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# Reviewing Transfer and Diffusion of Climate Technology in Households: Towards a Greener IT Future

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**Abstract.** As the gravity of the impact of climate change on everyday life grows ever more relevant, green technology involving sustainability are also garnering more attention, and, in turn, more sophisticated IT solutions are needed. In this paper we review existing literature on the diffusion and transfer of technology in households in order to strengthen and prepare the future adoption of more IT-oriented sustainability solutions of green IT. We find that a large portion of household studies have taken place in the farming and agricultural sector of developing countries. We find that a large portion of the studies propose implications from a government policy perspective. We also find that a large portion of studies confirm factors influencing the diffusion and adoption coming from diffusion theory. Another significant portion takes a socio-cultural approach perspective. Finally, we find that collaboration, co-creation and participation seem to be effective in furthering the transfer and diffusion of sustainable and green technology in households. We discuss the implications of these different approaches when tackling the diffusion of green IT and propose taking a pluralist and design-oriented perspective since no single perspective or approach so far has resulted in large-scale technology transfer or diffusion to households.

**Keywords:** Green IT, Climate Technologies, Households, Diffusion, Adoption, Technology Transfer, Socio-cultural, Participatory, Co-creation, Policy.

## 1 Introduction

Both the climate crisis and the pandemic crisis have shown that both change from the top of society to the bottom of society as well as on various societal institutional levels are in dire need of a change of the technologies that consume energy as well as the practices that support this consumption into “climate technologies”. Climate technologies are defined by the United Nations Framework Convention on Climate Change (UNFCCC) as technologies that help us reduce greenhouse gas emissions, and with direct relation to sustainable development goals from the UN (Ban, 2016). In 2010 they established the so-called technology mechanism to help countries with technology transfer in both a policy arm and implementation arm. Probably the most well-known part of the mechanism is the conference of the parties – COP held in UK in 2021.

The types of climate technologies include ‘hard’ as well as ‘soft’ types. Those designated as ‘hard’ are renewable low-end technologies such as “wind energy, solar power and hydropower” but also includes “drought-resistant crops, early warning systems and sea walls”. Hard technologies also include so-called ‘Green information technology’ (Green IT) either embedded or as add-ons that support maintenance, monitoring and management. A windmill for example includes chips that interface with dashboards in control centers to ensure that the windmill runs smoothly according to the general weather as well as the energy market. Green IT refers to “environmentally sound IT”, including “dimensions of environmental sustainability, the economics of energy efficiency, and the total cost of ownership...” (Murugesan, 2008). Green IT can be understood as higher-level information technology that utilizes, platformizes and visualizes low-level climate technologies, such as interfacing with solar panels, smart meters, water consumption surveillance etc. For this very reason the adoption of green IT requires the adoption of several low-end climate technologies as well as hardware and software that can capture data input and output. UNFCCC also includes ‘soft’ climate technologies, such as “energy-efficient practices or training”, e.g. by changing practices in households, that is necessary for green IT to be utilized to its fullest potential (UNFCCC, 2021). Various suggestions for how to attain this have been studied: from the diffusion of load shifting household appliances (Paetz, Kaschub, Jochem, & Fichtner, 2013) to smart meter implementation with the intention of close energy consumption monitoring to invoke energy-efficient practices (Dalén & Krämer, 2017).

Despite an abundance of studies on climate technology adoption in households, we still need more knowledge on approaching the transfer of soft energy-efficient practices leading to stronger green IT adoption. Hence, this study investigates the research question of “*Which approaches to technology adoption in households can be used to further the future adoption of energy-efficient green IT practices in households?*”

The path to combining green IT, diffusion and adoption, and households is a narrowly travelled road. As a result, technology adoption in households is the foreground focus as this seems to be the most general and fruitful approach to adopting next-level technology such as green IT. We investigate the research question through a structured literature review with the goal of bringing about a future agenda of sustainable and energy-efficient practices of the future, green, everyday household.

The remainder of the paper is structured as follows: First, we explain our method of our structured literature review. Then we outline our results into four main sections, each section shortly explaining the theoretical foundation for the basis of the reviewed results. Based on the results, we finally conclude our research question and discuss the main findings in terms of potential for research in the future.

## **2 Method**

As our research question is focused on a “which” and “what” question, we selected an inductive approach to discover the various strands of literature of diffusion and transfer of technology in households. Similar to Wolfswinkel et al (2013) we took a grounded

theory approach of 5 overall steps: 1) defining the scope, 2) search the literature, 3) decide on the sample to be analyzed, 4) analyze literature and 5) presenting the findings.

