TOWARDS UNDERSTANDING HOW REDEFINING SUPPLY SIDE CONSTRAINTS COULD SHAPE INDIVIDUAL DEMAND SIDE BEHAVIOUR

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Abstract

The impact of behavioural aspects on environmental solutions has received more and more recognition over the last couple of years. There is a general change of thinking away from purely technical approaches towards integrated and holistic concepts, which take especially the end user into account.

Many studies have shown (e.g. [1][14] [16]) that technical improvements and innovations do not necessarily cause the desired outcomes due to a lack of communication with the actual end users of these technologies. Other studies, for instance on improvements of house insolation or the use of LED bulbs, caused paradox behaviour, sometimes also called "Jevon's paradox" or "rebound effect", where the technical improvements are eaten up by the increasing demand they caused [6]. These are just a few examples to highlight the gap between new developments in environmental sustainable technologies and the actual behaviour towards these innovations from an end-user's perspective.

The fundamental question therefore is: "How to influence people's behaviour towards a more pro-environmental outcome, also in the long-term?" This paper will not be about another study, which proves incentives make people act in a more desired way, as long as the incentive is given [1]. All the various aspects of human behaviour have been replicated in several well executed studies [1], however none of these on their own were able to solve the problem of motivating people to change their behaviour also in the long term. So instead of reinventing the wheel over and over again, the idea presented in this paper is to use well defined behavioural theories and their inventory tools, which have been well established in psychology and the social sciences, and to integrate them into a holistic cycle of behaviour using the High Performance Cycle and the Action-Regulation Theory as foundation. We will show how the integration of these behavioural theories can be used to devise support tools for better shaping demand side behaviour towards meeting supply side constraints.

1. INTRODUCTION

Typical current energy systems assume a rather strict distinction between a consumer driven demand side on one end and a matching supply side on the other end, with the primary objective of always satisfying consumer demands. Although energy suppliers have always modelled demand side behaviour to adapt their production accordingly, and certain incentive schemes, like different tariffs, have always been in place to influence demand side behaviour according to supply side constraints, modern communication technology enables a much more granular and individualised approach. At the same time renewable energy sources are creating much more unpredictable, sometimes even unintuitive, supply side constraints that would require very specific targeted actions on the demand side, while at the same time the impact of such demand side actions has become increasingly important due to improved insulation and energy efficiency in general. Moreover, local generation and storage facilities have led to a situation, where the classical consumer also takes part in the supply side, being now able to provide this capability to the grid, effectively becoming what is called a prosumer these days.

To deal with this situation a couple of approaches have been taken: the easiest, but at the same time least cost effective, is by maintaining sufficient overcapacity in both the grid as well as energy production, in order to be able to always meet any possible consumer demand by controlling production accordingly. In order to better utilise existing assets in this scenario, modelling of consumer behaviour and other external factors, most prominently the weather, has been a very common approach. However, supply side constraints are never communicated to the consumer in this scenario, the energy grid is always completely transparent in this regard. More flexible energy tariffs combined with real-time information provided to the consumers have been proposed to overcome this issue, however smart-meters have so far not shown the desired outcome in the long run [4].

The approach proposed in this paper aims at going one step further by not only modelling demand behaviour as an external factor to the system, but by incorporating the individual building occupant and his/her characteristics as an integral part of the system itself. By developing an integrated behavioural theory we will show how demand side behaviour could be shaped based on supply side constraints.

Starting point are the theories of Action-Regulation (ART) by Winfried Hacker [7] and the High Performance Cycle (HPC) by Locke and Latham [9]. By integrating those two theories into each other a holistic cycle of behaviour is obtained [3], comprising of the basic aspects of human behaviour found in many other approaches (see Figure 1).

Through the fact that “basic aspects of human behaviour” might be based on the perspective taken, the model tries to be sufficiently open, so that further suggestions can be taken into account and tested within the model.

