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From local to global – The role of knowledge, transfer, and capacity building for successful energy transitions

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Abstract

From local to global –

The role of knowledge, transfer and capacity building for successful energy transitions

by Hanno Michel*

Germany has set the challenging goal of reducing its greenhouse gas emissions by 40 percent by the year 2020 as compared to 1990 (BMUB 2014). This German Energiewende (energy transition) has led to significant changes in the electricity sector, such as a continuously increasing percentage of renewable energies, supported by corresponding governance and political efforts. However, despite these political and economic efforts, the 2020 goal will most likely only be reached due to the tremendous unplanned effects of the COVID-19 pandemic on energy usage for transport and mobility (Agora Energiewende 2020). In addition to technological advances, a change in individual and collective behavior seems highly necessary to achieve future transition goals. The aim of this discussion paper is to summarize the state of research on how people's behavior in the context of climate change and energy transitions is shaped, and to put forward potential avenues for further research and action. The paper departs at a local level by looking at factors that guide citizens' individual energy-related actions and thus impact their energy-saving behavior. Knowledge about climate change and energy is generally believed to influence a person's energy-related behavior, although its measured effects vary significantly in different studies examining it. This may partly be due to the fact that knowledge is often assessed in a declarative way in these studies, instead of looking at knowledge-in-use (i.e. applying that knowledge to solve a problem in a meaningful way instead of simply stating that knowledge). This working paper thus argues for moving from climate and energy knowledge towards climate and energy literacy, with literacy involving knowledge, skills, and attitudes. With a climate and energy literacy perspective, as well as existing frameworks for how energy-related behavior can be modelled and explained, it theorizes how individual climate-friendly behavior can lead to collective action regarding energy transitions. As knowledge transfer and capacity building play a big role when scaling local solutions to a global level, the discussion paper advocates for concentrated efforts in interdisciplinary capacity building and lays out potential directions for future research.

Keywords: Energy transitions, education, knowledge transfer, capacity building

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The *Leibniz Research Alliance on Energy Transitions* (Leibniz-Forschungsverbund Energiewende), which was founded by 20 research institutes of the Leibniz Association in 2013, has set out to tackle central research questions regarding the German *Energiewende* and to generate and provide knowledge supporting its goals. To this end, the Alliance defined three core challenges as a framework guiding its interdisciplinary research efforts: (1) the role of centralized vs. decentralized systems in energy transition efforts, (2) potential synergies and/or conflicts between public and private interests, and (3) the interplay between local and global approaches and solutions. This discussion paper aims to summarize (from an educational science perspective) the underlying frameworks and state of research guiding the third core challenge.

1 Towards successful energy transitions: from local to global

Engaging in climate action while at the same time providing affordable and clean energy and sustainable cities and communities for all people already involves three of the Sustainable Development Goals as formulated by the United Nations (UN General Assembly 2015). This implies that energy transitions and their far-reaching consequences continue to be some of the greatest challenges the global society has to face. If human-produced emissions and other factors contributing to global warming cannot successfully be reduced or countered, risk scenarios predict significant costs and losses: a severe decline in biodiversity, a rise in catastrophic weather phenomena, climate-related migration processes, and high overall follow-up costs for society to counter the consequences of this development (IPCC 2014). Thus, transitions towards more sustainable and less emission-heavy technologies and habits seem more than necessary. And as the causes and consequences of climate change are and will be global, so have to be the efforts taken against it (IPCC 2014; UN General Assembly 2015). In this context, Germany has set the challenging goal of reducing its greenhouse gas (GHG) emissions (with the greatest contributor being carbon dioxide) by 40 percent by the year 2020 (as compared to 1990) (BMUB 2014). This German *Energiewende* (energy transition) has led to significant changes in the electricity sector, such as a continuously increasing percentage of renewable energies, supported by corresponding governance and political efforts (e.g. the renewable energy law). However, despite these political and economic efforts, the German government has already declared that the 2020 goal will not be reached (BMU 2018), or may – according to recent calculations – only be reached due to severe impacts on transportation and travel due to the COVID-19 pandemic (Agora Energiewende 2020).

2 The role of knowledge and education for energy transition processes

Given that knowledge of science contributes significantly to an individual's personal, social and professional life, an understanding of science is central for future generations' "preparedness for life" (OECD 2018) to face and handle the consequences of climate change, as well as for their willingness to engage in individual or collective actions to reduce energy use. Thus, knowledge plays a central role for the success of local energy solutions that rely on individual and collective actions, as well as for successful transfer of these local solutions to a global scale. Overall, energy transitions are an interdisciplinary topic. Accordingly, knowledge necessary to develop an understanding for climate change and energy transitions is scattered across multiple disciplines (e.g. earth science/geography; life sciences/biology; chemistry; physics; engineering; information technologies). In the following, the state of research regarding the role of knowledge and other individual factors for successful energy transition processes will be summarized. Departing from a science education perspective, research findings from educational and environmental education, as well as from social, political, and natural sciences will be taken into account to provide an interdisciplinary point of view on the subject. Due to the complex nature of the subject and the multitude of different disciplinary perspectives on knowledge, participation, and collective action, this section is by no means thought to be extensive, but is rather thought to provide an overview on some critical paths of reasoning that guide research efforts towards achieving successful energy transitions.