Our aim of running queries was for them to remain manageable. For example, “behavior” is not the only keyword that describes actions and performances of members in a household; a similar keyword is “practice”. While “household” synonyms could also include “family” and “home” we found that the inclusion of these would make the number of results unwieldy and so we decided on only using “household”. “Technology”, “information technology”, and “information systems” were all synonyms and for the process of adoption we used “adoption”, “use”, “change”. We used the query “TITLE-ABS-KEY (“information technology” OR “technology” OR “information systems”) AND (diffusion OR diffuse OR diffusing OR transfer OR transferring) AND (“household”) AND (“behaviour” OR “behavior” OR “use” OR “using” OR “practice” OR “practicing” OR “practising” OR “practise”)). Initially we included “Green IT” in the query but the query changed very little and we decided to omit this for the sake of simplicity. We further restricted the query to the years 2000-2022 and the overall research areas to business, energy, computer science, psychology and social sciences. We started our search with one initial query on “households, diffusion and transfer of technology” and found relevant literature based on this and identified different versions of central keywords. We chose Scopus as a single database as this historically contains the broadest range of results.

Initial results from Scopus added up to a total of initial 97 results. All abstracts of the initial results pool were read and assessed for inclusion and divided into six different categories.

**Table 1.** The initial categories and placement of results. Some results fit into more than one category.

#	Category	Description of category	Results
1	Diffusion of Innovations	Based on DoI, adoption and technology transfer theory	29
2	Socio-Cultural	Focus on socio-cultural dimension	10
3	Macro policy	Based on a macro-level societal point of view	17
4	Participatory & co-creation	Focus on participation and/or co-creation as methods/techniques	9
5	Other /minor) category or Not relevant	E.g. very technology specific or simply not relevant for us	12 + 24

Based on Table 1 we then identified explicit inclusion criteria and used these as the means to arrive at a more manageable number of net results. After the initial categorization, the included papers would be read thoroughly and more strict inclusion criteria would be introduced, so both titles and abstracts had to explicitly mention the main keywords, and if so, we would assess whether the paper fitted into an existing category or we should create a new one.

Next step was to code the results through open coding based on the publication outlet, type of publication (theoretical, practical, experimental), methods used, domain, technology type, household definition, and theoretical strands. Next, we axially coded the papers by comparing them to one another based on the dimensions from the axial coding, and finally we selectively coded the papers based on our findings.

The final review ended up identifying current research and knowledge on what influences how households transfer and diffuses new technology in order to find potential for the future of green IT adoption.

### **3 Findings**

Our findings covered 4 overall groups of papers based on their fundamental approach to household technology transfer. 17 related to macro policy suggestions, 29 related to Diffusion of Innovation theory, 10 related to taking a socio-cultural approach, and 9 related to taking a more participatory approach that would also draw on the method of co-creation.

#### **3.1 Diffusion and transfer seen from a macro policy level**

We found 17 results that all belonged on the “macro policy level”. The macro policy level indicates general policies and regulations decided on and implemented by political decision makers and leaders that are then followed or executed by lower “layers” of other policy makers or those receiving or handling technologies and practices for households. We identified additional abstraction layers that made up the macro policy level: “global”; “national”; and “municipal”. For all of the macro layers various actions and legislations have been proposed, yet one major finding indicated that for the policies to be effective in enabling diffusion and transfer of technology on the household level, general income for households needs to be increased and pricing of sustainable energy technologies need to be lowered (Alam, Rahman, & Eusuf, 2003) to create the possibility of choice (Reddy, Balachandra, & Nathan, 2009). Furthermore, the different initiatives taken on the various layers need to be aligned (Dong et al., 2007; Jin et al., 2006; Martiskainen, Heiskanen, & Speciale, 2018), indicating a strong interdependency between the policies and initiatives and communication between decision-makers and housing managers and communities rather than a centralized or decentralized composition (Habibis, Phillips, Phibbs, & Verdouw, 2014). Finally, technology and price have also been indicated to not be enough (Youtie, Shapira, & Laudeman, 2007) because: “... the different existing markets, institutions, consumer behaviors and cultural aspects need to be taken into account since in the end the energy has to be used by the people.” (Oldenberg, Murshed, Kremers, Mainzer, & Koch, 2015, p. 1)

#### **Global policy layer**

The global layer resides on a strategic and visionary level and did not only include decision and legislation. The 17 sustainability goals of the United Nations is an example

of such visions. Another example from our findings includes establishing global networks of energy access innovation centers to increase awareness and potential for similar ideas (Nathwani & Kammen, 2019). Another example where legislation and policy potentially can be established through agreement is through such semi-global institutions as the EU: in a recent report Energy Efficiency Directives ("German Retrofit Policy in Context," 2013) the problem of purely national market-led energy policies is made clear, as there is no concrete agreement on how to organize and define subsidies between EU countries.

