8 Outlook

When thinking about an electrical energy system for the future, many publicly stated thoughts and reported work products revolve around increasing the share of variable renewable energy (VRE) in the energy system to decrease use of carbon-based fuels and thereby reduce CO_2 emissions. This contribution to mitigating climate change and its consequences ensues an increasing challenge of mismatch between times of energy supply and demand arising for operating an energy system with large shares of VRE. Having identified the mismatch challenge to solving the environmentally relevant problem of too high CO_2 emissions from burning carbon-based fuels for energy generation, solutions are sought after. How or from what perspective one looks at problems can importantly influence the solutions one thinks about and suggests.

Early on, when behavioral sciences began to address environmental problems as a field of application, Cone and Hayes (1980) in their book *Environmental Problems/ Behavioral Solutions* from 1980 describe the following reoccurring sequence of events as they have observed them for dealing with several environmental problems: "First, the problem is recognized. Next, physical technology is developed to solve it. Eventually, it is realized that physical technology alone cannot solve the problem and that its behavioral components must be examined. Early work on the behavioral side of the problem usually deals with indirect features such as attitudes, knowledge, or information. Out of this, educational programs and appeals are developed that attempt to change these attitudes. Finally, as the problem continues, more direct behavior-change technologies are developed." (Cone & Hayes, 1980, pp. 14–15). This still appears to be a good description of the general sequence of events when dealing with environmental problems and holds for the problem of reducing CO_2 emissions in the supply of electrical energy as a current problem of environmental relevance. Introducing VRE generation

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units into the modern electrical system is an important physical technology solution (and increasing energy efficiency to reduce energy consumption is another). However, it entails a hindrance in implementation, the mismatch problem, which again is largely approached by technological solutions such as developing storage systems, expanding the grid and flexibilization of demand. The notion that behavioral components should be considered became probably most notably apparent in questions of placing and distributing these physical technologies (VRE generation units, storage systems, grid infrastructure). And in short it seems just to say that under the umbrella of the broad and unspecified term of acceptance, at first and mostly, attitudinal or intentional constructs are attempted to be changed. That behavior could be an important part of solving the mismatch problem is maybe more obvious in the approach of flexibilization of demand, especially when it targets residential electricity consumption. As part of this approach, a strong focus is put on the development of smart meter technology and information and communication technology but also on developing DSM strategies. Even though an emphasis seems to be put on technical and economic DSM potentials, more studies look at behavioral components such as information, framing and nudging interventions to increase participation and at more direct behavior-change interventions (as they target consequences of behavior) such as fine-tuning rates and incentive strategies. Apart from the questions of barriers arising from keeping in line with this sequence and potential benefits of switching it up or parallelizing it, the question is, where do we go in dealing with the challenge of integrating VRE into an energy system by behavioral means.

Where current research on solutions is too narrow sighted, is, where the transformation of the energy system is thought to be mainly achieved by physical technology in lieu of behavioral technology. This dominant conception is detrimental to finding solutions for environmental problems because it limits the questions that are asked. Energy research is in large parts driven by technical questions under the consideration of economic boundary conditions. It ensues a limited perspective on the role of human behavior in the transformation process, which is mostly expected to adjust to technical developments or innovations. Consequently, if the behavioral dimension is addressed, frequent research questions in psychology and social sciences are for example: How can an infrastructure project be implemented with few oppositions from citizens? What factors influence acceptance of certain policies, or specific renewable technologies? How do innovations diffuse and what influences the distribution of such technologies? How do types of communication or framing of information influence the acceptance or diffusion of political measures, projects or technologies? How can demand flexibility be increased? Without taking a step back at this point to conceptually and theoretically analyze the problem in question from a behavioral or other social science point of view, the barrier of a limited perspective is likely to be carried over to the planning and testing of interventions potentially limiting their effectiveness.

Arguing that this is the current situation for applying typical environmental psychology and current DR strategies to increasing demand flexibility, it is suggested that in order to go beyond the very roughly achievable 10% in peak demand shift, using behavioral analysis theory is helpful in finding answers to the problem of shifting energy using behavior. It highlights the importance of context structures which are not the main focus in the other approaches. By analyzing the variability in behavior in general and in appliance using behavior for similar patterns of behavior distribution in a large sample of subjects from the TUD, one could see that different behavioral patterns can be theoretically connected to regularities in context structure which provide common contingencies for large shares of people and influence the timely distribution of behavior. Thus, whatever addresses the problem of shifting appliance using behavior, it works within the limits of context structure, which can be more or less restrictive. Pointing in the same direction is the observation that behavioral effort for shifting appliance using behavior differs for different times of the day, which changes the effectiveness of DR and other interventions for different times of the day.