2.1 From energy knowledge to climate and energy literacy

When addressing knowledge relevant for understanding the underlying processes of climate change, as well as potential measures to counter it, three relevant knowledge types are mentioned in empirical studies: content knowledge, procedural knowledge, and epistemological knowledge (Azevedo & Marques 2017; Liu & Roehrig 2019). Knowledge about systems or system thinking (Evagorou et al. 2009) is argued to be central to understanding climate change, as the latter can be regarded as the result of a modification in the components of the Earth's climate system and their relationships to each other (Shepardson et al. 2017). In addition, several studies show that knowledge about energy (e.g. Besson & Ambrosis 2013) and about risks (e.g. Lee et al. 2015; Martens & Rost 1998) are relevant facets of climate knowledge.

However, the question remains whether such climate knowledge is a main contributor to actual climate action. Research about students' ability to engage in collective action (i.e. to successfully and meaningfully participate in socio-scientific decision-making processes) shows a somewhat unclear and ambiguous picture on what science education should focus upon, which may partly be due to a lack of consistency regarding the kind of assessment used in different studies (Mittenzwei et al. 2019). On the one hand, several studies show that students often lack conceptual knowledge and show multiple misconceptions when explaining climate change (e.g. Boyes & Stanisstreet 2011; Flener-Lovitt 2014; Shepardson et al. 2011). Hence, it is often argued that science education should focus on conveying sufficient conceptual knowledge about climate change, its causes, consequences, and potential ways of adaptation and mitigation. Sakschewski, et al. (2014), for example, finds that prior knowledge influences socio-scientific reasoning and decision-making competencies on energy-related socio-scientific issues. On the other hand, Allum, et al. (2008) conclude in their meta-analysis that there is only a minor relationship between general scientific knowledge and a person's attitude towards socio-scientific issues, with the impact strength varying depending on the respective socio-scientific issue and the related content knowledge. Further studies and analyses show a similarly mixed and ambiguous picture for the role of content knowledge for decision-making processes, pointing out the need for further research on this issue (e.g. Jönsson 2016; Sadler & Donnelly 2006).

Looking further into the literature, scientific content knowledge appears to be not the only contributor in question. Beyond knowledge, particular practices (e.g., assessing the validity of scientific arguments), as well as motivational orientations and attitudes are attributed to a climate literate person (e.g. Dietz et al. 2007). According to Kahan, et al. (2012), political ideologies have a stronger influence on the attitudes towards climate change than knowledge. Guy, et al. (2014) supplement that the skepticism against climate change increases with the number of people who are identifying themselves with conservative political parties and free-market economies. Of course, these factors can (or should) hardly be influenced by science education, but in order to understand people's decision-making regarding climate change action, they have to be taken into account. Lee, et al. (2015) showed that the public is in general not convinced that climate change is a personal threat (i.e. lacks risk perception). Dietz, et al. (2007) revealed that in addition to various personal characteristics (e.g., gender and age) such risk perception impacts the acceptance of political measures regarding climate change. With lower knowledge levels, trust in policy measures decreases and risk assessment appears to decline. Also, gender differences in risk perception were identified. Women are generally more worried about environmental issues and perceive their own vulnerability differently (Dietz et al. 2007). Recently, Aksit, et al. (2018) put forward that climate-change-related content knowledge (e.g., about energy and systems) influences risk perception, and risk perception can influence behavioral intentions. Hence, it can be concluded that energy and system knowledge have the potential to impact energy-related behavior through risk perception (Mittenzwei et al. 2019).