### **National policy layer**

The national layer is the current enabler but also the current problem as nations currently all legislate differently, leading to various degrees of openness or closedness towards establishing new potential markets and from here potential business models for innovative companies and households to take advantage of.

It includes creating policies for energy efficiency impact of the actual buildings for its occupants to take advantage of the potential for green energy use. A study found that the physical and materiality of the buildings very consistently predicted the energy use, though the largest discrepancy factor involved the type of inhabitants in the households (Zhao et al., 2018). The national layer provides opportunities for establishing large-scale rollouts through funding and resource deployment that are then creating opportunities for households to latch onto, either through subsidies or special tariffs. One example includes how the overall limitations of cost were reduced for buying and establishing a network of household appliances through IoT in the transition to more environmentally friendly devices (Strielkowski, Streimikiene, Fomina, & Semenova, 2019). Furthermore, the potential of energy efficacy has been shown to be done through government actively promoting cleaner fuels and consumption as well as setting up policies of investment between the services, construction and equipment industrial sectors (Yang, Dong, Xiu, Dai, & Chou, 2015).

Not all literature results point to only investment and promotion, though, and there are also indications of a need to include social influence and beliefs, effort expectancy and price-value beliefs to make households transition to new technologies such as rooftops providing solar energy (Aggarwal, Syed, & Garg, 2020; Martiskainen et al., 2018).

### **Municipal policy layer**

The municipal layer contains the potential for establishing local communities, incentives, initiatives and awareness that directly link the households to a relatable local whole. Within the municipal layer of green policies resides the notion of *urban development and design* which includes a "master plan" (Oldenberg et al., 2015) for strategies on decarbonization through stronger public transportation, transitioning to electric vehicles while also minimising road congestion, and also establishing scenarios for local development on neighbourhood and community level in regards to assessing carbon footprints and energy optimization. A central result, given these initiatives, is that such technologies as solar photovoltaic technology and its diffusion requires very different pathways based on the geographical locations of the users of the households with a

clear spatial difference between suburbs and inner cities, as well as dwelling type (Newton & Newman, 2013). The differences of dwelling types were also found to be of great importance for the local policies in the diffusion of photovoltaic rooftop panels where a change in policy to enable installations in community condominiums from increased by 80% (Schiera, Minuto, Bottaccioli, Borchiellini, & Lanzini, 2019).

Other examples on the community level includes the establishment of community-run Energy Cafes in the UK that resulted in various forms of advocacy and engagement with energy technologies on a household level (Martiskainen et al., 2018).

### **Final thoughts on macro policy level**

There is a need for alignment through the various macro policy layers all the way down to the households where the layers depend on one another. Successful transfer and diffusion of green technology in households can only happen by combining subsidy reduction of prices, establishing demand-side markets and innovation of technology but also through matching with community-driven awareness, trust and beliefs.

### **3.2 The importance of including factors from Diffusion of Innovations theory**

With a majority of the results using and drawing on, and confirming, Roger's (2010) diffusion of innovations theory, one of the identified papers phrased it very well: "The diffusion of innovation theory remains a valid and relevant framework in studying adoption..." - Nyairo et al. (2021, p. 57).

Originally Rogers defined diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 2010, p. 5). Innovation here is defined as the perception of newness of a thought, an idea or a technology. In our case we would define the innovation to include both soft and hard climate technologies.

Rogers' (2010) define five things that will make an innovation diffuse faster, namely having a relative advantage, being more compatible, being less complex, having observable advantages, and offering trialability. The adopters of innovations are also placed into five overall groups: (1) Innovators, (2) Early adopters, (3) Early majority, (4) Late majority and (5) Laggards. The first two groups are more open to new ideas and willing to try out technologies whereas the latter 3 become gradually more content with waiting on the technology to mature.

### **How to shape climate technologies in the household for stronger diffusion**

Relative advantage and compatibility are aspects of an innovation that strongly influence the intention of a household to adopt new climate technologies (Kapoor & Dwivedi, 2020). An example of these two characteristics is for example connection speed of the technologies to WiFi and the internet in general, as well as the general level of trust in IoE (Internet of Everything) applications (Strielkowski et al., 2019). Furthermore, Rizzo et al. (2018) find that performance and sustainability of Green IT



“... have a significant impact on household adoption intention”. In a study of conservation of water and energy, the main cited adoption reason was the overall cost saving (Hustvedt, Ahn, & Emmel, 2013) and barriers of initial costs (Alam et al., 2003).