In this paper we will give a brief introduction to these concepts, but the main focus will be on the “redefinition of task” aspect of these theories and we will show how it can be made more specific using the Theory of Planed Behaviour (TPB) by Ajzen [2] together with inventory tools like the environmental attitudes inventory [13] to design a probability model focusing on the redefinition of task’s demands, norms and values and goal-setting and –anticipation aspects. Clustering individual’s responses then enables providing

customised suggestions for the redefinition of task as well as goal-setting and - anticipation. Based on the conjectures of ART and the HPC, more precise goals should have a higher potential to be transformed into behaviour. We will show how this idea can be applied to better shape demand side behaviour according to supply side constraints.
By focusing on the redefinition of task aspect (see Figure 1), we will show how it can be supported by providing custom made suggestions based on both a supply side constraint profile as well as our understanding of the individual prosumer's attitudes and characteristics. By clustering individual's responses to the relevant inventories, we are able to react to specific supply side constraints by customising end-user engagement and support tools accordingly. This methodology allows to better shape demand side behaviour, thereby moving from a purely demand-response driven approach towards a more integrated prosumer centric approach of energy supply. Furthermore a rigorous behavioural model like the one presented here could also lead to a better integration of demand behaviour into energy modelling, ultimately allowing reducing the gap between predicted and actual energy consumption.

2. THEORETICAL FOUNDATION

2.1. Introduction of the High Performance Cycle and the Action-Regulation Theory

To obtain a holistic model of behaviour the HPC serves as a foundation, which needs to be adapted and augmented with further theories. The origin of the HPC lies in the goal-setting theory [9] and in a nutshell goal-setting theory states that people who are trying for specific goals perform better than people who should do their best [8] [9]. Furthermore, feedback and goals together have a much better outcome than either one aspect alone [8].
The ART like the HPC was developed in the context of organisations and work performance and therefor is focused on efficient and humanized work [7]. Still the basic concepts in both theories are easy to translate into a more general behavioural model applicable to many applications including energy efficiency.
Behaviour or activities in the ART can "…be described in terms of sequential phases and hierarchical "levels" or modes of control. Roughly, three levels of conscious awareness of processes and representations that simultaneously regulate…" behaviour "…can be distinguished" [7] (see Figure 2). On top, the intellectual level is the highest level where consciousness is required to orient on and "redefine the task" into a self-set goal. The second level would be the knowledge-based level. It can be conscious and takes the surrounding conditions and the available abilities into account to develop strategies and action schemes. The third level is routine and sensomotoric based, which is mainly subconscious and includes the actual execution. On all levels feedback-loops are found, which continuously report back the level of progress towards the desired goal and eventually make adjustments on the level required to achieve the task criteria. "The most important characteristic of action regulation is that actions are controlled by goals that, from a cognitive perspective, can be seen as anticipation of the results that one intends to achieve." … "These goals can be decomposed into several partial goals that together constitute the main goal" [7].

Both theories, the ART as well as the HPC, have a humanistic background so that no contradictions in this regards are expected (for a detailed discussion see [3]).
The integration of the two theories was the attempt to overcome each one's limitation and to build a more holistic model of human behaviour. Following the statement of Ulich: "Where the Action-Regulation Theory has a motivational gap, the motivational theory (HPC) has a regulation gap" [17].
We will present a short overview to describe how the two theories are supplementing each other and can be integrated into a holistic cycle of behaviour [3] (see Figure 1).

