by removing the user from the loop through automation via smart appliances, or through economic incentives like time of use pricing. However, these three challenges stem from the process of shifting itself, so they must be addressed regardless of the specific intervention technique. Furthermore, there is no way to completely remove the user from the loop, so it is critical to understand users and their everyday practices.

Aligned with recent work in HCI [18], we use practice theory [23] to help us to understand the interwoven practices that make up everyday life, which consume electricity as a side effect. This understanding of how people go about the mundanities of residential life is crucial, since encouraging changes in one area (such as shifting when the laundry is washed) may imply changes to other areas such as exercise, personal hygiene, or an active social life, which people may find unacceptable.

In the following sections, we explain these three challenges in detail and discuss the need to understand users' everyday practices. Then, we describe how the challenges relate to automation and pricing-based solutions, ending with a set of recommendations for future research in this area.

## 2. CHALLENGE: UNDERSTANDING THE CONCEPT OF SHIFTING

The first barrier to getting residential users to shift their electricity use is getting them to understand the concept of shifting. To understand the underlying motivation for shifting, users need to grasp the challenges of the modern grid such as the variable output of renewable electricity generation, which are not widely appreciated by the general public. In contrast, curtailment is an easy concept to understand: using less electricity reduces the environmental impact of electricity generation, such as greenhouse gas emissions, and also saves money. In addition, the concept of curtailment also parallels other domains such as personal finance: an obvious way to save money is to spend less of it, whereas spending money at different times during a day will have no effect on the balance at the end of the day.

In order to consciously shift, users must be given some kind of information about when it is more or less desirable to use electricity. This information could take the form of variable pricing, or the "greenness" of current electricity generation. In order to shift effectively, users also need to be able to plan their more substantial electricity use, and such planning requires a forecast of electricity use desirability. In some cases, however, having information about electricity usage and consumption patterns could actually encourage shifting but at the same time increase consumption, and thus undermining the overall goal of shifting [20]. Thus, getting people to understand the concept of shifting is very complex, as there are many variables that play an important role while shifting electricity use.

Electricity feedback has frequently been used as a way to foster energy literacy [22] and encourage curtailment of electricity use [6, 9]. Therefore, it seems crucial that users trying to shift should also be able to see and understand their historical electricity use in comparison to the desirability metric. Consequently, a user trying to shift would potentially consult three different sources of data: a forecast of desirability, historical usage, and historical desirability. The addition of the desirability data makes shifting more difficult for users to understand than curtailment. For example, while conducting a pilot study of a casual mobile game intended to encourage players to reduce and shift their electricity usage by providing them with $CO_2$ intensity forecasts and feedback data on their usage, no player reported that they had attempted to shift [13]. Furthermore, 60% of questionnaire respondents (n=10) were unable to correctly answer a simple question about how well a particular day's usage matched a forecast of $CO_2$ intensity [13]. Players appeared to pursue a strategy of curtailment rather than shifting, in part because the concept of curtailment was easier and more familiar to them. This example reveals how difficult is for residential users to actually understand and shift their electricity use even if they are motivated to do so.

## 3. CHALLENGE: UNDERSTANDING WHEN TO SHIFT

In order to shift, there must be a way to signal and measure when the good and bad times are for electricity use. There are a variety of possible data sources to guide shifting:

- The $CO_2$ intensity per kilowatt-hour of electricity generated is an aggregated measure of how much greenhouse gas is emitted for electricity use. It can be affected by the amount of renewable generation, imports of electricity from other areas, and power plants being taken out of service due to scheduled or unscheduled maintenance.
- The percentage of renewable electricity generation in the grid is another measure of the environmental impact of electricity use.
- Grid utilization measures the logistics of transporting electricity from generators to consumers. This measure is important in the face of electric vehicle charging, which can potentially overwhelm existing residential subsystems [10].
- When time-of-use pricing is used, price is another factor to take into account.

Note that these data sources can potentially be in conflict over the best and worst times to use electricity. For example, a time of low CO2 intensity might not necessarily correspond to a time of low pricing, or low grid utilization, and vice versa. Those entities who are encouraging the shift of electricity use will need to pick one, or possibly a combination of these metrics in order to produce an appropriate forecast of the best and worst times for electricity use.

If we assume the metric has been normalized to a scale from 0 (worst time) to 1 (best time), it still must be communicated to users in some meaningful way. Should the forecast use an absolute threshold, where all time periods above some value are considered bad, and below some value are considered good? Or should all the time periods (such as hours in a day or days in a week) be compared only to each other, providing a relative indication of which are the best and worst times over the specific time interval? Absolute thresholds keep users in touch with the reality of the underlying metric, but leave open the possibility of long forecast periods that might be all good (any time is good for using electricity) or all bad (there is no time that is good for using electricity). Relative thresholds ensure that there is always some variation in the forecast, but only at the expense of exaggerating insignificant differences in the metric.