While cost and cost savings do seem to play an important role they should not stand alone. Youtie et al. (2007) also found that reducing the cost of technology alone is not enough to raise demand and increase diffusion. Finally, Franceschinis et al. (2017) used psychological constructs from Rogers’ theory as a set of criteria and suggested that also beliefs and attitudes of individual consumers play a crucial role in the diffusion.

### **Household adopter groups**

Households willing to adopt new green IT have a desire to be at the forefront of technological development as innovators and early adopters (Fischer, 2008). This specific type of adopters would also explain why adoption may be less robust, as innovators and early adopters often will try out innovations and then fall back to prior behavior more easily (Jeliffe et al. 2018). In the case of Jeliffe et al. (2018) it was the farming practice of saving seeds that, over time, would undermine the use of a specific high-yield variety of groundnut. Another reason for the lack of robustness was found by Choragudi (2016) who found that many alternatives would also decrease adoption.

### **Additional nuances of household diffusion and adoption behavior**

Broughel (2019) put up an interesting distinction, namely between voluntary and involuntary (forced) adoption. Voluntary adoption is when the adopter him or herself decides whether to adopt or not. Whereas involuntary adoption is when someone such as management makes it mandatory (forces) to adopt and use something. Keil et al. (2017) found that adoption behavior of a household may also be dependent on the (social) networks that the household belongs to. Thus, you will more likely adopt something if someone you trust and relate to can persuade you. Klingler (2017) found that the individual electricity consumption behavior were often neglected. In fact, behavior can be so different and have a major impact to whether a climate technology is diffused or not that it can be seen as a contingent problem for which we need contingency theory (Donaldson, 2001). This contingency was also elaborated on by Newton & Newman (2013) through the vast differences of households between and within types of cities, as the infrastructures and regulations vary differently from city to city. Finally, Jensen et al. (2015) found that the impact of a climate technology in a household depends on three things: (1) the impact of a device within a household, (2) the diffusion of devices to other households and the number of adopters, and (3) the diffusion of the induced behavioral change beyond these households.

### **Central findings from diffusion of innovations studies**

From diffusion of innovations theory, we identify that cost savings and initial cost of acquiring climate technologies can be viewed as a central factor to adoption. Existing behavior and practices were also found to be a challenge as it can be too easy to fall back on these, and finally that too many alternatives and reliance on voluntary adoption might even hinder the choice to adopt climate technologies.

Assumptions include the household as a central unit, an actor viewed as a black box which ultimately also leads to limitations when the dynamics within and between households, as well as other electronic devices, are also factored in.

#### 4 Taking a socio-cultural perspective

Where diffusion of innovations favors the innovation, and somewhat uncritically at that, the change in behavior and practices are treated as the outcome of an explicit, cognitive decision of change made by the individual, and as such, not the household that consists of more than one individual. A socio-cultural perspective differs from the diffusion of innovations theory primarily in what is foregrounded and what is backgrounded. The socio-cultural approach provides a sociological, psychological, or anthropological model for investigating the particularities of social practices, discourses, norms, and moral orders. Grounded in social constructivism, perspectives such as these tend to treat technological systems and their devices as the end products of historical construction and thus socially shaped. In giving space to articulate processes of social construction, historical materialism, or even capitalism, the socio-cultural approach often takes a critical perspective on technology and development and on human behavior that is deeply embedded in: *“social situations, institutional context and cultural norms”* (Shove, 2010, p. 1276). The socio-cultural approach thus addresses these issues by instead treating change as an outcome of social practices in which any given object is embedded.

The 10 results categorized here varied significantly depending on the case in question and whether the socio-cultural was an approach, a perspective, or an observational method of unit of analysis. For example, Haque et al. (2021) make the argument that: *“adopting a socio-cultural perspective is a crucial, but often overlooked, aspect of scholarly and policy analyses of, and strategies for, energy transitions in the global South.”* (Haque et al., 2021). This study shows that energy transitions and technology transfer often will benefit low-income households, more typically referred to as the ‘urban poor’. These households can ultimately held become ascribed with accountability because of their systemic failure of energy technology adoption, and without contextual consideration of their socially situated position and limited capital.

Displaying another variation of the socio-cultural approach, (Jagadish & Dwivedi, 2018) conduct a study of cooking practices in rural India as a contribution to the study of sustainable energy alternatives. In this approach, a method referred to as ‘consensus study’ is utilized with the aim to deconstruct cultural domains related to cooking. Here we see how socio-cultural forces and practices become foregrounded as the units of analysis that are taken to influence the uptake and use of cooking technology, in this case by rural households in India. The study treats ‘the social’ or ‘cultural’ as a separate domain of reality, and as abstract models or schemas that are treated as resources for cognition: *“people reason using cultural models, defined as cognitive domains/schemas that are intersubjectively shared by a social group.”* (Jagadish & Dwivedi, 2018).