When looking at the instruments used to assess knowledge in the mentioned research studies, it becomes apparent that most studies focus on general scientific knowledge (e.g. Kahan et al. 2012) instead of specific knowledge about climate change, which might have a significant effect on the correspondent results and conclusions. The U.S. Global Change Research Program (USGCRP), in cooperation with the National Oceanic and Atmospheric Administration (NOAA) and the American Association for the Advancement of Science (AAAS), thus promotes to focus education on *climate literacy*, which includes specific knowledge about climate change, its causes and consequences, as well as skills relevant to act in a climate protecting manner, and attitudes towards such actions. Following an extensive development process, the USGCRP defined a list of seven climate literacy principles which include aspects of conceptual knowledge (content, procedural, and epistemological knowledge), the ability to analyze climate data and to evaluate and reflect on students' own behavior, as well as relevant knowledge of and about scientific practices and scientific inquiry (USGCRP 2009). However, a comprehensive literature review (Mittenzwei et al. 2019) revealed that existing assessment instruments for climate change still primarily take declarative knowledge into account and do not focus on climate literacy or on conceptual knowledge about climate change, nor do they address scientific practices or attitudes. Furthermore, such instruments vary greatly between different research studies, making the results somewhat incomparable. For this reason, when pursuing research aiming at collective climate change action and the role of knowledge and knowledge transfer, it appears necessary to base these research efforts on a sound climate literacy assessment instrument, which creates a comparable data basis and covers conceptual knowledge, scientific practices, and attitudes towards climate change and climate action at the same time.

From an educational research perspective, learning processes can occur in three different contexts: formal, non-formal, and informal education. Formal education in school offers students structured, syllabus-guided opportunities to learn knowledge and skills, but also cultural values are conveyed that may influence students' attitudes and beliefs. Today, science education in schools is increasingly enriched by outreach activities that add non-formal learning opportunities, e.g. in out-of-school student labs. And finally, students gain knowledge and skills in everyday life situations (e.g. by watching television), so-called informal learning (OECD 2018). It can be assumed that for the development of climate literacy, all three learning contexts are relevant and should thus be further investigated. However, the educational system only has direct access to the formal and non-formal approaches. So far, evidence about specific learning activities regarding climate literacy is scarce. Shepardson, et al. (2017) propose an approach focusing on system thinking. Hufnagel and Kelly (2018) describe a framework for attending to emotional expressions; Zeidler and Newton (2017) suggest to apply a socio-scientific issues framework. Furthermore, scholars propose approaches that address the usage of physical models (Shepardson et al. 2017) or fostering students' argumentation skills about the impact of global warming (Choi & Shepardson 2017). In order to investigate, which kinds of instructional approaches are successful in conveying knowledge and competences necessary for students and future citizens to make sense of climate change and collective measures to mitigate it, further comparative research has to be conducted. In this context, Wals, et al. (2014) call for a closer integration of science education and environmental education. In their opinion, science education would often be too superficially aimed at knowledge and skills as preparation for university studies, whereas environmental education would focus on imparting real-life experiences and corresponding values, but at times tends to disregard knowledge and competence aspects. To address urgent challenges such as climate change, Wals, et al. (2014) propose to synergize both research directions through common approaches - for example in the field of Citizen Science.

2.2 From climate and energy literacy to energy-saving behavior

In educational psychology, peoples' (change in) behavior can be depicted by several different models. One of these is the expectancy-value model of achievement (Eccles & Wigfield 2002). According to this model, achievement-related choices and performances are based on the expected success and the value of an action. Among other things, the value of an action is influenced by its relative cost. This cost can include expenses that occur when an action is performed, as well as when an action is avoided. For example, the use of public transportation may lead to a perceived reduction in comfort, while driving by car instead leads to an abstract threat in the future from the consequences of climate change. Evaluating these costs directly influences the intention to act by determining the value of an action. In this process of evaluation, previous experiences are of great importance. These experiences can refer both to the success of an action or to its relative cost. Actions that have already shown to be successful in the past and that have low relative costs as well as high value assignments are performed more often. On the other hand, actions that have high relative costs, because they restrict the standard of living, or actions, of which the success cannot be experienced, due to its consequences only being visible in the future, are performed less frequently. With regard to climate change, this poses a great challenge because both the success of an action as well as the threats resulting from an action (or lack of action) will only become visible in the future and mostly in a rather abstract way. Thus, it seems important to foster citizens' system thinking ability, i.e. their ability to perceive a system's organization and behavior and to estimate potential systemic effects of certain actions or processes and thus develop system-adequate intentions to act (Mehren et al. 2018). Among other factors (e.g. scientific knowledge regarding the respective topic or challenge, or a basic understanding of statistics and reliability of data), such system-thinking seems important for citizens in order to be able to properly identify and evaluate context-specific risks and benefits and to make informed and evidence-based decisions (see Hansen & Hammann 2017).

Another psychological model that can help explaining how expectations and values are transferred into active behavior is the Integrated Action Model based on Martens and Rost (1998). The Integrated Action Model describes the preconditions under which individuals are willing to engage in environmental-friendly behavior (see Fig. 1). Risk perception (i.e. acknowledging personal risks from inactivity regarding environmental-friendly behavior) and responsibility attribution (i.e. who citizens deem responsible for taking action – government agencies, economic entities or themselves) play a role in the development of motivation, which itself influences the intention to act and volition. The combination of these two models from educational psychology leads to the conclusion that factors like risk perception, self-efficacy beliefs and responsibility attribution influence the value of an action over its relative costs or mediated by motivation. For this reason, regional consequences of climate change and knowledge about the spatial distribution patterns of global warming could have the potential to initiate behavioral change among people. This involves knowledge about climate change and energy, but also system-thinking, as effects of certain measures on the global economic or ecological system have to be estimated and evaluated. To make personal as well as societal risks visible and to thus affect personal behavior and willingness-to-act, tools and approaches are needed that foster citizens' awareness as well as their knowledge about potential ways of action.