What is a person expected to do when faced with a forecast where all hours or days are bad for electricity use? It is not reasonable to expect people to defer all electricity use until some future point in time. One potential advantage of the shifting concept is that users can reduce the impact of frivolous electricity use by consulting the forecast and picking a desirable time. However, a forecast that shows that all times are good for electricity use could lead to a sense of impunity about electricity use. If the forecast shows the same value (in relation to the aforementioned scale 0–1) for a prolonged period of time, users may decide that consulting the forecast is pointless and cease to do so. Even when the forecast provides useful information, convincing users to check the forecast on a daily basis is challenging, as can be seen with longer term use of electricity feedback technology [14].

As with electricity usage feedback technology, researchers need to ensure that the forecasts are 'sticky' by providing reasons for users to continue to consult them over the long term [1].

# 4. CHALLENGE: THE DYNAMIC NATURE OF SHIFTING

A fundamental aspect of shifting is that the desired pattern of electricity usage is dynamic and not static. While there might be some fixed times when electricity usage is undesirable from a grid utilization perspective, such as the evening cooking peak, dynamic factors such as weather or generation failures will ensure some variety in the forecast over time. This variation poses a problem when attempting to encourage users to shift electricity usage, because it makes it more difficult for people to develop habits that will lead to shifting. A rule such as "avoid doing laundry in the evening" is much easier to follow than consulting the electricity forecast before doing the laundry, as it implies less cognitive and practical demands in our otherwise complex and busy everyday lives. Encouraging shifting stands in stark contrast to encouraging curtailment, where it is always better to use less electricity, and thereby much easier to develop habits and rules of thumb.

The dynamic nature of shifting means that there is no strong analogy to other areas of behavior change that users might be familiar with. If a person wants to save money, there is no constantly changing time of the day or week when reducing spending is more or less effective. If a person wants to lose weight, there is no constantly changing time of the week when calories are more or less additive to one's waistline. As mentioned previously, curtailment of electricity use does permit this very direct analogy to personal finance or weight loss. In contrast, the benefits of shifting might be perceived over a longer period of time, in which people's motivation as well as the dynamic aspects of shifting would play an important role to actually shift and reduce consumption.

The dynamic nature of the forecast also creates challenges for the forecast providers, who must decide how far into the future the period will stretch, the granularity of the forecast, and how frequently the forecast should be updated. A forecast duration that is too short (for example, only a few hours into the future) might not provide users with enough information on which to make decisions about shifting, because an appropriate time to shift might lie just beyond the current forecast. Forecasts can potentially be updated at a high frequency (for example, once every 5 minutes), but this frequently updated forecast can pose a problem if users have already made decisions about their activities based on a previous version of the forecast. To prevent users from becoming frustrated with the shifting process, a system might choose not to inform users of insignificant changes in the forecast.

Another curious property of shifting is that if an intervention is broadly successful in shifting residential electricity load from bad times to good times, then it is likely that the good times would then become bad times due to the increased load in the long term. Thus the progress towards the goal of shifting the load will actually affect the metric that measures that progress over time. One solution to this problem would be to provide users with different individual forecasts that specify different good times for electricity use, thereby smoothing out peaks instead of just shifting them. However, this change adds additional complexity to the system, and also complicates any social encounters between users, who might discover that the system is recommending different times of day as most desirable for each user.

# 5. DISCUSSION

In this section, we cover the use of practice theory as a way to better understand the challenges of shifting, how the challenges apply to shifting through automation and pricing of electricity, and we end with our suggestions for future research in this area.

## 5.1 Understanding Practices

We have found practice theory to be helpful in uncovering these problems around shifting electricity use. One reason encouraging shifting is complex is because people generally do not see themselves as electricity consumers, instead they are simply going about the activities of daily life (cooking, eating, cleaning, washing, relaxing, exercising, etc.), which may have the side effect of consuming electricity [21]. These everyday practices are influenced by many factors, including societal structures like legislation and social norms, as well as physical things like the architecture of a building or the appliances installed in a home [23]. Therefore, when trying to encourage people to shift electricity use, practice theory can serve as a tool to understand the particularities of shifting in relation to people's everyday lives, pointing to solutions that should also consider the material and structural factors that affect practices rather than only counting on individuals to change their behaviors and schedules [7].