The socio-cultural approach can be criticized of situating the ‘essence’ of a technology within social groups or cultures and lead to a form of determinism. For example, the version of ‘praxis’ called upon by Haque et al. (2021) carries with it an understanding of temporality as a linear flow of conflicts that are carried forward into the future as they simultaneously pass into history.

## 5 Co-creating diffusion and adoption

In contrast, but like the socio-cultural approach, nine of the papers made use of what we have called ‘participatory’ or ‘co-creative’ approaches. For instance, Martiskainen et al. (2018) show how energy can be conceived as a site of political engagement and public participation by studying what they refer to as a ‘grassroot innovation’ – the case of the community-run energy café in the UK. While said to be less explicitly political than the community participation of the 1970s, the community-run energy café is nevertheless shown to work as a practical, economic, and political device through which the public can gather around financial issues or mundane concerns, such as for example energy bills. As such, this ‘grassroot innovation’ comes to perform ‘energy’ itself as a political and social matter, but unlike the socio-cultural approach ‘energy’ is not treated here as a ‘social’ or ‘mental’ construction that resides in the heads of any given social group or culture but in the practical activities, behaviors, and material arrangements that bring people together around a shared issue. Here ‘energy’ is not merely about the ‘idea’ of energy but involves coffee too.

One study by Zhang et al. (2016) addressed the issue of food sustainability by increasing agricultural yields through a method referred to as “the Science and Technology Backyard (STB) platform”. The study was something of a reversal of the more commonsensical model of scientific diffusion where something called ‘science’ is first thought of as performed, constructed, or cooked-up in a laboratory and then transferred to such sites of production where it may become useful, such as aquacultural warehouses or agricultural settings, The study showed how a radical, participatory approach can be accomplished by involving: *“agricultural scientists living in villages among farmers, advancing participatory innovation and technology transfer”* (Zhang et al., 2016). In contrast to the socio-cultural approach that brings ‘the village’ into science then, this study brought ‘science’ to the village.

The literature on co-creation and participation shows a pragmatist approach that involves the target audience. It contrasts the previous literature in that it foregrounds the households themselves as both innovators, creators, practitioners and decision-makers themselves. The limitations of the approach is the scalability as it also involves third-party members in the facilitation, progression and production of the new climate technological innovation.

## 6 Discussion and Conclusion

We have now shown that technology diffusion and transfer in households is a domain of great variety, importance, as well as a rather comprehensive process. The literature

review revealed that many factors and approaches are needed to accomplish transfer and diffusion, all the way from the macro level of governance and legislation to the minute level of involving each household in a more participatory approach. While the macro level can be considered a gatekeeper of factors, including the importance of finding ways to limit the number of choices available, keeping both costs down as well as cost savings, we also found that additional aspects from diffusion of innovations theory are important as well. Here the specific relative advantages of the climate technologies, as well as the compatibility of existing hardware, and a homogeneous relation to the beliefs, values and attitudes of the adopters require alignment. Finally, there is a great risk of mainly identifying innovators and early adopters which may lead to higher number of discontinuances over time. As a result, future focus needs to be on complementing the legislation and technology with approaches that foregrounds the households as a social practice and detailed unit of individuals instead. One way to do so is to take a socio-cultural approach in order to better detail out the capabilities of those engaged in the household and how existing climate technologies could integrate with new technologies as well as the practices of the household. Finally, we also found results that pointed in the direction of direct engagement with the households for stronger sustainability where the households themselves learned about the fit between technology and themselves in a more pragmatist approach to technology transfer.

All the approaches had their own limitations which is why we conclude that there is a need for a more pluralist point of view to support future technology transfer and diffusion of climate technologies in households. The macro level requires a bottom-up understanding as well as firm regulations to ensure the limited but useful choices. Diffusion of innovations theory did not adequately cover the specific shape of the technologies nor focused on the specific structures and interactions of the household as a social system. Whereas the findings on macro level and diffusion of innovations theory could be viewed as “technologically deterministic” in the sense of a real bias towards foregrounding technology as positive, the alternative socio-cultural approach could equally be criticized for adding a scope of practical determinism that fails to include the specific nature of the climate technologies in the foreground, leading to failed attempts to properly propagate the technology transfer in a broad sense. The material or technical dimensions, also known as ‘interobjectivity’ (Latour, 1996), becomes backgrounded in order to give space to the attitudes, beliefs, or social constructs that are treated as shared patterns of cultural or social ‘intersubjectivity’ (Jagadish & Dwivedi 2018).