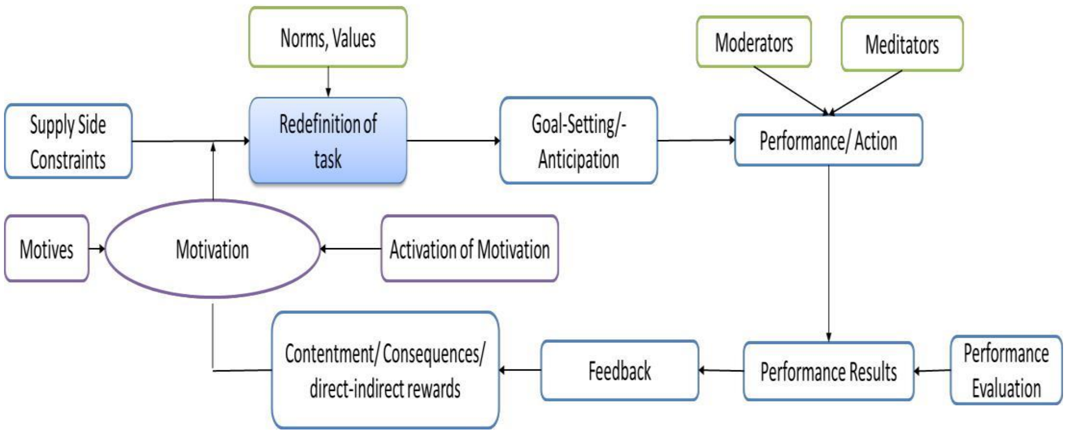

Figure 1: The original integrated cycle of HPC and ART [3]

Both theories are starting with demands imposed on the individual, which in the energy efficiency scenario we are tackling here translate into supply side constraints. However, instead of going straight into action and perform, like it is done in the HPC, the important aspect of "redefinition of the task" is added from the ART including the issue of norms and values, which is found in both theories mentioning the influence of goal-setting [3][8]. This is of particular importance in our scenario, so the aspect of "redefinition of task" and "norms and values" will be discussed in detail after the brief description of the cycle.
After the "redefinition of task", where the external "demands" are translated into personal goals the "goal-setting and –anticipation" takes place. Here the hierarchical-sequential concept of the ART is strongly reflected, because sub-goals need to be defined and action plans developed (see Figure 2). While the "redefinition of task" happens on the highest level, "goal-setting and –anticipation" is happening on the intermediate knowledge-based level, followed by the aspect of "performance/ action", which goes down to the sensomotoric level, where the actual execution happens [7].

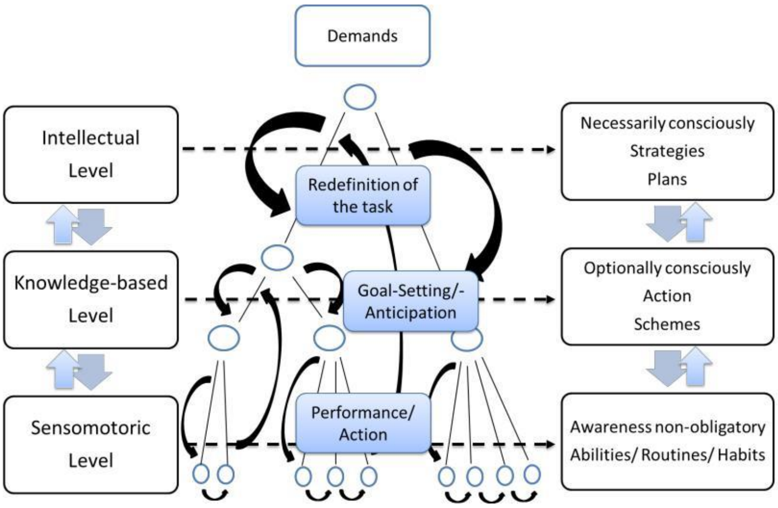

Figure 2: hierarchical sequential model of behaviour

The "performance results" are then the actual achievement and the visible part of an action/ behaviour. While performance traditionally has been only measured from the outside at the end of an action through the visible results, nowadays there are much more flexible approaches via just-in-time analysis and feedback technologies. The new technology tries continuously to sense and monitor end-user behaviour as well as the supply side constraints and is capable of sending instant feedbacks to both sides to improve the interaction between both of them. "Performance results" lead to external as well as internal "feedback", which influences the "well-being" and a level of "contentment", which strongly influences the "motivation", which itself has a strong impact how someone deals with "demands" again, finally closing the cycle [9][3].

Although motivation is a key aspect for human behaviour, it is beyond the scope of this paper, and we intend to discuss key aspects like "motives", "activation of motivation" and "mediators", which Locke at al. [10] defined via direction, effort, and persistence, in subsequent works. Those three traits are often used to describe motivation and should be discussed in that context. Mediators also include task specific strategies, but because this aspect is already included via the moderators in the ability aspect, for the simplicity of the behavioural model presented here we will not go into this detail here.