Moreover, people may also consider certain practices to be "non-negotiable", meaning they are unwilling or unable to consider changes to the schedule or duration of the activity [27] for various reasons, including social norms, personal preferences, or interconnections with other practices. For example, while conducting an investigation of the practices at a student dormitory, we found that residents were unwilling to consider shifting their dinner time later in the evening as part of an intervention, because dining was intertwined with other practices such as exercise and studying [7, 19]. In a longer field study of the mobile game described in [13], we found that while the game could help players to understand shifting, that understanding was not a gateway to actual shifting. Most players indicated that they felt that they had very limited opportunities to shift their electricity use because of the interplay between the various everyday practices in their lives.

In order to apply practice theory to design more sustainable technological interventions, it is necessary to understand the constitutive elements of practices. For example, we developed the Contextual Wheel of Practice as a way to remind researchers and designers about the important aspects of practice that goes beyond a focus solely on the individual [7], aiming to support people's sustainable intentions to actually reduce consumption.

While using the practice orientation does not ensure the success of an intervention intended to encourage shifting, failing to take practices into account makes success less likely due to the complicated and interconnected nature of activities in everyday lives and settings. However, it is precisely these practices that need to be understood and re-configured to enable shifting electricity consumption.

## 5.2 Automation and Pricing

Automation is another technique that has been proposed to shift residential electricity use: for example, introducing smart appliances that can be configured to run only when electricity use is most desirable. While automation is appealing because it seemingly removes users from the loop, in fact it suffers from all three of the challenges we have identified in this paper:

- Users still need to *understand the concept of shifting*, otherwise they will not upgrade to new smart appliances, and will not accept the delays that a smart appliance will introduce when it automatically delays operation to a future time.
- Smart appliances will need to decide *when to shift*, based on the factors we discussed previously (e.g., $CO_2$ emission, grid utilization, price). This decision is even more sensitive in the case of a smart appliance, due to the reduced user agency and potential for conflicts of interest: whose interests are being served by the shift?
- Similarly, automation cannot conceal the *dynamic nature of shifting*. Based on a dynamic forecast, the best time for a smart appliance to run might be in three hours, three days, or immediately. With automation, the situation is actually more complicated, because devices will need to explicitly negotiate with users to ensure that user needs are still met when shifting occurs: a fully-loaded smart dishwasher that decides to run in three days when electricity is expected to be very inexpensive may not be acceptable to the residential user.

Shifting through automation faces the additional challenge of getting users to upgrade their appliances to new, more expensive smart versions.

Pricing is also being used as a way to encourage shifting of residential electricity use, both through time of use pricing, and critical peak pricing where the price of electricity is raised dramatically when demand for electricity may exceed the supply. While pricing can be part of a shifting solution [12], it is unlikely to succeed by itself because people are not purely rational actors who seek optimal solutions based on the information available to them [26]. Indeed, as mentioned previously, people generally do not see themselves as resource consumers.

Therefore, while automation and pricing or a combination of the two may seem to remove the user (and the complexities that go with) from the loop, they actually need to understand and take users into account just as much as information-based systems do [28].

## 5.3 Research Directions

As we have shown, simply applying techniques, such as resource feedback, that have been used to encourage curtailment are unlikely to succeed in encouraging shifting (outside of specialized circumstances).

We propose that the best hope for success in residential shifting research lies in combining information, automation, and pricing techniques while targeting everyday practices. In particular, the targeted practices should meet two criteria: they can be shifted without extensive reconfiguration of other practices, and they use substantial amounts of electricity. In most homes, these criteria will probably limit the possibilities to heating/cooling, laundry, dishwashing, and electric vehicle charging.

There are some recent indications that residential electricity storage may become economically viable, such as the upcoming Tesla Powerwall [29]. If storage becomes viable, it will open a new area for research, because to be viable, the amount of storage capacity installed should be as small as possible, while still meeting the users' needs. Successfully integrating storage will also require a full understanding of the everyday practices that influence electricity use.

# 6. CONCLUSION

Based on our experiences investigating the everyday practices at a student dormitory, this paper shows how encouraging residential users to shift their electricity use to better match the changing needs of the modern electrical grid is a far greater challenge than encouraging curtailment of electricity use. This paper discusses major challenges including: getting users to understand the concept of shifting, deciding what shifting metric to use, how to communicate the shifting metric to users, and the inherent variability of forecasts. Based on our findings and experiences working in this area, we recommend researchers focus on understanding the everyday practices of residential users as a way of coping with the interconnectedness of the activities that must shift in time to shift electricity use.

Finally, the presented challenges may need further investigation and validation with other target groups such as families and in other settings. As the presented challenges are most likely far from complete, we encourage the e-Energy community to continue uncovering and understanding the particularities of everyday practices in order to support people to actually shift consumption.

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