3 How to Look at Shifting Energy Using Behavior: Theoretical Analysis of Behavioral Variability

Different subdisciplines within psychology and neighboring disciplines look at different aspects, when analyzing and identifying relations between humans and other parts of environment. Some look for biological and genetic features of organisms to give an account of their behavior, some look strictly to social factors outside the organism, some focus on building internal models and test them against overt behavior, some look for functional relations in the interaction between behavior and features of its environment (Chiesa, 1994). Due to the scope of the applied problem of integrating VRE, many disciplines give accounts for explaining energy behaviors. Endorsing the statement that “No science can give a comprehensive list of causal relations for any given circumstance because this would amount to a description derived from most of the sciences now practiced, in effect an impossibly complete account of phenomena that includes all contributory factors” (Chiesa, 1994, p. 115), it is necessary to formulate the assumptions and thereby limits associated with a chosen perspective for describing, analyzing and changing behavior.

Examining models of energy using behavior, it becomes clear, that the ideas of how to categorize and describe behavior and its relation to other things and to what other things differ. The most common categorization of energy behaviors (or forms thereof with slightly different terms) are made on the basis of the aims that are to be achieved in relation to energy consumption and the means by which to achieve it: conserve or save energy by reducing behavior frequency, duration or intensity, make energy demand flexible by shifting behavior in time and conserve or save energy by purchasing, adapting, investing in or owning and using efficient technology. Although this type of categorization is useful because it identifies the targeted impacts for the energy system at the intersection of energy demand, it

F. Wille, *A Behavior Analytical Perspective on the Relationship of Context Structure and Energy Using Flexibility in Problems of Supply and Demand Mismatch*,
https://doi.org/10.1007/978-3-658-35613-2_3

does not help in changing these behaviors because the categorization does not hold enough information about behavior itself.

Categorizations of behavior, as found within psychological or behavioral science literature within the energy research context, are often made on the basis of assumed determinants of behavior, i.e., motivation, context and habit (Steg & Vlek, 2009). This type of categorization and theory building is in principle useful because by saying what causes behavior, it could also explicate how behavior is influenced and thereby map onto interventions. However, other suggested shortcomings of energy using behavior models remain unaddressed by this type of theory building. For example, Steg and Vlek (2009) sort perceived costs and benefits, moral and normative concerns and beliefs, as well as affections and symbolic factors to motivational determinants, constraints and facilitators to contextual determinants and automated cognitive processes and goal-based processes to habitual determinants[1]. As the entities in each category are diverse in what their assumed relationship to motivational, contextual or habitual behavior is, they again have models, which describe how for example perceived costs and benefits determine behavior, how normative concerns influence behavior etc. In some regards such an approach to categorization seems to entail a vast number of

[1] From a behavior analysis point of view the category of habitual behavior is unnecessary because no sperate process is assumed to underlie this "type of" behavior as it is assumed within an intentional perspective of behavior. Skinner made this point when describing a shaping procedure for a pigeon with the target of stretching the head to larger heights than before starting the shaping procedure: "To say that it has acquired the "habit" of stretching its neck is merely to resort to an explanatory fiction, since our only evidence of the habit is the acquired tendency to perform the act. The barest possible statement of the process is this: we make a given consequence contingent upon certain physical properties of behavior (the upward movement of the head), and the behavior is then observed to increase in frequency." (Skinner, 1953, p. 64). Even though the intentional perspective assumes automated cognitive and goal-based processes to underlie "habitual" behavior, thus necessitating an additional category of behavior on top of motivational and contextual behavior, habitual behavior is linked to context in this perspective as well. For example, van den Broek et al. (2019, p. 817) make the connection between habit as a descriptive term for frequent and regularly occurring behavior by writing: "Most energy behaviour takes place in stable contexts (homes) where strong energy habits can be formed and this study suggests that these habits may override people's intentions. Indeed, habits have consistently been found to be relevant to energy use (Macey & Brown, 1983; Maréchal, 2010) as energy behaviour is context dependent, automatic and frequent (Verplanken and Aarts, 1999)." While one conclusion within the intentional perspective from this observed relation between context, habitual behavior and importance of intentions in influencing behavior is to focus intentional interventions on living situations with changing contexts, e.g., when people are moving to a different place, another conclusion would be to focus changing the context by interventions in order to firstly shape a targeted behavior and secondly in order to increase opportunities for intentional interventions.

assumed internal constructs. One reason for this could be the many and in principle unlimited levels of hierarchy (of which only three levels were explicated) another might be, that on the second level of hierarchy, the only common element of the entities is that they apparently influence either motivational, contextual or habitual behavior without answering the question of how (this is delegated to the next level of hierarchy and potentially so forth) and whether there is a common principle according to which entities in each category influence motivational, contextual or habitual behavior. A result of this strong focus put on the relationships between internal constructs that together in the end are assumed to influence behavior might be, that the categorization approach leaves too soon the level of describing behavior and neglects contextual behavior as it is only one category of behavior that can be analyzed instead of being important for every behavior. Both proposed consequences are discussed shortcomings of energy behavior models and implications of applying this theoretical approach, which is why a different perspective is employed[2].