Finally, moderators are factors trying to explain how strong the effect between goals and action is. The main aspects are: ability, commitment, feedback, expectancy and self-efficacy, task complexity and situational factors [9]. While in the HPC moderators are connected to the performance it could be reasonable to move them to a more central point in the model, because those mentioned aspects reflect personal traits, which influence all aspects of the cycle.

To summarise the above, behaviour always consists of two aspects: a cognitive – non-visible part and a performing - visible part. While the HPC is skipping the whole cognitive part, or stays very unspecific about it, the ART can fill that gap with a well-defined and visualised sub-model explained above. By tracking the end-user's behaviour and his/hers interaction with the implemented system, which has an underlying Bayesian probability model, the long term goal is to be able to make conclusion about every single aspect mentioned above.

2.2. The Redefinition of the Task

In order to develop the behavioural model further and integrate other theories to supplement missing or unclear parts, the focus of this paper will be the "redefinition of task". As mentioned before, other aspects, like motivation, are important for the applicability of the model as well, but are beyond the scope of this paper and will be looked at in subsequent work.

"Redefinition of the task" is a psychological concept, which focuses on the fact that different people perceive and interpret identical tasks in different ways [7] [3]. The approach of "redefinition" was developed by the Russian psychologist Sergei Rubinstein in 1914 [15] and addresses the mental regulation of tasks. This "mental regulation of activity is mediated by the object of that activity" [7] not necessarily directly but through the variety of people's goals, motives, knowledge, experience, norms, attitudes, and moderators. As a consequence externally set tasks are subjectively interpreted and made into personal ones by taking under reconsiderations personally available resources and the cognitive and emotional evaluation of the task [7].

It is important not to confuse the "redefinition" with reflexion, because the redefinition is based on the internalised norms and values without questioning those [3]. On the other hand the "redefinition of task" is already an extension of the seeming passivity of taking over a task within the HPC [3]. To overcome both, the non-reflective takeover as well as the seemingly passive takeover of a task the Theory of Planned Behaviour will be discussed.

2.3. The Theory of Planned Behaviour

The TPB was proposed by Icek Ajzen [2] to improve the theory of reasoned action, which was developed by Icek Ajzen and Martin Fishbein in 1975 [5]. The TPB is based on three aspects, which are linking beliefs with behaviour: "behavioural beliefs", "normative beliefs" and "control beliefs" (see Figure 3).

"Behavioural beliefs" are defined as "beliefs about the likely outcomes of the behaviour and the evaluations of these outcomes" [2]. "Normative beliefs" are defined as "beliefs about the normative expectations of others and motivations to comply with these expectations" [2] and "control beliefs" are defined as "beliefs about the presence of factors that may facilitate or impede performance of the behaviour and the perceived power of these factors" [2].

"Behavioural beliefs produce a favourable or unfavourable attitude toward the behaviour; normative beliefs "result in perceived social pressure or subjective norm and control beliefs give rise to perceived behavioural control" [2]. "In combination, attitude toward the behaviour, subjective norm, and perception of behavioural control lead to the formation of a behavioural intention" [2]. That leads to the assumption that "…the more favourable the attitude and subjective norm, and the greater the perceived control, the stronger should be the person's intention to perform the behaviour in question" [2].

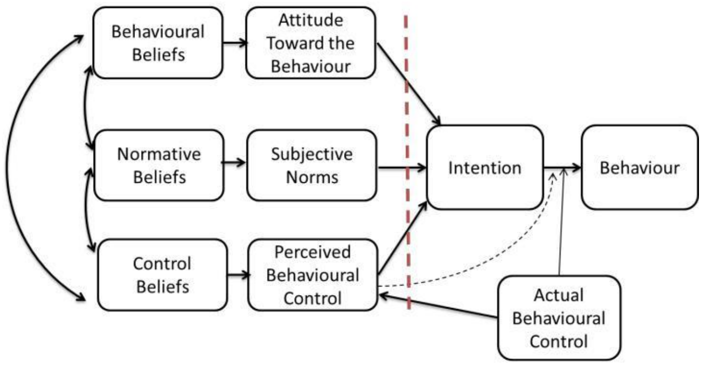

Figure 3: The theory of planned behaviour [2]

The TPB like the HPC shows a gap in the cognitive development of goals and action plans. This is why the integration of the TPB into the holistic cycle of behaviour would give us the opportunity to overcome this issue.