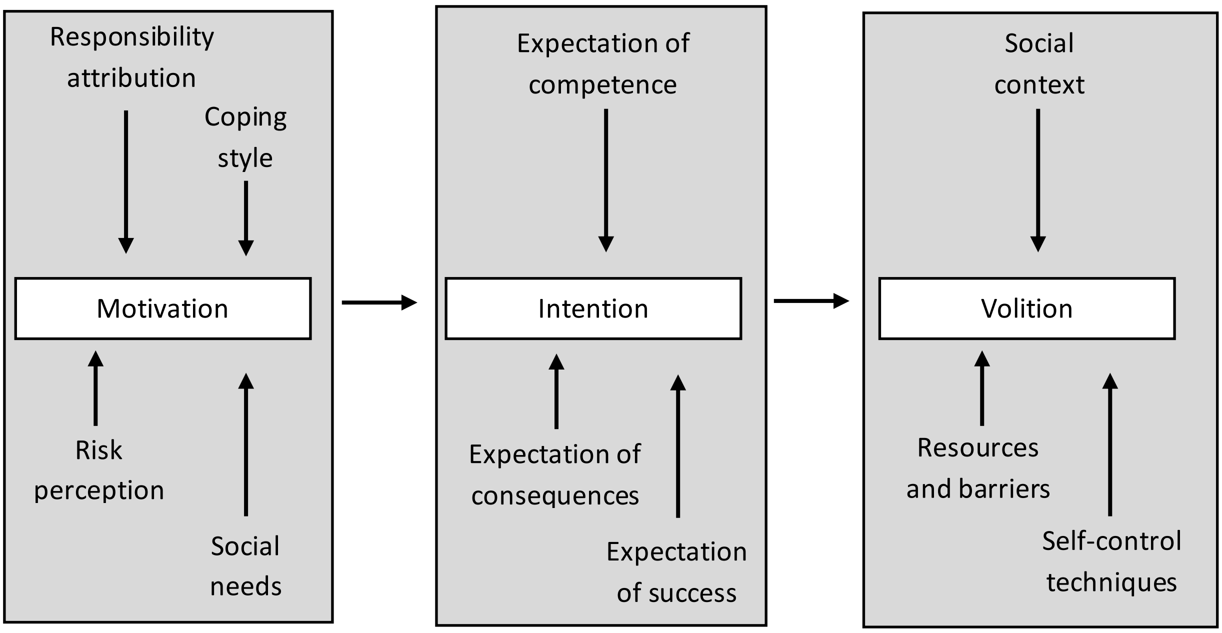

Figure 2: Integrated Action Model (Martens & Rost 1998; Schlüter 2007)

A third model that is frequently used in environmental psychology is the Theory of Planned Behavior (e.g. Ajzen 2011). In this model, peoples' intention to act (which eventually leads to their actual behavior) is influenced by their attitudes towards this behavior, their subjective norms, and their perceived behavioral control. Bamberg (2013) applied the Theory of Planned Behavior to the context of self-regulated change in car use and could show that an intervention which was oriented towards his "stage model of behavioral change" was successful in reducing people's motor car use. All of the three described models can be used to structure and guide research on how climate literacy and other factors influence people's behavior and what policy and governance measures could be helpful in supporting individual, as well as collective changes and solutions in the context of energy transitions. Which model to choose, depends on the research question at hand, as well as the disciplinary (or interdisciplinary) approach that is taken.

In conclusion, it can be supposed that there is a complex network of personal factors that contribute to people's behavior (Mittenzwei et al. 2019). Among these factors are climate literacy (which involves system-thinking ability, risk perception and responsibility attribution), socio-economic status, efficacy expectations, and others. However, it remains somewhat unclear, which of these factors impact behavior to what extent. Modelling these factors and deriving correspondent recommendations for educational and participation efforts, as well as governance measures, are all central aims of future research and could lead to fostering energy transition efforts.