Another theoretical approach, which provides categorizations, descriptions and determinants of behavior, be it of internal, verbal or overt behavior, is behavior analysis with main concepts coming from the works of B.F. Skinner. In the 1930s and 1940s B.F. Skinner established a science of behavior (experimental analysis of behavior) and its underlying philosophy referred to as radical behaviorism (Morris, 1997). With its emphasis on the selective role of the environment, radical behaviorism looks for causal relations in the interaction between behavior (the organism) and environmental consequences (Chiesa, 1994). Spoken from a perspective focusing internal constructs, behavior analysis offers a focus on situational influences, even though it would probably be more accurate to say that behavior analysis focusses on the interaction between environment and behavior. In behavior analysis theory, it is assumed that context influences behavior because the context on the one hand sets the consequences which select behavior, or in a more precise phrasing, the contingencies of reinforcement in a given context select behavior, and on the other hand delivers discriminative stimuli which indicate different structures of contingencies (Skinner, 1981). The object of study are changes in behavior occurring during a single lifetime of an organism which are

[2] This is not to say that approaches focusing on internal constructs and motivational behavior have no merit or are unimportant for describing behavior in general or even energy using behavior in particular, even though there appear to be some empirical findings pointing in this direction (e.g., van den Broek et al., 2019). It is just to say that given the admittedly skewed overview of (environmental psychology) energy research the identified drawbacks in describing energy using behavior could be improved upon by applying a behavior analysis perspective.

assumed to be results of a selection process paralleling a natural selection process on the level of behavior (e.g., Hull, Langman, & Glenn, 2001; McDowell, 2019; Skinner, 1981). According to Hull et al. (2001) most scientists studying this type of behavior refer to it as operant behavior and often define it “as behavior that operates on the environment and changes over time (in form, organization, or relations to the antecedent environment) as a function of its consequences” (p. 521). This is the chosen perspective and object of study for describing and explaining energy using and shifting behavior as well as deducing interventions for changing behavior. Thus, when writing about “behavior” of living organisms it is always meant as referring to operant behavior.

3.1 Behavior Analysis Theory Underpinnings of Why Variability is Important

Behavior analysis theory nowadays is a rather uncommon perspective within environmental psychology which can add well to current understandings of energy using behavior. It has a different way of looking at variability in data, as a functional relation is assumed between variation in behavior and consequences of behavior as contextual determinants. Within this approach, variability between individuals and within behavior sequences of individuals can be analyzed and interpreted.

Humans do not always do the same thing. One can observe different types of behavior, different sequences of behavior, different forms of execution of behavior, different results of behavior, different surroundings of behavior. But where do these differences come from? They are assumed to be a result of selection by consequences. The observable differences in all those aspects of behavior or the observable variability, it might be said more general as this term captures the meaning of referring to a continuum from differences to similarities in behavior better, is explained as a function of the consequences of behavior (which are a result of the interaction between behavior and context). Analyzing behavioral variability and its functional relation to consequences is an important aim of a behavior analysis research approach and the chosen perspective has consequences for the way variability is treated within research (Chiesa, 1994).

For the field of psychology Chiesa (1994) points out a fundamental difference in the way variability is viewed and handled within most of psychology and within a behavior analysis (radical behaviorism) view: While most of psychology relies on inferential statistics for means of analyses, which considers variation as undesirable features of measurement error, as attributable to something yet unknown and often imposes a model of average and normal distribution (or some other central tendency and distribution model), the behavior analysis perspective is rooted in a biological concept of variation and the analysis of individual variation is an integral part in its scientific approach as one of its main tasks is to account for variability and seek order in variability. Chiesa (1994) argues that experimental analysis based on comparing group means cannot specify for an individual if the manipulation will work, it can only make statements about a nonexistent average case. By this, she also points to a possible explanation which might limit the effectiveness or usefulness of interventions derived from standard psychological study design: They do not necessarily apply to the individual; they just do so on average, which is also one of Wilson's and Dowlatabadi's (2007) main points of critique on energy behavior models.

Analyzing variability in energy using behavior could thus try to establish order for patterns of energy using behavior between different humans for certain time periods or for changes in patterns within one human over a longer time period and try to relate the observed variability to selecting characteristics of context. Variability between humans would be assumed to relate to common (shared / similar) and uncommon (not shared / unsimilar) contingencies of reinforcement. Variability within behavioral patterns of one human would be assumed to relate to (non-)changes in contingencies of reinforcement over time. While the latter could also provide information on the importance of the history of contingencies of reinforcement for changes in behavior, the former cannot, due to the smaller time period, even though the history of contingencies of reinforcement is important for observing behavior at a smaller time scale because the history of contingencies of reinforcement describes the selection process of which the observed behavior is a result. One implication of this perspective of behavior analysis theory on variability of behavior being that time as a characteristic is an important descriptive characteristic.

3.1.1 Timely Distribution of Behavior

Time is an important characteristic to account for when describing behavior. Specifically, for this analysis, because as detailed in the mismatch problem analysis for integrating VRE, the problem is mainly one of non-synchronous timing between supply and demand and a behavioral solution can mean a shifting of behavior in time. So, distribution of behavior in time (including the aspect of variability in distribution) is the main characteristic of behavior that has to be analyzed when dealing with the mismatch problem. More generally speaking, time is an important characteristic within behavioral analysis theory because selection by consequences is a process occurring over time (history of reinforcement) and because one of the most important and basic measures for describing effects of contingencies of reinforcement on behavior is expressed in relation to time, i.e., the operant rate or response rate (e.g., Baum, 2017; Hull et al., 2001; Skinner, 1938).