For example, the sociologist Elisabeth Shove critiques dominant models of energy policy and governance for failing to recognize that human behavior is deeply embedded in: “*social situations, institutional context and cultural norms*” (Shove, 2010, p. 1276). The socio-cultural approach thus addresses these issues by instead treating change as an outcome of social practices in which any given object is embedded.

Our final finding, the co-creation and participatory approach, struck a balance between the previous issues, yet could be criticized for being impractical on a large industrial scale, which is very much needed for this specific type of technology. The findings of Zhang et al. (2016) show the similarity to the idea of science and technology as ‘immutable mobiles’ (Latour, 1986, 1987) that draw visualization and cognition together in material devices and artifacts that can be transported or transferred to the

places they may be best put to use. The participatory politics of Marres (2016) are no doubt greatly inspired by her mentor Latour and the philosophy of ‘association’ that he contrasts to such ‘sociology’ as that of Shove (2010) and the socio-cultural approaches. Approaches such as these also tend to be grounded in pragmatist philosophy or versions of social constructionism that attend less to the ‘social’ and more to the ‘material’ dimensions of a given case. For example, (Martiskainen et al., 2018) draw on the device sociology of Marres (Marres, 2013, 2016) and her concern with green experiments as devices of political and material participation. In her work, material devices such as green eco-homes, environmental teapots, and smart meters come to take the stage as material-semiotic actors that also participate in social, political, and ethical activity.

Much of the knowledge acquired through this review can be very useful for tackling the future challenges of adopting more information heavy technology, such as green IT. However, compared to diffusing and transferring technology to household there will most likely be even more to change than simply having households adopt. Technology transfer to households of green IT will most likely be an even larger challenge than what we have seen in past studies on technology diffusion. Behavioral changes are inherently and initially individual and will need to be reinforced by serving up information in an easily digestible manner while also providing the household as a social system a platform for interconnecting other unknown green IT solutions. The process will require more knowledge on the household level as a specific unit of analysis rather than the black box it has been presented as so far because more IT would have to be specifically addressing the physical as well as normative, cognitive and social dimensions of the households. One example that comes to mind is a household that both consumes power, water, gas while producing electricity from solar panels. Combining these into a larger information system certainly requires approaches that lend themselves to continuously assist the household towards a wanted “target behavior” by gathering data and providing suggestions for new practices. Opportunity through context also matters, as situations such as dwelling type should also be factored in. Being owner-occupied, an investment property, or a rental property might affect the interests of the stakeholders involved to improve and change energy-efficient practices.

Based on the target audience we see implications for opportunities as well as caveats that need to be either considered or cleared first and foremost. Designers of climate technologies will need to consider which type of household are the recipients, what the barriers are and how easily it is to penetrate the legislative level or if the solutions proposed are aligned with these. Household theorists must not forget that households make up very complex dynamics that one cannot take for granted. For academics who study households we see that there are many interesting approaches to understanding the dynamics of the household, yet the caveat is that there may be a bias in either swaying towards the technological determinism (i.e. all technology is good) or towards the determinism of the praxis of the household (leading to the drowning of the household technology). There is also an overall issue with specific prescriptive actions and techniques for improving the overall transfer and diffusion that the mere socio-cultural understanding does not cover completely, nor does the participatory approach address these shortcomings.