2.3 From energy-saving behavior to collective action

For some elements of the *Energiewende*, such as the electricity sector, the challenges lie mostly in providing sufficient infrastructure regarding energy storage and distribution (challenges which are mostly approached on a state-wide or national level), there is (apart from potentially rising prices) no real change for consumers and thus no strong need for behavioral change. Using electrical energy works the same way, whether it is renewable or not. For other elements, such as a change in mobility patterns, however, consumer habits and behavior play a huge role, not only on an individual, but also on a collective level. New transportation technologies not only require a whole new infrastructure, but also different mobility patterns. While in traditional mobility patterns, one single transportation device (e.g. a car) is used for the complete travel distance, sustainable mobility relies on a network of different transportation methods, of which often several are used subsequently in order to reach a destination (e.g. bike, train, shared car). Thus, in order to participate in and eventually facilitate successful mobility transitions, citizens have to be enabled to engage actively in correspondent decision-making processes (in order to develop collective identity) and to shape transition processes through their own behavior. For this to be successful, factors that influence peoples' decision-making and subsequent behavior, as well as interdependencies between these factors have to be identified in order to develop measures to approach them. In a second step, tools are needed to improve awareness of climate change (i.e. risk perception), the necessity to act and the awareness of methods to do so (i.e. efficacy knowledge).

Following up on the example of the transport sector, the German climate protection and energy consumption goals are unlikely to be achieved by 2020. Although relative GHG emissions per vehicle and kilometer traveled have been significantly reduced since 1995 as a result of technological advances, absolute emissions in the transport sector even increased during the same period (BMU 2018). This "rebound effect" translates into a 13 percent increase in total vehicle mileage, which stands for increased motorization and increased activity, and a trend towards larger and heavier passenger cars (SUVs) (Canzler & Wittowsky 2016). This development shows that technical efficiency improvements alone will not reduce energy consumption or emissions of greenhouse gases and pollutants. For an efficient transport system that takes the choice of transport in day-to-day traffic into account by promoting cycling, walking and public transport, and by interconnecting different modes of transport, people's behavior has to be included as a factor. Incentives can be set by providing urban-scale parking space reductions and speed limits, but eventually a change in collective identity is needed in order to develop visions and strategies towards a sustainable transport system and mobility behavior (Bamberg et al. 2015), as well as for other elements of the *Energiewende*.

Bauwens (2016) states that collective efforts, such as community-based renewable energy initiatives may be important actors in the transition towards low-carbon energy systems and are an important condition for success in financing the transformation of energy systems. According to Wright, et al. (1990), "a group member engages in collective action any time that she or he is acting as a representative of the group and the action is directed at improving the conditions of the entire group". Bamberg, et al. (2015) explored, how theoretical and empirical insights into the motives underlying participation in collective action – gained in the domain of social injustice and protest – can be transferred to the field of collective climate protection action. They state that there is growing skepticism whether an approach focusing on changing individual behaviors alone will achieve the degree of change required for the transformation toward a more sustainable society and conclude that instead of (only) focusing on changing individuals' consumption behavior, it could be valuable to investigate how, when, and why people take collective action aiming to engage in sustainable production and consumption patterns. As examples for such collective actions, Bamberg, et al. (2015) name initiatives such as "Transition Town" (www.transitiontowns.org), which pursue many locally-based activities, such as establishing locally-owned renewable energy companies, promoting locally-grown food, encouraging energy conservation, exemplifying low-carbon living, and building supportive communities around these activities. From their review of the literature, Bamberg, et al. (2015) identify four different pathways or motives that lead people to get engaged in collective climate change action:

The cost-benefit pathway

According to Olson (1965), people calculate the costs and benefits of a particular action and then try to maximize their subjective utility. Whereas everybody may profit from the benefits of successful collective action, such as in the case of mitigating climate change, the costs and efforts of participation have to be borne by individuals. Opposed to a strictly rational actor, which would do nothing and wait for others to take care of the collective action ("free-riding"), active participation in collective action appears more likely if it is associated with benefits only obtainable through participation. For this, three "selective" motives can be formulated (Klandermans 1984): A *collective* motive, relating to the benefit of the collective action goal for the individual, and the individual's belief in the accomplishment of that goal. A *normative* motive that represents the individual's assessment of his/her peers' thoughts about the collective action. And a *reward* motive that relates to individual costs and benefits of collective action.

The collective efficacy pathway

According to Bamberg, et al. (2015), empirical research showed that a group's objective resources are less important than the individual actors' subjective perceptions that the group as a whole is able to successfully organize and conduct collective actions. This can be framed as *collective efficacy*, referring to expectations that one's group is able to achieve social change through collective action. A high perceived collective efficacy appears to be linked to a higher motivation to participate in collective action (van Zomeren et al. 2008).

The group-based emotions pathway

Group-based emotions, e.g., anger resulting from unfair collective disadvantage, can lead to taking collective action. This relation could be replicated in a meta-analysis of related studies (van Zomeren et al. 2008).