The history of contingency of reinforcement during the lifetime of an organism is relevant for the current or present behavior of an organism because the fit between present environment and behavior is a result of past selection (Hull et al., 2001). Chiesa (1994) contrasts this "historical" view on current patterns of behavior as being established over long periods of time by patterns of consequences in an organism's environment with a perspective focused more on episodic short term events in which the current organism is "divided into behavior and an internal, independent system that is said to account for behavior." (p. 121). This conceptual difference can be exemplified by the treatment of "past behavior" in one prominent theoretical approach to explaining behavior falling into the category of episodic research. Within the reasoned action approach (Fishbein & Ajzen, 2010) to which the TPB and the theory of reasoned action (*TRA*) belong, the importance of past behavior for predicting future behavior is recognized. However, the problem focus is not on analyzing past behavior and its role in influencing behavior, but instead to fully explain its effects by the theory's internal predictors, making the model sufficient for explaining behavior and rendering past behavior unnecessary in an explanation of behavior, e.g.: "The fact that past behavior is consistently found to have a residual effect on intentions after controlling for attitudes, perceived norms, and perceived control lends credence to the proposition that other possible determinants of intention may be missing from our model. Among the most frequently studied potential additions are self-identity and anticipated affect." (Fishbein & Ajzen, 2010, p. 317). Thus, in this perspective all influences on behavior must run through internal constructs and there is no place for analyzing behavioral processes over longer periods of time.

The importance of time as a relevant characteristic for describing behavior was already emphasized by Skinner (1938, p. 20) in his description of operant behavior: "One important independent variable is time. In making use of it I am simply recognizing that the observed datum is the appearance of a given identifiable sample of behavior at some more or less orderly rate. The use of rate is perhaps the outstanding characteristic of the general method to be outlined…". Operant rate or rate of response refers to the number or count or frequency of operant responses appearing in a certain specified unit of time and measures the probability of behavior (e.g., D. W. Pierce & Cheney, 2017; Skinner, 1938, 1953)[3]. Relating this important datum of behavior to the selection process, Hull et al. (2001) state that the recorded frequencies of operant responses over time are those which "satisfy" the contingencies of selection set in an experimental analysis of behavior and that these result in changes in frequency, distribution in time and selectable properties of behavior such as force, interresponse time, duration, form, direction and variability (e.g., Hull et al., 2001; Neuringer, 2002). To understand what is selected one has to specify the concept of an operant (response) and the concept of an operant class.

The idea for describing the unit of behavior as response class originates in Skinner's (1935) description of the generic nature of stimulus and response in which he defines a stimulus and response not as singular event but as a class of events which is specified by its defining or relevant properties for producing a consequence (Baum, 2002). In the book "Science and Human Behavior" (Skinner, 1953), Skinner introduces and defines the terms in the following manner: "A response which has already occurred cannot, of course, be predicted or controlled. We can only predict that *similar*[4] responses will occur in the future. The unit of a predictive science is, therefore, not a response but a class of responses. The word "operant" will be used to describe this class. The term emphasizes the fact that the behavior *operates* upon the environment to generate consequences. The consequences define the properties with respect to which responses are called similar. The term will be used both as an adjective (operant behavior) and as a noun to designate the behavior defined by a given consequence." (pp. 64–65). An operant response is thus viewed as a singular instance of the operant class. A main point of operant response classes is that they are functionally defined and that the unit of behavior is "whatever interacts as a cohesive whole with the environment" (Leslie, 2001, p. 543 and e.g., Glenn, Ellis, & Greenspoon, 1992). This is to say, operant responses can vary in form and appearance as long as

[3] Within the field of behavior analysis theory exist as in any scientific community ongoing discussions on concepts, methodology and terminology. In regards to response rate for example Baum (2002) and Baum and Rachlin (1969) proposed to think of the dependent variable as proportion of time spent responding and to think of behavior as divided among activities that last for periods of time. Baum (2002) argues this to be an important part of a paradigm shift in analyzing behavior from a molecular to a molar view, while others argue against the point of a paradigm shift but acknowledge other aspects of such a molar or multiscale view on behavior as being a helpful perspective on behavior (e.g., Pitts, 2013). This example is meant to point out that the way behavior analysis theory is presented here is one way to describe behavior in a behavior analysis theory approach and discussions within behavior analysis theory are neglected as this is not necessary for applying the principles as they are described here.

[4] Emphasis are as they are in original text.

they produce a common environmental consequence, they are the same operant, the same behavior. This is also important for observing seemingly the "same behavior" because similarity in appearance does not ensure that it is the same operant.