2.4. Integration of the Theory of Planned Behaviour as an approach to fill the gap

As mentioned above the ART is missing sufficient reflexion for redefining a task, while norms and values are acquired as an active process during socialisation, they are never questioned again [3]. The ART asserts that in the HPC values are actively acquisitioned through experience. Locke & Henne [8] state that values can be conscious or subconscious, hence values might become focus of reflection but no further details are given in this regard and their model's explanation gives the impression that demands are taken over without questioning.

By adding the TPB to the norms and values box of the behavioural model (see Figure 4) it can overcome the limiting aspects of being non-reflective from the ART and the latent passivity from the HPC. But to do so the aspects "intention" and "actual behavioural control" need to be disconnected (see **Error! Reference source not found.**) and added in a different location into the cycle. The reason to do so is due to the fact that there is no real goal planning or action regulation involved in the TPB. All that is mentioned is a behaviour, which is more or less favourable [2]. Hence, the "redefinition of task" and the "goal-setting and -anticipation" are a supplement to the TPB making it much more practically applicable in our scenario. Furthermore, a strong intention to act in a certain way can be an indicator that the person finally does so, but an intention alone does not necessarily lead to the desired behaviour [12]. Especially in the area of sustainable behaviour this phenomenon is quite common and a big issue to solve, because on the one hand people have good intentions to behave environmental friendly, but on the other hand the observable behaviour is not matching the claimed intentions. This is called attitude-action-gap or value-action-gap [11] [12], which we want to overcome by our proposed approach.

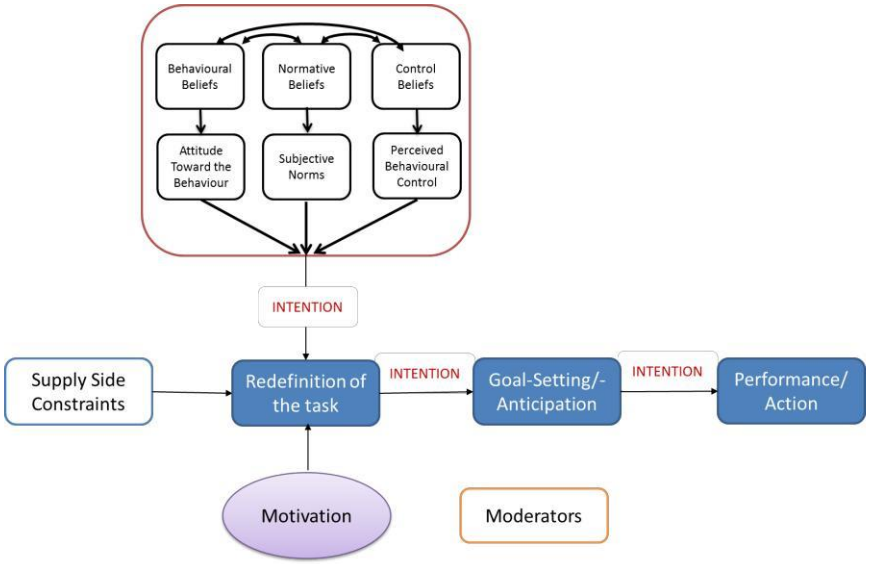

Figure 4 Integration of the TPB into the holistic cycle of behaviour (Figure 1)