It is not necessarily a bad thing to first try out more or less well working heuristics on how to change behavior, if the effects one needs to achieve are small or if tests show them to be even of medium size if designed and implemented very well. If this is sufficient because, for example, the flexibility form residential demand is only one small part in a set of measures which together achieve the result of providing enough flexibility in the energy system to integrate close to 100% VRE, then it could be more cost effective. But is this really the case for the problem of designing an energy system which can incorporate large amounts of fluctuating energy?

While currently the effects of "typical" behavioral interventions for shifting energy using behavior in time are estimated to be small to medium, the needed effects are not. For a while it looked like behavioral interventions would play an important part in a set of other interventions taken on a technical level to deal with fluctuations in energy generation and unmatched demand. But as was exemplified for price-based DR and some intentional psychological interventions, the contribution of behavioral interventions designed in this fashion seems too small in relation to implementation cost. Roughly speaking, the possible options at this point seem to be either dump the idea of designing behavioral interventions within the limits of current context structures or keep the context structure and focus on alternatives which only require small behavioral adjustments to technical changes. Choosing the latter option will mean focusing on technical solutions which have a larger impact on energy consumption in households like electrical heat pump, electric vehicle and battery storage and have them be managed automatically without a need to change energy using behavior beyond the point of buying, installing, letting it run automatically and repairing the technical solutions. This is the standard way of doing things it seems and although there might be some risk of failure or at least difficulties due to a possible lack of adopting innovations, it appears the safer approach for stabilizing a current system of living and working in the short run. Choosing the former option would mean pursuing the suggested intervention approach of lifting context structure restrictions and also to keep working on the conceptual and theoretical analysis of the problem with a focus towards integrating knowledge from neighboring disciplines such as sociology and behavioral economics.

For intervention purposes, accessible context structures influencing energy behavior are suggested to be occupational and educational regularities. This relationship would have to be experimentally demonstrated. Then one would have to evaluate to what degree interventions aiming at increasing behavioral variability in occupational and educational activities can reduce the mismatch problem by producing more evenly spread load patterns and by making other interventions to shift energy using behavior to specific times more effective. Given that these relations can be demonstrated, the suggested intervention of lifting context restrictions could support the implementation of VRE into the energy system beyond the already achievable effects. Implementing such interventions would entail societal changes in addition to the main aim, but arguing that a transition towards a new energy system, which influences many aspects of human life, should be possible without adjusting other structural aspects of living does seem a detrimental limitation in perspective. Also, even though at a first glance it might appear a higher impact change in terms of societal relations than changing energy rates and pricing schemes, it should be kept in mind that consequences of interventions which are not the main outcome of interest are also important to consider as potential unwanted or negative consequences. For example, recent research investigates potential negative side-effects of DR in terms of health and financial impacts for different socio-demographic groups (Fell, 2020; White, 2019; White & Sintov, 2020).

Just as it was argued that a blind spot or limiting factor of effectiveness within the typical intervention approaches is the neglect of context structure, an important shortcoming of this behavioral analysis (and by extension its suggested intervention) is the neglect of discriminative stimuli for shifting energy using behavior. It could very well be that even though it is suggested to change flexibility of working hours and schooling hours alike, which should make children more flexible as discriminative stimuli for some parental energy using behavior like cooking or mobility, important others remain unchanged and or similar for a large amount of people limiting the effectiveness of changing these specific contingencies of reinforcement for making energy using behavior more flexible.

Employing a behavior analysis perspective could become a real asset in problems of designing a less CO_2 emission intensive or even more sustainable energy system. In the specific case of shifting energy using behavior it should encompass a discussion if an investment in further investigating the option of changing context structures would change consequences of living and working in a way that seems favorable not only for the problem of generating and using energy but also favorable for living together. For these types of consideration other behavioral and social sciences are needed as well as the technical perspective which describes the consequences of behavior and context structure on the technical side of the energy system. When thinking about an energy system for the future, I think it worthwhile to envision an energy system which is a result of an ongoing process of design which systematically evaluates and tests behavioral technology and physical technology alike.