For an analysis of energy using behavior this means that the category "energy using behavior" is not necessarily an operant and hence would not refer to a useful category for an analysis of such behavior because it is not the appropriate unit of behavior which is selected. Nonetheless, by referring to energy using behavior an important consequence of such behaviors is referenced, namely the result of using electrical energy. It is questionable whether this consequence is a relevant consequence in the sense that it selects the associated behavior or parts thereof. However, it is the essential category as far as the relevant consequences for the energy system are concerned. This is why it is kept as category for describing the range of targeted behaviors. Without an experimental analysis of the different energy using behaviors, which is not a part of this work, potentially wrong behavioral units will be discussed as one behavior. The closest one comes to the idea of an operant under these circumstances is probably to group behaviors according to assumed important consequences. As the focus of analysis lies on household energy using behaviors, behaviors using appliances with different functional designations will be treated each as an operant and referred to synonymously as behavior. So, using (turning on) the appliance dishwasher is regarded as an operant because the main function of this appliance is (presumably) clean dishes, which is different from turning on a washing machine because the main outcome is clean wet laundry, which is different from turning on the dryer because the main function is drying clean laundry and the main outcome of turning on the stove is prepared food or drink. This might seem somewhat justifiable but it becomes more difficult with other appliances which have less clear or multiple assigned functions. For example, turning on and then watching the TV can have quite different consequences. Watching TV can produce diverse consequences such as laughing, relaxation or falling asleep and a description of a behavior as "watching TV" cannot differentiate between these different consequences. Furthermore, turning on the radio or laptop or computer can produce similar consequences in which case it would be appropriate to describe them as one operant. This problem of identifying the relevant unit of behavior is not solved but relevant in discussing potential problems in different analysis of energy using behavior. As far as the question is concerned of how to look at energy using and shifting behavior in a behavior analysis approach, frequency and timely distribution of operants which coincide with electrical energy consumption should be the focus of description to identify patterns of behavior which can be related to selecting contingencies of reinforcement over different timescales.

3.1.2 Defining Context

The selecting environment can be viewed as a subset of a larger domain of events in a world often referred to as environment and to distinguish between the two, Hull et al. (2001) refer to the former as behavioral environment. But this is not common terminology, as for example in D. W. Pierce and Cheney (2017) the term "environment" is defined as "functional environment" which is "all the events and stimuli that affect the behavior of an organism. The environment includes events "inside the skin" like thinking, hormonal changes, and pain stimulation." (p. 510). The communality being that the attribute "behavioral" or "functional" refers to parts of environment which relate to behavior. In case of operant behavior, these parts of the environment are a class of stimulus changes in the environment referred to as consequences and a class of antecedent stimulus referred to as discriminating stimulus (Glenn et al., 1992). Skinner specified the concept of discriminative stimulus as a stimulus in which's presence an operant is more likely to result in contingent reinforcing consequences (Glenn et al., 1992). The operant response is thus controlled by discriminative stimuli and by consequences. Red traffic lights are for example for many people in many environments the discriminative stimulus to operate the brake on their bike and a discriminative stimulus to operate the laundry machine might be for some people a full laundry basket and for others it might be an empty sock drawer. Discriminative stimuli signal the consequences in an environment and result in different operant responding and are often said to "set the occasion" for operant behavior (e.g., D. W. Pierce & Cheney, 2017). The relationship between an operant and its consequences can also provide a discriminative stimulus (Ferster & Skinner, 1957; Neuringer, 2002). Together, these three terms (discriminative stimulus, operant and reinforcing consequences) and two contingencies (between operant and reinforcing consequences and between discriminative stimulus and the contingency between operant and reinforcing consequences) are the basis for an analysis of operant behavior and also referred to as three-term-contingency (e.g., Glenn et al., 1992). This conceptualization of environment of operant behavior of which operant behavior is itself a part defines the context of operant behavior.

Different meanings of the word "context" exist within social, cognitive and behavioral sciences and as part of the contextualism debate (Morris, 1997). Whereas the meaning of context in contextualism is that of context-as-history, the meaning of context in social, cognitive and behavioral science is (also) that of context-as-place (Morris, 1997). Applying these two foci to the given definition of context one can integrate and clarify the role of time as visualized in *Figure 3.1*.

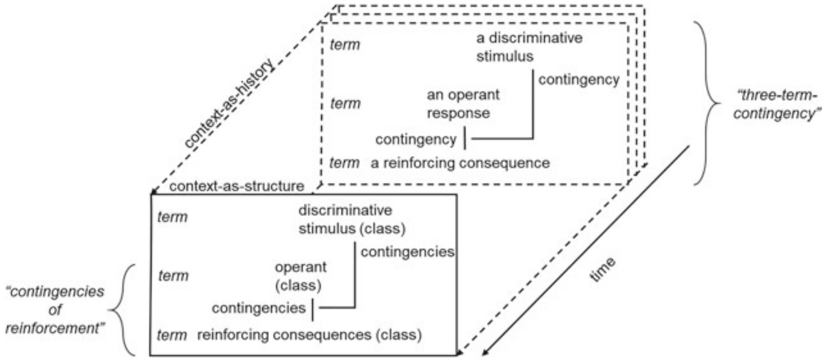

Figure 3.1 Defining context. (Own diagram)