By redefining a demand, which is coming in from the supply-side constraints, different suggestions are made to facilitate the intellectual process behind it according to the ART. The selection of a sub-goal is strongly influenced by the aspects described in the TPB. Furthermore, beside the individualised redefinition there is a more general aspect, which applies to all human beings and that is the tendency of "cognitive economy" [7]. This trait is reflected in the aspect of "perceived behavioural control" described in the TPB. It would not be wise to choose a goal, which is not achievable. The suggestions made should support the likelihood to choose an attainable goal, to reduce possible failures, which could have a negative impact on the motivation and further involvements of the prosumer. The suggestions made should also give the prosumer the opportunity to visualise the desired behaviour and get support to develop easy consecutive action plans to execute the behaviour. The visualisation of action plans is essential to increase the intention to perform the behaviour in question. For that reason the redefinition of task and selection of a suggested goal should be followed by proposing different action plans in the subsequent step of goal-setting and –anticipation. Those proposed action plans should present a variety of ways, how to achieve the chosen goal. Many theories seem to ignore this crucial aspect, although it is well-known that good intentions ("I will conserve energy!") will not necessarily lead to a change in behaviour. Very specific action plans need to be developed and remembered to increase the probability to show the behaviour in question. Especially if new behaviour needs to be learned, this in the beginning can take a lot of cognitive capacity and is easily interrupted (see Figure 2). Therefore facilitating new behaviour not just clear goals are mandatory [8] [9], but also a very clear specification of the way how to get there [7] [3] as otherwise set goals are more likely to be abandoned as predicted by the ART.

Two more aspects need to be discussed, where to place them in the integrated model: "actual behavioural control" and "intention." "Actual behavioural control" can be filled into the feedback loops described in the ART, which take place on all levels and continuously report back the level of progress towards the desired goal and eventually make adjustments on the level required to achieve the task criteria.

Next “Intention” needs to be fitted in. “Behavioural intention” is defined here as the intention or the subjective probability of a person to perform various behaviours/ the behaviour in question in respect to a given object [5]. In the behavioural model depicted here there are different points where these subjective probabilities come in (see Figure 4). The first is between the TPB block as a whole and the “redefinition of task” aspect. By taking “behavioural beliefs”, “normative beliefs” and “control beliefs” into account a subjective probability/ intention is created to choose a specific suggested goal or build one on their own. Knowing the strength of intention between the TPB and the redefinition of task it is possible to predict the subjective probability between redefinition of task and performance as a whole using information from previous studies or calibrating the system accordingly. The next step would be to see, if the specification of action plans in the “goal-setting and –anticipation” would increase this subjective probability between the aforementioned aspect and the performance compared to the subjective probability between the redefinition and the performance, skipping the goal-setting and -anticipation aspect in between.

3. APPLICATION TO ENERGY EFFICIENCY BEHAVIOUR

How does the integrated theory outlined in the previous sections help an energy application? The first contribution is the identification of relevant parameters and their mutual interaction. It highlights the necessity to measure these parameters and act accordingly on an individual basis, which can be achieved by dedicated communication channels to each individual stakeholder in the system down to the prosumer level enabled by modern digital interaction devices.

Focusing on the aspect of redifinition of task outlined above this means that adequate support tools need to be made available, which allow the prosumer to create actionable plans for meeting supply side constraints. In order for this to work, these support tools need to take all the individual parameters into account, as stressed by the theories described above.

This is the key differenciator between our approach and more ad-hoc smartphone or smartmeter based incentive schemes. Key to this approach is the ability to measure pre-cursor variables and generate individualised support actions accordingly. This way the overall energy performance optimiser can make more optimal use of the prosumer’s abilities to perform actions outside of the more direct classical control mechanisms and can integrate those into the overall control strategies, ultimately resulting in more optimal, and hence more energy efficient operation of the overall system.

We will illustrate the above giving an example on how to optimise a district heating system using individualised prosumer engagement. In a typical scenario heat is provided by the district heating operator to each building through a number of substations and then used by individual building occupants to heat up individual rooms or water storage tanks by manually controling thermostats or radiator valves for each room. Although consumers are usually economically incentivised to optimise this setup based on their individual needs, this rarely