The social identity pathway

As collective action represents behavior as a group member, a strong sense of collective identity is necessary for group members to engage in collective behaviors aimed at improving their in-group's situation. At one point, the movement's norms, interests and goals become self-defining, resulting in an "inner obligation" to become actively involved (Simon & Klandermans 2001).

Overall, the named pathways reflect the importance of focusing on *climate literacy*, i.e. a combination of climate knowledge, skills, and attitudes, when investigating factors contributing to collective climate change action, as opposed to climate knowledge on its own. Educational measures should convey norms and attitudes, supporting the cost-benefit pathway. At the same time, efficacy knowledge (i.e. knowledge about potential measures to mitigate climate change and their respective efficacy) could promote the collective efficacy pathway towards collective climate change action. And conveying the risks attached to climate change could trigger group-based emotions, which would then lead to a higher willingness to engage in collective action. Following their study results, Bamberg, et al. (2015) reason that peoples' motives for engaging in collective action might change throughout their commitment. When approached for the first time to join a collective movement, a person's decision seems to be mainly driven by perceived personal costs and benefits (Olson 1965). Over time, however, frequent contacts and group activities appear to increase the person's identification with the group. Internalized group norms and participative efficacy seem to play a growing role for a person's participation over the course of his or her engagement. According to Bamberg, et al. (2015), future studies should focus on the association between participation intention and actual participation, as there is supposed to be an "intention-behavior-gap".

3 Realizing local solutions through knowledge transfer and collective experiences

If collective energy transitions are to be successful and social identity of its participants is to be raised, shared experiences must be made possible on the part of those involved. In addition to the transfer of knowledge, this could achieve the conveyance of values and positive attitudes towards the *Energiewende*. A key instrument for linking knowledge transfer and value transfer and thus enabling transformative processes is the Citizen Science Approach (CS) (Bela et al. 2016; Groulx et al. 2017; Wals et al. 2014). In a comprehensive systematic review, Groulx, et al. (2017) identified a total of 23 variables that can be influenced by CS, including knowledge and competence, but also attitudes, awareness and empowerment. The authors distinguish between factors at the individual as well as the community level and point out that the state of research and data quality regarding the effects of CS is still low. For further research projects, they suggest that in addition to a classic consideration of the impact of CS on climate change and communication, the perspective of transformative learning (which emphasizes how and at what points CS involvement leads to critical reflection on one's own ideas, attitudes, values and behaviors) should be taken into account (e.g. Diduck et al. 2012). Such transformative processes do not seem to be limited to the individual level on which they are often examined. Bela, et al. (2016) highlight the potential of CS to support transformation processes at the organizational and institutional levels, but at the same time point to a low level of research.

For a successful decentralized energy transition, Kemfert and Canzler (2016) describe as key prerequisite to create transparency, improved information and education, and the training of decision-makers and consultants. CS approaches provide great potential to do so, if they are designed thoughtfully and theis goals are set accordingly. Radtke (2016) argues that participation in energy transition projects can be fatiguing and frustrating if these projects set out with relatively rigid initial goals and strategies in combination with discursive participation procedures. If open participation is desired, the ways and procedures to achieve those goals should be kept as open as possible. As part of their report to the European Commission, Gancheva, et al. (2018) state that at local and regional level, access to technical information as well as advice on the initiation, financing and social implementation of energy transition measures is crucial. The experience gained as part of the work of “energy communities” could contribute significantly to the success of projects in other places through appropriate outreach.

Community energy can be characterized as projects with a high degree of community ownership and control, in which members of that community benefit collectively from the outcomes (Becker et al. 2017). From the point of view of the European Commission, resulting "energy communities" play an important role in achieving the envisaged goals in the area of energy transitions (Gancheva et al. 2018). Goals for community energy projects include “addressing climate change, the overall reduction of energy consumption, the protection of biodiversity, sustainable agriculture, a transition town agenda, or social justice and the empowerment of disadvantaged social groups” (Kunze & Becker 2015, p. 427). Bauwens, et al. (2016) point out the hybrid character of community energy projects as pursuing both profit and non-profit motivations, while Fleiß, et al. (2017) argue that financial motivation is the main factor for turning people towards community energy projects. Overall, the link between social movements, its motivating factors, and community energy has been poorly explored (Becker et al. 2017) and requires further research to tell, which individual factors are needed for successful community energy projects– or at least from which factors they benefit. Examining information from four community energy projects (*Machynlleth* in Wales, *Som Energia* in Spain, *Retenergie* in Italy, and the

Berlin Energy Roundtable in Germany), Becker, et al. (2017) conclude that such projects seem to share "general aims of socio-ecological transformation, which may extend beyond the energy sector" (p. 33), implying that financial revenue is not the only motivation for people to participate, but that other aims and values seem to play an important role as well. Interestingly, as Becker, et al. (2017) state, all four examined community energy projects originated from previous social movement activities and their activities continue to be linked to these movements.