As can be seen, instances of operants (operant responses), consequences and discriminative stimuli are depicted as discrete events observable at a specific time interval (for an alternative view, see e.g., Baum, 2002). Reinforcing contingencies and discriminative stimuli can change over time, while operant units are said to evolve as they are the result of selecting contingencies over time (e.g., Glenn et al., 1992). Describing a single instance of behavior does tell very little about the relationship between behavior and environment but describing the timely distribution of the three terms and two contingencies does. Analyzing the three-term-contingency relationship as it changes over time can be said to focus context-as-history. Choosing the focus of context-as-place does not mean to observe single, discrete instances but instead to describe the existing or ongoing structure of the three-term-contingency without focusing the evolution of operant behavior even though, what is observed and described as operant class, as class of reinforcing consequences and as class of discriminative stimuli is a result of the history of selecting contingencies and cooccurring stimulus changes in the environment. As the word structure leaves more room to encompass timely structures and the relationship between behavior and environment than the word place, this focus is referred to as context-as-structure instead. Even though for a complete behavior analysis all aspects of context are necessary, here an emphasis is put on regular occurring changes in the consequence outcomes when operated upon (patterns of contingencies of reinforcement over time). Since they select the distribution of behavior, it can be said that contingencies of reinforcement constrain or restrict variability in distributing behavior over time to a more or lesser extent. Describing these constraints and restrictions in distributing behavior over time is thus a key issue in describing possibilities for shifting energy using behavior.

Morris (1993) distinguishes between two meanings of context-as-place, i.e., here context-as-structure: "context-as-place may be most useful if we restrict it to two meanings: (a) one formal, as in initial and boundary conditions (cf. Marr, 1993), and (b) the other functional, as in conditions that alter functional relations within the three-term-contingency (e.g., establishing operations for reinforcement; Michael, 1982; see Morris, 1992a)." (p. 265). In a formal meaning for example, one could say that contingencies of reinforcement must be producible in a spatial as well as timely sense and if this is not the case, a boundary condition for performing an operant is not fulfilled. When talking about energy using behavior in households, a boundary condition could for example be for some humans being at home, while changing contingencies such as availability of electrical power from solar PV systems could be a condition that alters the functional relations with the three-term-contingency as there are regular occurring changes in production patterns. Both of these meanings can be useful to consider when describing energy using behavior.

In short, in behavior analysis theory the contingencies of reinforcement in a given context select behavior, and on the other hand, context delivers discriminative stimuli which indicate different structures of contingencies (Skinner, 1981). The contingencies of reinforcement are often characterized by different schedules of reinforcement, which describe the temporal and behavioral conditions of reinforcer delivery (DeLeon, Bullock, & Catania, 2013). A stimulus is referred to as reinforcer if access to it is contingent on an operant response which makes the operant responses within the same operant class more probable because of the contingent production of the stimulus (DeLeon et al., 2013 citing Skinner, 1938, 1981). Not only in experimental settings, but also in everyday life, environments vary along multiple dimensions determining the availability of reinforcers, i.e., the schedules of reinforcement and include aspects such as frequency of responses, time of response and passing time between operant responses (DeLeon et al., 2013). In case of everyday operant behavior which occurs in an ongoing behavioral stream multiple schedules of reinforcement operate simultaneously for different operant classes. Such concurrent contingencies of reinforcement are relevant for the relative distribution or allocation of behavior from different operant classes (DeLeon et al., 2013) or for the allocation of time taken up by behavior (Baum & Rachlin, 1969). Thus, when analyzing context structure, not only the contingencies of reinforcement of the "target" operant are relevant but also the concurrent or competing contingencies of reinforcement for other operants. The competing contingencies are important because they influence the distribution of the different behaviors in time in relation to one another. In case of energy using behaviors, it is hence useful to also describe non-household related and non-energy using behaviors in households for describing the variability of energy using behaviors as their contingencies of reinforcement influence the distribution of energy using behavior.

The way different operant responses are distributed among alternatives of operant classes according to the associated contingencies of reinforcement were first described by the matching law formulated for response rates for two alternatives (Herrnstein, 1961). Later, the distribution of behavior among alternatives was also described for seemingly single-alternative behavior in which all other behavior is allocated to other or extraneous alternatives. Here, it is assumed that the sum total of behavior is a constant (also represented by a parameter *k* in other forms of the equation) (Herrnstein, 1970, 1974) and the relation is written in the form

$$\frac{B_1}{\sum_{i=1}^{n} B_i} = \frac{r_1}{\sum_{i=1}^{n} r_i} \tag{3.1}$$

where the *B*s represent rates of behavior and the *r*s represent rates of reinforcement and which states that the relative rate of behavior of any of *n* alternative behaviors matches the relative reinforcement produced from those *n* alternatives (e.g., Baum, 2002; McDowell, 2013). As the original statement in 1961 from Herrnstein applied only to a small number of choice situations (symmetrical choice which is perfectly controlled by resource allocation), others (Baum, 1974, 1979; Baum & Rachlin, 1969) have proposed what is referred to as the power function version or generalized version of the matching law which provides a better description of empirical data and for two alternatives takes on the form (McDowell, 2013)

$$\frac{B_1}{B_2} = b\left(\frac{r_1}{r_2}\right)^a \tag{3.2}$$

where the parameter *b* is supposed to represent a bias which differs from unity if choice is asymmetrical as for example when the two alternatives as denoted by the subscripts require different amounts of cost or effort and the parameter *a* is sometimes referred to as sensitivity which also deviates from unity if the behavioral allocation is more or less extreme than supposed by the original matching law (McDowell, 2013). In many experiments with different species, the average estimate of exponent *a* takes on a value of 0.8, which is referred to as a case of undermatching, as the value is smaller than 1 (D. W. Pierce & Cheney, 2017). Even though different ideas exist for explaining undermatching, e.g., that changes in relative rates of reinforcement are not well discriminated (Baum, 1974) or that organisms may not detect subtle changes in schedule arrangements and that its allocation of behavior lags behind the current reinforcement schedule, the origin of undermatching is currently not resolved (D. W. Pierce & Cheney, 2017).

