned in one project are not passed on to new and similar projects; resulting in discontinuity in the accumulation of knowledge and making experiential learning difficult (Drinkwaard at al 2010). Peoples' current perceptions and actions are guided by established social structure formed around conventional energy technologies systems focusing on hydrocarbons (Drinkwaard et al, 2010), which are hard to change. These social structures prevent people from noticing potentially viable alternative to current structures; resulting in technological closure and lock-in that prevents RETs from breaking through. Most projects tend to over-emphasize financial consideration at the expense of qualitative issues in assessing RET projects (Cooke et al, 2007). However, Demand-side policies are needed to encourage diffusion and innovations (Loiter & Norberg-Bohm, 1997).

Verbruggen et al (2010) address the cost disadvantage of RET as a barrier to their dissemination. However, conventional accounting tends to ignore environmental and social costs; resulting in apparent cost advantages for the conventional energy options (Owen, 2002). Owen (2006) shows that damage costs resulting from combustion of fossil fuels, if internalized into the price of the resulting output of electricity, could lead to a number of renewable technologies being financially competitive with generation from coal plants.

Huacuz (2001) proposes six strategic elements to eliminate barriers to RET diffusion namely: enabling policy and regulatory frameworks; adequate and effective institutional and technical settings; ad hoc financing mechanisms; concerted action plans among government sectors; mechanisms to facilitate participation of private and social sectors; and effective coordination among national and international stakeholders.

Socio-Economic Considerations - Users and Social Acceptance

As concern for the low diffusion of RET especially in developing countries grows, there is increased interest in investigating the drivers of RET transfer and successful receptivity (Thorne, 2008). There is need to encourage user participation and exploitation of user-led innovations(Ornetzeder & Rohracher, 2006); by combining the technological and sociological outlook (García & Bartolomé, 2010) as a means of stepping up the deployment of RETs. Developing policies and projects through this inclusive approach reduces contradictions between the technology and the social perspectives; resulting in more successful diffusion (Stidham & Simon-Brown, 2010).

Incorporating the users in the initial phases of project organisation would allow for the development of productive and sustainable solutions (Monroy & Hernandez, 2005). However, because of the complexity often associated with new technologies, potential users of RET may be unable to express their demands to the vendors. By involving them and encouraging their participation "fragmented potential customers" can formulate and communicate their expectations in the long run (Jacobsson & Johnson, 2000). It is their ability to somehow communicate their expectation that will ultimately lead to acceptance.

RET diffusion studies often ignore the importance of social acceptance (Mallett, 2007), and technology diffusion models need to adequately reflect the effects of local cooperation on technology adoption. Social acceptance is most likely to be achieved when active participants from various sectors interact continuously throughout the diffusion process. Wüstenhagen et al (2007) identified three dimensions of social acceptance: socio-political, community and market acceptance. They use these dimensions of social acceptance to explain contradictions between high public support for RETs and the low RET diffusion actually achieved.

Acceptance has often been seen as a passive consent by the public (Sauter & Watson, 2007), although RET diffusion requires active acceptance in which users become part of the RET supply infrastructure. Acceptance may be expressed in various forms: attitudes, behaviour and investments. Different deployment models with varying degrees of vendor and user involvement will have a significant influence on the social acceptance of RET and therefore the market uptake of these technologies.

Socio-Economic Considerations - The Impact of Learning

Compared to conventional forms of energy, RETs provide a more active role for both users and vendors, inducing more active learning processes (Markard & Truffer, 2006). This is enhanced by "higher order learning" among various societal groups (Vergragt and Brown, 2007), through a multi-stakeholder visioning processes, scenario building, back-casting exercises, and small-scale socio-technical experiments. Most studies on the effect of learning on diffusion of RET tend to focus on Research and development efforts of the technology developer. However, Kwok and Watanabe (2006) call for more interest in the learning that takes place closer to the technology user, in order to understand the unique needs and application requirements of the new technology.

Szarka (2004) recommends societal engagement in RET deployment processes to foster policy learning and bridge gaps between economic, environmental and societal interests in designing RET policy. Technological learning is strongly related to the presence of international learning and R&D spillovers (Pettersson & Söderholm, 2009).

Kahouli-Brahmi (2009) analyses the effects of learning -by-doing, learning-by-searching and returns to scale; observing that dynamic economies from learning effects coupled with static economies from scale effects are responsible for the lock-in phenomena of the energy system.

Using the experience curve framework Kwok and Watanabe (2006) have demonstrated that learning takes place with cumulative installation of RET projects, and that learning effectiveness improves over time. User oriented system customization involves inter-projects learning, rather than volume-driven learning by doing; formalized as a dynamic economy of scope used to manage the local and downstream aspect of RET deployment (Kwok & Watanabe, 2006) .