> "All projects share the notion of empowering citizens, either as members or as voters, and to take part in addressing climate change. However, the scope of aims ranges from topics around energy consumption and regional development in Machynlleth, a social and sustainable energy perspective for urban areas in Berlin, to the more radical socio-ecological agendas of the two cooperatives [Som Energia and Retenergie]. Machynlleth and Berlin involved the realisation or the discussion of specified funds to direct revenues to a specific cause. In short, all four cases combine claims for a more democratic economic model for energy provision with other social and environmental goals." (Becker et al. 2017, p. 32)

Overall, it thus appears that for the establishment of community energy projects, existing social movements and a strong community identity seem to be important prerequisites, while several different factors influence their ongoing success and individual people's willingness to become and stay engaged. Bauwens (2016) describes the heterogeneity amongst participants of community energy projects and argues that it can partly be explained by institutional factors (e.g. market and community logics within the initiatives, including financial incentives), spatial patterns, and attitudes towards cooperative management of community energy projects. To account for this heterogeneity, it is important to ensure adequate methods of communication and knowledge transfer amongst participants of community energy projects. The Berlin Energy Roundtable movement, for example, suggested a number of participatory processes, such as "public meetings at a municipality level, key documents made publicly accessible, and an extended steering board with representatives from the City Council and elected citizens" (Becker et al. 2017, p. 31) towards this end.

4 Future directions

The theoretical rationales and models, as well as the empirical evidence to date (although not exhaustive) suggest that a multitude of internal and external factors has to be considered if people are to be meaningfully involved in collective efforts aiming at energy transitions and climate change mitigation. This calls for interdisciplinary research projects that take into account psychological, educational and societal factors, as well as the provided infrastructure, governance, and technical preconditions. In this section, some potential lines of future research and knowledge transfer efforts in the context of energy transitions will be elaborated.

To address complex, multi-factorial problems such as climate change and energy transitions (and related research questions), interdisciplinary approaches are needed, which leads to a strong demand for interdisciplinary capacity building. Such interdisciplinary capacity building would involve integrating knowledge from different sources (both theoretical and practical) on the on hand, but also appropriate research infrastructure on the other hand, including interdisciplinary journals, conferences, teaching programs, and physical spaces designed to facilitate interaction and thus calls for sustained public investment in the long term (Lyall & Fletcher 2013). Numerous national and supra-national founders (e.g. BMWi 2018; Horizon 2020 Work Programme 2018-2020 - 10. Secure, clean and efficient energy 2019) call for interdisciplinary research collaborations between social and natural sciences to address research challenges connected to clean and renewable energy, as well as its acceptance and beneficial utilization in society. However, there seems to be little consensus about how interdisciplinary capacity building can be achieved in different settings (Lyall & Fletcher 2013). According to Lyall and Fletcher (2013), interdisciplinary integration rarely happens spontaneously and as such, effective interdisciplinary research has to be catalyzed, planned and continuously revisited.

To address challenges that require interdisciplinary approaches to be dealt with, research networks and research alliances gain importance. The *Climate Literacy and Energy Awareness Network* (CLEAN, www.cleanet.org), for example, sets out to explicitly promote inter- and transdisciplinary input from individuals and groups with a range of expertise, aiming for a collective impact on the climate literacy of the public and on the effects of climate change on society (Ledley et al. 2014). According to the network, knowledge transfer between its members, as well as towards other organizations, are central to achieving its goals. Sustained interdisciplinary capacity building can be key to success in establishing robust institutional relations necessary to influence policy and governance and in promoting responsible innovation (Lyall & Fletcher 2013). Research networks and alliances such as the CLEAN network or the *Leibniz Research Alliance on Energy Transitions* rely on continued institutional and financial support, as well as on fundamental interdisciplinarity-oriented infrastructure in order to pursue their ambiguous goals. For interdisciplinary research projects, it is often difficult to set a research agenda, which fully addresses the interdisciplinary research aim at hand while at the same time providing sufficient opportunities to all project partners for publications and visibility in their respective fields – factors that still remain crucial for individual careers as well as funding opportunities for other research. However, such interdisciplinary projects are essential to the goal of mitigating climate change and working towards successful energy transitions on local and global levels and should thus be supported by institutional efforts and systematic interdisciplinary capacity building, if they are to be sustainably successful.

With regards to the state of research on the role of knowledge, literacy and other factors on individual energy-saving behavior, as well as on collective transformative action (as explicated in section 2 of this working paper) several lines of research can be formulated, which bear interesting challenges and important aims to aid energy and mobility transition efforts on local, regional and global scales. Without the aim of being exhaustive, a selection of potential research questions will be provided here, each of which could guide future disciplinary or interdisciplinary projects:

Climate and energy literacy:

- How can climate and energy literacy be conceptualized and adequately measured?
- How can peoples' knowledge about climate change and about measures to mitigate it (i.e. efficacy knowledge), as well as their risk competence and decision-making be fostered?
- What characterizes effective learning opportunities for promoting climate literacy?
- What recommendations can be derived for governance and participation efforts?