Overall, the matching law describes adaptive behavior in environments in which an individual can alternate between alternatives and allocate any amount of behavior or time associated with a behavior on an alternative (McDowell, 2013). Adaptive behavior is defined as “behavior that occasionally results in the acquisition of resources, or the escape from or avoidance of threats.” (McDowell, 2013, p. 1000). Reviewing empirical and theoretical research on the matching law, McDowell (2013) summarizes that the generalized version gives very good descriptions of human and other animal behavior in single- and multi-alternative environments as it is studied in laboratory as well as natural settings.

How behavior distributes depends on the timely pattern of contingency structures and the resulting structure in form of relations of consequences of competing operants. In behavior analysis theory context structure is not static. In interaction with behavior a structure of contingencies results that selects the rate of behavior over different possible time spans, which can be analyzed in the form of variability of patterns.

3.2 Conceptualizing Flexibility in Energy Using Behavior

While user or consumer flexibility as understood within a DSM perspective is relatively clear in terms of its’ aim to alter electrical consumption patterns by means of shifting energy using behavior in time, it does not help to understand the behavioral dimensions of energy using flexibility. By looking at how *behavioral flexibility* is generally understood within behavioral sciences one can clarify this behavioral dimension before further describing its’ conceptualization.

Behavioral flexibility describes an organisms’ adjustment of behavior to changing environments throughout its life (D. W. Pierce & Cheney, 2017). When specifying the concept of environment as done above, one can say that behavioral flexibility describes an organisms’ adjustment of behavior to changing context structures throughout its life. One may define this adjustment of behavior or "learning" as a change in probability of operant response and specify the conditions under which it comes about (Skinner, 1950). To do this, one must survey some of the independent variables of which probability of response is a function (Skinner, 1950). Using the less overloaded term adjustment instead of learning, this can be rephrased to the statement that adjustment of behavior can be analyzed by looking at changes in probability of operants over time. Thus, one looks at the variability of behavior in time and the survey of independent variables of which probability of response is a function refers to the analysis of the three-term-contingency.

This understanding of behavioral flexibility can also be linked to the description of behavior allocation as formulated by the generalized matching law. The reinforcement ratio constitutes the known contingency relations in a current context structure according to which behavior distributes or to what behavior adjusts in changing contingency relations. As was seen in empirical studies on the matching relation, deviations from perfect matching are often observed. Thus, these deviations describe important aspects of how behavior adjusts to current context structures. The generalized matching law assigns the description of how behavior adjusts to context structure beyond the specified or known contingencies of reinforcement to two parameters: The bias parameter, often understood as a preference caused by some factors not yet identified (Baum, 1974) like for example different amounts of effort associated with different behaviors and the sensitivity parameter for which, as stated before, the interpretation is not completely clear, but often taken to implicate that an organism fails to detect subtle changes in it's environment and lags behind in distributing behavior according to current contingency specifications (D. W. Pierce & Cheney, 2017). More generally, the deviations are thought to be related to the biology and environmental history (context-as-history) of an organism (D. W. Pierce & Cheney, 2017) and the fact, that these parameters play a role in describing the distribution of behavior in different context structures warrants their consideration when conceptualizing behavioral flexibility as an adjustment of behavior to changing environments.

Although in behavior analysis theory as outlined above, the term behavioral flexibility can be well described, there are also differences in employment when using the word flexibility to describe behavior. Bond, Kamil and Balda (2007) identify at least three different, though similar connotations of the term flexibility within the behavioral literature: In a first sense, flexible organisms modify their behavior quickly based on limited experience in response to subtle variations in consequences or context. Secondly, the term flexible is used to refer to exploratory, playful and versatile behavior without changing contexts and third it refers to behavior patterns, which can be repeatedly reversed depending on changes in context, as it is studied within the operant procedure of reversal learning by reversing reward contingencies.

In the first sense, the term flexibility is used qualitatively as an adjective only referring to adjustments to context structure which are quick and sensitive to subtle or small changes in context instead of large ones. Even though it describes the same process of adjustment to context, the word flexible seems to refer more to a characteristic of an organism than to a characteristic of behavior for which flexibility could differ for different behaviors of one organism. Defining "quick" and "sensitive to subtle changes" is probably one difficulty in employing the term in this first sense. However, if one considers the interpretations of the sensitivity parameter in the generalized matching law as indication of discriminatory capability and sensitivity to subtle changes in contingencies, then the sensitivity parameter could be also considered as an indicator of behavioral flexibility.