The learning curve is a collection of many smaller learning curves constituting a series of discontinuous improvements of the technology (Weyant & Olavson, 2006; Ibenholt, 2002). Without the aggregate learning resulting from the smaller adjustments, the big learning cannot be achieved. Romijn et al (2010) recommend a focus on learning and capacity building achieved through experimentation, adaptation, participation, a flexible managerial approach and gradual organic expansion. The complexity of energy systems makes progress uncertain; and a trial and error approach involving experimentation and continuous interaction more appropriate (Ibenholt, 2002).

Technological learning enables new technologies, which are often relatively more expensive at the time of introduction, to become cheaper and replace inefficient technologies when production costs and market prices of new technologies, offering enhanced consumer satisfaction, decline (Weyant & Olavson, 2006). Using the experience curve approach, Weiss et al (2009) quantified potentials for price and cost reduction for renewable energy technologies, observing that technological learning is important for both energy demand and energy supply technologies. This might support the market diffusion of such new RETs. However, learning rates are time dependent and vary according to the system boundary chosen for analysis.

Role of Government Intervention and Support

Most researchers tend to hold the notion that a Supportive policy framework is a prerequisite for successful RET diffusion (Li 2008; Jacobsson & Lauber, 2006; Vergragt & Brown, 2007; Kobos et al, 2003) This support is necessary to remove barriers to adoption, build capacity, facilitate a wider energy debate, provide leadership and regulation (Martinot et al, 1993), and provide incentives for adoption (Martinot et al, 1993). Jacobsson & Lauber (2006) attribute the rapid spread of wind turbines and solar cells in Germany to the policy instruments in use and illustrate the struggle between national institutions in the enactment of RET Supportive policies against opposition from conventional energy systems stakeholders and their sympathizers.

Integrating learning curve information on RET into a dynamic programming formulation with real options analysis, Kumbaroğlu, et al (2008) were able to show that, the diffusion of RETs only occurs if targeted policies exist. In the absence of subsidies or other promotion policy instruments, market players can hardly be expected to invest in more expensive RETs, especially in a liberalized energy market environment. Monroy and Hernandez (2005) suggest that new sources of financing could be mobilised to support RET diffusion especially in developing countries.

However, contrary to most studies Faiers and Neame (2006) observed that the policy of stimulating the market with grants was not resulting in widespread adoption. And, when Velayudhan (2003) used the ‘‘diffusion of innovation’’ framework to examine the RET dissemination process, he discovered that the benefits promoted by government programme were, in most cases, at variance with the reasons buyers advanced for adopting RET. They argue that over-emphasizing subsidies tends to shift focus to the cost of a RET at the expense of other RET benefits. According to Chang et al (2009), the growing level of subsidy is generating a negative impact on sustainability of the RET industry and the development of local market. Theodorou, et al (2010) attribute this to the misinterpretation and lack of attention to parameters involved in drafting subsidy schemes.

Foxon et al (2005) have also noted that in spite of existing incentives in place to promote RETs, the number of ‘gaps’ in the broader RET innovation chain prevent their diffusion. Indeed, government efforts to promote RET may sometimes create the gaps in the innovation chain that slow commercialization and diffusion of these technologies (Balachandra et al, 2008). Using data on government investment in research and development and technological improvements Schilling & Esmundo (2009) were able to show that greatly under-funded wind and geothermal energy were making greater strides towards commercial sustainability compared to over subsidised solar technologies.

It is the low diffusion of RET through government driven pathways that generates the need for market based approaches (Balachandra et al, 2008). Indeed Dinica (2006) argues that the prospects for technology diffusion will be higher if large companies dominate the market for RET because then, the size of the financial pool on which diffusion may potentially rely will be large. Shum and Watanabe (2007) contend that existing energy dissemination incentives mostly rely on financial subsidies, and production tax credits, which tend to target system-level decisions of end users. However, in RETs, private value and public value are mixed (Taylor, 2008). The involvement of a big variety of stakeholders with varying explicit and tacit interests, that sometimes are at variance with each other, may sometimes limit the long-term diffusion of RET (Madlener and Vögtli, 2008).

Conclusion

This paper examined the concept of diffusion of RET that has been emerging across wide varying sectors and nations in recent years, providing an overview of the existing literature in this area. The first section examined the contextual factors influencing the emergence of diffusion of RET while the second section focussed on the nature and dynamics of RET diffusion. The third section briefly highlights the barriers to RET diffusion before the final section examined some of the key socio-economic issues emerging in this rapidly developing area, including the need to integrate the user and the learning process in the diffusion of RET. The section ends with an evaluation of the role of government in the RET dissemination effort, noting that while most studies allude to the indispensability of government and policy support in the dissemination of RET, an emerging minority is questioning its significance.

This paper illustrates the transferability of RET diffusion studies across geographical boundaries and across specific energy technologies. It is hoped that this consolidation will help researchers to find RET dissemination solutions across their geographical and technological scoping. The paper acknowledges the large number of gaps in the research literature, and opportunities for future research in this area. In particular, the lack of documented lessons learned and best practices which are sublimated from a specific geographic location and population idiosyncrasy and made available to a wider range of RET projects in the global perspective.

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