Climate-friendly and energy-saving behavior:

- Which aspects of climate literacy are particularly relevant in the development of climate change-related behavior?
- Do people performing climate actions have a different perception of climate change risk than people who do not take action?

Participation in collective action:

- How do participation measures have to be constructed in order to activate the previous knowledge of the participants?

- What is the nature of the relationship in the strategic coupling of social movements and community energy projects and what are potential contradictions it may entail (Becker et al. 2017, p. 33)?
- What additional information can qualitative analysis such as in-depth interviews with cooperative members provide towards a more fine-grained analysis of member's motives and level of engagement (Bauwens 2016, p. 289)?

Energy-saving behavior and collective energy action:

- Which individual and systemic prerequisites are important for sustainable energy behavior and participation in collective action?
- Which variables can be influenced and how can and should corresponding interventions be efficiently designed? How can curricular and extracurricular interventions be designed to empower and motivate citizens to participate in energy-related decision-making processes?

A further important line of research and subsequent action relates to the transfer of concepts that have been successfully implemented on a local level to a global scale and the promotion of corresponding measures (e.g. as *best-practice* examples). For such transfer activities, the educational science concept "Science Technology Society" (STS, Aikenhead 2009) can be action-guiding. The interactions between science, technology and society are to be explicitly considered and aspects of mutual benefit, but also potential areas of tension, should be worked out and discussed together with participants of respective transfer actions. Appropriate transfer methods include knowledge transfer in student laboratories (e.g. Heyduck & Harms 2015), Open Educational Resources, competitions, and participatory learning (e.g. Hagedorn-Saupe et al. 2014). It is important to enable communication between experts and stakeholders of different levels of knowledge in order to strengthen the feeling of a "community" (Einsiedel 2007). Continuing education efforts as well as using municipal energy transition projects (e.g. community energy projects) as best practice examples should therefore be employed to foster knowledge transfer and a "globalization" of successful local energy transition measures. According to Schäpke, et al. (2017), living labs can serve as transformation tools by creating transformation knowledge and contributing to societal change at the science-society interface and can help to realize local social innovation potential. In a transdisciplinary cooperation (i.e. co-design of research process and co-production of knowledge with actors from economy, politics, administration, research and societal stakeholders), participants develop and test solutions, evaluate them and come up with a joint long-term conception of transferable solutions. An additional area of research and action would be the educational impact of CS projects in the context of climate change and energy transitions, as well as their impact on an organizational and institutional level.

5 Conclusion

Energy transitions can only be successful if they do not solely rely on technological and regulatory efforts, but also take people's decision-making and behavior into account. Such behavior can only be indirectly influenced, for example by setting certain incentives or by appealing to people's risk perception regarding climate change and their intention to act accordingly. While studies show that specific knowledge (and thus education) can have an impact on such risk perception in the context of climate change, it is not completely clear how this pertains to actual individual behavior or engagement in collective action and what other factors contribute to this (as elaborated in section 2.1). Several theories (e.g. from educational or environmental psychology, as outlined in section 2.2) model how people's intention to act is formed, taking into account not only knowledge, but also prior experiences, system-thinking ability, risk perception or other personal and external factors. Thus, while knowledge seems to be one prerequisite for people to make informed decisions, it appears to be by far not the only, or even main contributor. Educational efforts and participation efforts that aim at supporting successful energy transitions should thus not focus on knowledge transfer exclusively, but also put a strong emphasis on allowing positive experiences with collective climate action, addressing risk perception and efficacy knowledge as well as positive attitudes towards climate change action. All these factors do not only appear to influence individual climate-friendly behavior (as depicted in section 2.2), but also to potentially support collective climate action (as outlined in section 2.3), and are thus part of *climate literacy*, i.e. the knowledge, skills and attitudes necessary to engage in climate-related action in an informed manner. Using a citizen science approach or organizing collective action in the form of an energy community are two potential pathways in which such holistic approaches towards supporting energy transitions can be realized (as discussed in section 3).

Overall, however, there are still a lot of open questions relating to the structure of climate literacy, the role of knowledge and knowledge transfer in the context of energy transitions and the design of respective educational and participation efforts (see section 4). Addressing these questions requires interdisciplinary approaches, which in turn require respective financial and operational resources. If such efforts are taken and the correspondent research questions are addressed, the energy transitions necessary for the future well-being of the global society as a whole can be meaningfully supported and empowered.

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