In the second sense, the term refers to specific behavioral systems such as exploratory and playful behavior which are perceived as examples of versatile behavior under an unchanging context structure[5]. Here the term seems to be applied to a subcategory of behaviors (exploratory and playful behavior) for which high versatility or variation is maybe more often observed than for others and where behavioral variability independent of changes in the current context may be adaptive and thus reinforced. In addition to using flexibility as a term referring to the selection of behavioral variability in behavioral systems, selection of variability occurs also as part of ontogenetic selection, i.e., during the lifetime of an organism. Conditions or changes in current context structure which select for behavioral variability are characterized by a period of extinction, meaning that reinforcement is withheld for the "old" operant, making an increase in behavioral variability adaptive because it allows for selection of behavior by new contingencies (D. W. Pierce & Cheney, 2017). And as Neuringer (e.g., 2002) shows, variability is a property of operant behavior which can be changed by arranging specific contingencies of reinforcement. As the term behavioral flexibility is used here as referring to adjustments of behavior to changing contexts during a lifetime of an organism, the ontogenetic selection of variability and thus contexts-as-history and current contexts which select for it are the focus for the

[5] When talking about "unchanging context structure" this is a simplified approximation meaning that no relevant, i.e., with selecting effect, changes in the three-term-contingency occurred. As at least time always changes in human perception context structure cannot be unchanging.

concept of behavioral flexibility, even though due to the relative stability of contexts during a species history, behavioral systems differ in their variability (or depending on usage of the term flexibility) as well.

In the third sense, flexibility is again related to adjustment to context structure but restricted to behavior for which repeated and reversible adjustments can be observed. For a conceptualization of energy using flexibility the first and third connotations are not differentiated and behavioral flexibility is defined as adjustment to changing context structures during an organism's lifetime[6]. As can be seen by looking at the first connotation of behavioral flexibility and the generalized matching law, behavioral flexibility is also a question of adjusting to small changes in context structure. This aspect of behavioral flexibility addressing adjustments to relatively unchanging context structures is relevant when regarding common applications of the term flexibility within energy research.

Consumer or user flexibility within energy research is mostly defined as capacity to decrease or increase load during a certain time (Palm, Ellegård, & Hellgren, 2018). Palm et al. (2018) assert a technological and a social approach to achieving flexible demand. The technological approach focusses on appliances and solutions which can be controlled more and more independently of the user such as smart appliances automatically responding to price fluctuations (Palm et al., 2018). The social approach focusses on influencing the users' way of using appliances (here specified to mean only shifting it in time) which is mostly done by implementing pricing strategies to "motivate" using an appliance in certain time-periods (Palm et al., 2018). Recognizing the meaning of behavioral flexibility as a characteristic of behavior in its behavior analysis definition gives a theoretical perspective of how one can look at flexibility in energy using behavior and thereby expands a so far often limited focus on pricing strategies for changing behavior. Also, following a social approach and an exception to this often limited focus on pricing strategies is Nicholls and Strengers (2015) investigation of the timing and coordination of daily routines in households and their potential flexibility. They describe flexibility as "the degree to which routines could be disrupted or shifted to other times of the day." (p. 2). This phrasing also suggests the importance of analyzing flexibility in relatively unchanging context structures because routines (which are seemingly close in meaning to behavioral patterns) are still in place when describing shifting potential relevant for household energy flexibility.

In light of a behavior analysis concept of behavioral flexibility and the aim of describing the potential of shifting energy using behavior in time, flexibility

[6] In the following empirical analysis of observational data, it will not be possible to differentiate between the different connotations of behavioral flexibility.

in energy using behavior seems appropriately describable by the variability (e.g., degrees of freedom) in distributing behavior in time given the constraints by a current selecting context structure and by the effort for adjusting the timing of behavior. How variability in timely distribution of behavior is selected by context structure and describes the possibilities for shifting energy using behavior in time was argued above. The reason to also include effort for adjusting behavior in a conceptualization of energy using flexibility is that energy expenditure for performing a behavior can be different for different times of day and that other aspects beyond changes in current context structure are also not yet considered in their influence on the way behavior is allocated to alternatives. It can be assumed that energy expenditure for performing a behavior can be different not only for different behaviors but also for behaviors performed at different times of the day because of possible differences in the pattern of contingencies of reinforcement of the target behavior, the relation to contingencies of reinforcement of other behaviors and the pattern of discriminative stimuli at different times of day. In discussions of the generalized matching law, differences in the amount of effort required for a behavior is regarded as one source of deviation which leads to systematic departures from the original matching relation as included in the bias parameter (D. W. Pierce & Cheney, 2017). If a different timing of a behavior can be associated with different amounts of effort for the behavior, then the distribution of behavior between different time points will also depend on the difference in effort for different timings. It is also relevant to include a concept of effort for changing behavior in considerations of behavioral flexibility because transition costs between behavioral alternatives, which are not part of the contingency structure as described by the generalized matching law, have an influence on the sensitivity parameter and hence on the adjustment of behavior to changes in contingency structure. For example, it has been observed that if no change-over-delay, i.e., no extra cost for transitioning between alternative behaviors, is included in concurrent schedules of reinforcement, that rapid and repeated changes between alternatives can be observed resulting in less sensitivity to changes in reinforcement ratios, i.e., undermatching (D. W. Pierce & Cheney, 2017). This result is surprising because one could have supposed that higher transition costs lead to undermatching due to incurring costs for switching between behavior alternatives. But instead, including transition costs in form of a change-over-delay procedure reduces undermatching. Depending on transition costs, it could be expected that behavior is more or less flexible in adjusting to changing context structure. So, effort in addition to describing possibilities and limits for switching between timings of energy using behavior based on behavioral variability as selected by current context structure, is an important factor in describing behavioral flexibility.