results in an optimal configuration [4].
Phrasing the above scenario in terms of the behavioral theories, supply side constraints amount to the requirement for individual building occupants to adapt their heating behaviour according to overall system goals, i.e. individuals are either required to increase or decrease their heating requirements or adapt their schedules accordingly to facilitate optimal overall use of available resources. Note, that this is more complicated than a simple requirement for mere energy saving. Not only is peak energy supply management becoming more of an issue, also improved heat efficiency due to better insolation has led to a situation, where behavioural aspects become more and more important when managing heat supply and demand. However, managing behaviour is more invovled than merely sending out control commands, unlike a directly controllable system we are dealing with individual occupants and their energy behaviour, which we intend to shape to meet our optimisation goals. However, we cannot assume that everybody is always willing to fully cooperate with this, even if incentives are given.
To do this effectivly, we propose to apply the behavioural theories developped above and start by looking at the redifinition of task aspect, which amount to designing adequate support tools for the management of prosumer behaviour with the ultimate goal of optimising the overall districtg heating system. The most relevant parameters affecting the redifinition of task have been identified to be: Supply side constraints, behavioural beliefs, normative beliefs, control beliefs, motivation, and moderators (ability, commitment, feedback, expectancy, self-efficacy, task complexity and situational factors).
In the context of energy efficiency behaviour the three belief parameters can for instance be measured using well-developped inventories like for instane the Environmental Attitude Inventory [13]. As outlined above, all these are then aggregated into a level of individual intention to perform actions as required by the given supply side constraints. This insight can be used to calibrate the system by finding clusters in the data collected prior to the operational stage of the system. The three other aspects supply side constraints, motivation, as well as the moderators are (at least partially) measureable from the actual system operation and the individual user's interaction with the system, resulting in correlations between the individual parameters for each particular application. This can be used to learn the parameters of a Bayesian network representing the mutual probabilistic relation between all variables involved.
Using these pre-calibrated correlations in conjunction with actual measurements of the interaction of the occupant with the heating system then enable assigning values to each of these variables, even without going through the inventories all the time. This is important, as a practical heating application cannot rely on continuous questinaires to be carried out on an ongoing basis. However, it does not preclude the system operation from re-calibrating and adapting its internal state based on occasional surveys.
The resulting calibrated Bayesian network is then able to make adequate suggestions to individual occupants based on his or her individual characteristics, taking not only the supply side constraints itself into account but also the other parameters descibed above. According to the behaviour theory developped above, these suggestions are split into providing appropriate goals followed by a choice of action plans, which increase the intention and thereby the

probability of the desired control actions being taken by the occupant ultimately resulting in better energy performance and predictability. The latter is the second major outcome from applying the behavioural theories to energy efficiency application design.

The benefit of the approach outlined above is two-fold: first and foremost more appropriate suggestions and support tools based on the individual's attitudes and personality can be provided, which ensures better long term commitment of the participants. The second advantage is that the district heating optimiser can select the most appropriate individuals to perform certain control tasks, and by taking the individual’s behavioural parameters into account has a higher probability of this action being taken ultimately resulting in more efficient and more predictable system operation.

4. CONCLUSION

We presented a holistic model of behaviour integrating the three theories HPC, ART, and TPB into a unified circle of behaviour and discussed how they complement each other’s shortcomings focusing on the redefinition of task aspect. We also discussed how this type of model can be applied to energy efficiency applications, showing how demand side behaviour can be shaped based on supply side constraints. Two conclusion can be drawn from the behavioural model at this stage: first we identified key parameters governing the redefinition of supply side constraints into individual tasks, which can be taken into account when modelling the energy system leading to more optimal operation and improved predictability. The second conclusion is that every occupant support system should not only focus on supporting intentions, but has to also provide very specific and individualised action plans in order to be effective.

By enabling the energy model to take both the supply side constraints as well as the demand side behaviour into account, and by enabling a two-way communication between energy supplier and prosumer behaviour, a more optimal operation can be facilitated that can make use of all available assets both on the supply as well as on the demand side. This means that by incorporating end-users as active participants into the overall system, more efficient as well as more predictable energy consumption, production, and distribution scheduling could be achieved.

The applicability of the proposed approach hinges on the participation of end-users and requires a ceratin level of mind-shift away from a pure consumer attitute towards a more active prosumer role. While long term motivation is covered by the presented model, consumers need to be convinced initially to take part. Therefore information, transparency, and incentives need to be part of any deployment if we intend to build commitment and trust on the consumer side.

The behavioural model presented above is not final; to be fully applicable there are still some important building blocks missing. As we pointed out above, in particular the aspect of motivation is still vague and we intend to supplement it with other more specific approaches, like for instance self-determination theory, in the future and continously improve the predictability of demand behaviour.

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