## References

- Aggarwal, A. K., Syed, A. A., & Garg, S. (2020). Diffusion of residential RT solar – is lack of funds the real issue? *International Journal of Energy Sector Management*, 14(2), 316-334. doi:10.1108/IJESM-02-2019-0004
- Alam, M., Rahman, A., & Eusuf, M. (2003). Diffusion potential of renewable energy technology for sustainable development: Bangladeshi experience. *Energy for Sustainable Development*, 7(2), 88-96. doi:10.1016/S0973-0826(08)60358-0
- Sustainable Development Goals, United Nations (2016).
- Choragudi, S. (2016). India revamps green energy sector: What lies for domestic biogas technology? *International Journal of Global Energy Issues*, 39(6), 413-431. doi:10.1504/IJGEI.2016.079371
- Dalén, A., & Krämer, J. (2017). Towards a user-centered feedback design for smart meter interfaces to support efficient energy-use choices. *Business & Information Systems Engineering*, 59(5), 361-373.
- Donaldson, L. (2001). *The contingency theory of organizations*: Sage.
- Dong, S. K., Gao, H. W., Xu, G. C., Hou, X. Y., Long, R. J., Kang, M. Y., & Lassoie, J. P. (2007). Farmer and professional attitudes to the large-scale ban on livestock grazing of grasslands in China. *Environmental Conservation*, 34(3), 246-254. doi:10.1017/S0376892907004213
- Ebers Broughel, A. (2019). On the ground in sunny Mexico: A case study of consumer perceptions and willingness to pay for solar-powered devices. *World Development Perspectives*, 15. doi:10.1016/j.wdp.2019.100130
- Fischer, C. (2008). Who uses innovative energy technologies, when and why? The case of fuel cell MicroCHP in households. *International Journal of Environmental Technology and Management*, 9(2-3), 236-258. doi:10.1504/IJETM.2008.019036
- Franceschinis, C., Thiene, M., Scarpa, R., Rose, J., Moretto, M., & Cavalli, R. (2017). Adoption of renewable heating systems: An empirical test of the diffusion of innovation theory. *Energy*, 125, 313-326. doi:10.1016/j.energy.2017.02.060
- German Retrofit Policy in Context. (2013) In: Vol. 148. *Green Energy and Technology* (pp. 29-46).
- Habibis, D., Phillips, R., Phibbs, P., & Verdouw, J. (2014). Progressing tenancy management reform on remote Indigenous communities. *AHURI Final Report(223)*, 1-103. Retrieved from <https://www.scopus.com/inward/record.uri?eid=2-s2.0-84905373098&partnerID=40&md5=96725306f5aed54daa3201a007974d82>
- Haque, A. N., Lemanski, C., & de Groot, J. (2021). Why do low-income urban dwellers reject energy technologies? Exploring the socio-cultural acceptance of solar adoption in Mumbai and Cape Town. *Energy Research and Social Science*, 74. doi:10.1016/j.erss.2021.101954
- Hustvedt, G., Ahn, M., & Emmel, J. (2013). The adoption of sustainable laundry technologies by US consumers. *International Journal of Consumer Studies*, 37(3), 291-298. doi:10.1111/ijcs.12007
- Jagadish, A., & Dwivedi, P. (2018). In the hearth, on the mind: Cultural consensus on fuelwood and cookstoves in the middle Himalayas of India. *Energy Research and Social Science*, 37, 44-51. doi:10.1016/j.erss.2017.09.017

- Jelliffe, J. L., Bravo-Ureta, B. E., Deom, C. M., & Okello, D. K. (2018). Adoption of high-yielding groundnut varieties: The sustainability of a farmer-led multiplication-dissemination program in Eastern Uganda. *Sustainability (Switzerland)*, *10*(5). doi:10.3390/su10051597
- Jensen, T., Holtz, G., & Chappin, E. J. L. (2015). Agent-based assessment framework for behavior-changing feedback devices: Spreading of devices and heating behavior. *Technological Forecasting and Social Change*, *98*, 105-119. doi:10.1016/j.techfore.2015.06.006
- Jin, Y., Ma, X., Chen, X., Cheng, Y., Baris, E., & Ezzati, M. (2006). Exposure to indoor air pollution from household energy use in rural China: The interactions of technology, behavior, and knowledge in health risk management. *Social Science and Medicine*, *62*(12), 3161-3176. doi:10.1016/j.socscimed.2005.11.029
- Kapoor, K. K., & Dwivedi, Y. K. (2020). Sustainable consumption from the consumer's perspective: Antecedents of solar innovation adoption. *Resources, Conservation and Recycling*, *152*. doi:10.1016/j.resconrec.2019.104501
- Keil, A., D'souza, A., & McDonald, A. (2017). Zero-tillage is a proven technology for sustainable wheat intensification in the Eastern Indo-Gangetic Plains: what determines farmer awareness and adoption? *Food Security*, *9*(4), 723-743. doi:10.1007/s12571-017-0707-x
- Klingler, A. L. (2017). Self-consumption with PV + Battery systems: A market diffusion model considering individual consumer behaviour and preferences. *Applied Energy*, *205*, 1560-1570. doi:10.1016/j.apenergy.2017.08.159
- Latour, B. (1986). Visualization and cognition. *Knowledge and society*, *6*(6), 1-40.
- Latour, B. (1987). Opening one eye while closing the other... a note on some religious paintings. *The Sociological Review*, *35*(S1), 15-38.
- Latour, B. (1996). On interobjectivity. *Mind, culture, and activity*, *3*(4), 228-245.
- Marres, N. (2013). Why political ontology must be experimentalized: On eco-show homes as devices of participation. *Social Studies of Science*, *43*(3), 417-443.
- Marres, N. (2016). *Material participation: Technology, the environment and everyday publics*: Springer.
- Martiskainen, M., Heiskanen, E., & Speciale, G. (2018). Community energy initiatives to alleviate fuel poverty: the material politics of Energy Cafés. *Local Environment*, *23*(1), 20-35. doi:10.1080/13549839.2017.1382459
- Murugesan, S. (2008). Harnessing green IT: Principles and practices. *IT professional*, *10*(1), 24-33.
- Nathwani, J., & Kammen, D. M. (2019). Affordable Energy for Humanity: A Global Movement to Support Universal Clean Energy Access. *Proceedings of the IEEE*, *107*(9), 1780-1789. doi:10.1109/JPROC.2019.2918758
- Newton, P., & Newman, P. (2013). The geography of solar photovoltaics (pv) and a new low carbon urban transition theory. *Sustainability (Switzerland)*, *5*(6), 2537-2556. doi:10.3390/su5062537
- Nyairo, N. M., Pfeiffer, L. J., & Russell, M. (2021). Smallholder farmers' perceptions of agricultural extension in adoption of new technologies in Kakamega county, Kenya. *International Journal of Agricultural Extension*, *9*(1), 57-68. doi:10.33687/ijae.009.01.3510