Others also view a concept of effort for adjusting behavior as an important point in evaluating potentials for changing environmental behavior (e.g., Moore & Boldero, 2017; Otto, Kibbe, Henn, Hentschke, & Kaiser, 2018). Often (behavioral) effort or cost (terms are used with no apparent differences) is viewed as an indirect cost of behavior in comparison to direct financial cost associated with a behavior (Davies, Foxall, & Pallister, 2002), it is regarded as all non-monetary input required for performing a behavior (Moore & Boldero, 2017) and as most closely linked to circumstances referred to as structural conditions under which a behavior occurs (Otto et al., 2018). All three groups of authors give examples to further specify behavioral effort or cost: e.g., labor associated with separating waste, space occupied by storage bins for waste, time to sort waste for recycling, searching and obtaining information, time for transportation of waste to recycling facilities (Davies et al., 2002; Moore & Boldero, 2017; Otto et al., 2018). Also, they communally use the descriptive terms easy and difficult to differentiate between high and low behavioral effort or cost. All of these descriptions except occupation of space by waste bins appear alignable with viewing behavioral effort as energy expenditure for performing behaviors when taking labor, time and type of behavior (e.g., sorting vs. transporting waste) as signifying different energy expenditures but something like transition costs for switching between behaviors seems not to be part of the given examples. Even though the assumptions why differences in behavioral effort occur might differ (it is left unspecified in Davies et al. (2002) and Moore & Boldero (2017)) or differ in case of Otto et al. (2018) who state their theoretical foundation for behavioral costs to be the Campbell Paradigm, as described in Kaiser, Byrka and Hartig (2010), we all share the idea that behavioral effort or cost can be used as an assessment or indicator of relative ease or difficulty in changing or adjusting behavior.

3.3 Summary of Research Aim and Questions

This thesis is to make a contribution to the discussion on mitigating the mismatch challenge arising from an integration of increasing amounts of VRE into the German power system by influencing "user behavior", i.e., by shifting energy using behavior in time from a behavior analysis perspective. Solving the mismatch challenge is an important part of enabling a more sustainable energy system.

Based on the problem description of discrepancies in timing between energy supply and demand, flexibility on the demand side for the energy system coming from changing human behavior was defined as shifting energy using behavior in time without an overall reduction in power consumption. Applying behavior analysis theory, flexibility in energy using behavior can be appropriately described by analyzing variability in timely distribution of behavior given the constraints by a current selecting context structure and by the effort for adjusting the timing of behavior under conditions of (un)changing context structure. Thus, the main questions are:

- How variable are timely patterns of energy using behavior?
  - How does the probability of operants (rate of behavior) change during the course of a day within and between behavioral patterns of energy using behavior?
  - How does rate of behavior vary as a function of context structure including both patterns of contingencies of reinforcement from target behavior and alternative behavior, i.e., what constrains do they put on a free distribution of behavior?
- How does current context structure relate to shifting energy using behavior in time?
  - How do usual times of using an electrical appliance distribute under current context structure, i.e., how variable are preferred times?
  - How does current context structure relate to behavioral effort for shifting household appliances?

The above questions will be attended to by analyzing and interpreting empirical observational (correlative) data. To exemplify the consequences of such a behavior analysis perspective on energy using flexibility for resulting electrical consumption in the energy system and for the selection and implementation of intervention approaches, the results will be discussed by addressing the following questions:

- In what way can energy using flexibility be integrated into a building model to simulate electrical power profiles on a household level?
- In what way can the results inform the discussion on intervention approaches within environmental psychology and demand response strategies?

As much of the research in behavior analysis uses experimental designs (e.g., Glenn et al., 1992), the choice of method might need a word of framing. Outside an experimental analysis of behavior which can establish the relationship between relevant parts of the environment and changes in relevant parts of behavior, selection by consequences can be applied as principle to understand and analyze behavior. Such an analysis will remain interpretative in regards to whether or not relevant aspects have been identified. Thus, outside of experimental work, "an observer must identify environmental events hypothesized to be elements in ongoing contingencies. The observer in this situation is not in a position to create the operant unit to be studied but must detect the natural lines of fracture in order to intervene systematically. The operative contingencies that are maintaining a behavioral unit can be ascertained only by observing repeated instances of activity with respect to the environment." (Glenn et al., 1992, p. 1335).

Often, analyses based on correlational data are a first step towards understanding a problem and exploring important characteristics of target behaviors. In case of energy shifting behavior, this seems an appropriate choice as a behavior analysis perspective on energy shifting flexibility appears to be rare. Employing such an applied analysis on observable behavioral variability in household energy using behavior to formulate assumptions about flexibility in energy using behavior under current context conditions (associated degrees of freedom and behavioral effort) is thus an important first step to discern possibilities and difficulties in changing the timing of energy using behavior. A strong argument for the usefulness and power of applying the principle of selection by consequence and not another perspective is that selection as causal influence is not an assumption but empirically validated by "thousands of behavior analytic experiments that demonstrate shaping and maintenance of complex behavior by complex contingencies" (Chiesa, 1994, p. 120) and is integrated into a wider theoretical perspective given by the theory of evolution and its main mechanism, natural selection.