- Oldenberg, O., Murshed, S. M., Kremers, E., Mainzer, K., & Koch, A. (2015). Model-based analysis of urban energy systems (On the basis of a city's energy master plan). *Emergence: Complexity and Organization*, 17(2). doi:10.emerg/10.17357.03a4747a4b28258c105148d3775522a1
- Paetz, A.-G., Kaschub, T., Jochem, P., & Fichtner, W. (2013). *Load-shifting potentials in households including electric mobility-A comparison of user behaviour with modelling results*. Paper presented at the 2013 10th International Conference on the European Energy Market (EEM).
- Reddy, B. S., Balachandra, P., & Nathan, H. S. K. (2009). Universalization of access to modern energy services in Indian households-Economic and policy analysis. *Energy Policy*, 37(11), 4645-4657. doi:10.1016/j.enpol.2009.06.021
- Rizzo, C., Piper, L., Irene Prete, M., Pino, G., & Guido, G. (2018). Exploring the perceived image of Energy Efficiency Measures in residential buildings: Evidence from Apulia, Italy. *Journal of Cleaner Production*, 197, 349-355. doi:10.1016/j.jclepro.2018.06.149
- Rogers, E. M. (2010). *Diffusion of innovations*: Simon and Schuster.
- Schiera, D. S., Minuto, F. D., Bottaccioli, L., Borchiellini, R., & Lanzini, A. (2019). Analysis of Rooftop Photovoltaics Diffusion in Energy Community Buildings by a Novel GIS- and Agent-Based Modeling Co-Simulation Platform. *Ieee Access*, 7, 93404-93432. doi:10.1109/ACCESS.2019.2927446
- Shove, E. (2010). Beyond the ABC: climate change policy and theories of social change. *Environment and planning A*, 42(6), 1273-1285.
- Strielkowski, W., Streimikiene, D., Fomina, A., & Semenova, E. (2019). Internet of energy (IoE) and high-renewables electricity system market design. *Energies*, 12(24). doi:10.3390/en12244790
- UNFCCC. (2021). What is technology development and transfer? Retrieved from <https://unfccc.int/topics/climate-technology/the-big-picture/what-is-technology-development-and-transfer>
- Wolfswinkel, J. F., Furtmueller, E., & Wilderom, C. P. (2013). Using grounded theory as a method for rigorously reviewing literature. *European Journal of Information Systems*, 22(1), 45-55.
- Yang, Z., Dong, W., Xiu, J., Dai, R., & Chou, J. (2015). Structural path analysis of fossil fuel based CO2 emissions: A case study for China. *PLoS ONE*, 10(9). doi:10.1371/journal.pone.0135727
- Youtie, J., Shapira, P., & Laudeman, G. (2007). Supply, demand and ICT-based services: A local level perspective. *Telecommunications Policy*, 31(6-7), 347-358. doi:10.1016/j.telpol.2007.05.005
- Zhang, W., Cao, G., Li, X., Zhang, H., Wang, C., Liu, Q., . . . Dou, Z. (2016). Closing yield gaps in China by empowering smallholder farmers. *Nature*, 537(7622), 671-674. doi:10.1038/nature19368
- Zhao, D., McCoy, A. P., Agee, P., Mo, Y., Reichard, G., & Paige, F. (2018). Time effects of green buildings on energy use for low-income households: A longitudinal study in the United States. *Sustainable Cities and Society*, 40, 559-568. doi:10.1016/j.scs.2018.05.011