Shifting Dishwasher Usage Based On Renewable Energy

Ariën Helder
Eindhoven University of Technology
5612 AZ Eindhoven, The Netherlands
a.helder@student.tue.nl

Jochem Verstegen
Eindhoven University of Technology
5612 AZ Eindhoven, The Netherlands
j.r.p.verstegen@student.tue.nl

Jesper Kapteijns
Eindhoven University of Technology
5612 AZ Eindhoven, The Netherlands
j.m.h.kapteijns@student.tue.nl

Amber Wu
Eindhoven University of Technology
5612 AZ Eindhoven, The Netherlands
y.wu5@student.tue.nl

Abstract
This project explores how we can encourage people to adjust the timing of high-power appliance usage based on renewable energy production, focusing specifically on dishwashers. Employing a data-enabled design methodology, we conducted a two-phase research process: a contextual exploration to understand participants' dishwasher usage patterns and motivations, followed by an informed exploration involving deploying a digital user interface intervention. Our findings reveal that while participants are receptive to adopting more sustainable behaviours, factors such as the absence of clear financial incentives and the increased effort required to use appliances at less convenient times impede behavioural changes.

This research demonstrates the potential of data-enabled design in creating interventions promoting more sustainable energy use patterns. By addressing the challenges of aligning household energy consumption with renewable energy availability, this work contributes to the broader goal of fostering more sustainable energy practices in the future.

Author Keywords
Data-enabled design; Sustainability; User Interface design; High-power appliances

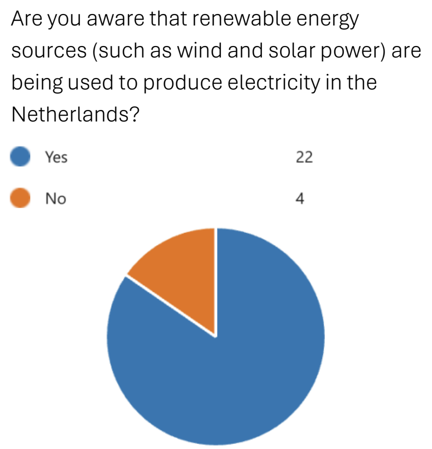

Figure 1: People who are aware of sustainable energy

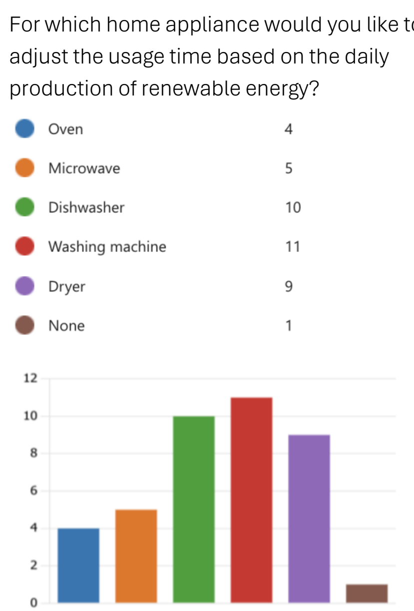

Figure 2: The high-power appliances people are willing to adjust

Introduction

Over the past years, the amount of available renewable energy has increased dramatically [8]. Solar and wind energy have seen a steep rise, especially. The availability of wind energy is fairly unpredictable but remains relatively constant. Solar energy, naturally, is mostly available in the middle of the day. The peak in solar energy throughout the day is generally when the most renewable energy is delivered to the grid. As energy cannot be stored on the grid, it should be consumed as soon as it is produced to consume power most sustainably. Otherwise, there is the risk that this energy goes to waste without being used [5]. In 2023 in The Netherlands, there were 308 hours with negative prices for electrical energy, up from 85 hours in 2022 [10]. This means that increasingly often, more renewable energy is being generated than it is being consumed.

For several reasons, however, people might choose to consume power by using their household appliances at times that are not the most sustainable [4]. For instance, as many people are not at home during the day, using their appliances in the morning or at night might be more convenient. Additionally, some people might be financially incentivised to use their appliances in the early morning or at night because they have an energy contract offering low prices for energy at off-peak moments, which are often between 23:00 and 7:00 and originally implemented based on fossil power plants in the 1960s [3]. This off-peak system is not related to renewable energy availability.

To investigate the reasons why people use their household appliances at certain times and how to align this optimally with the moments when the most renewable energy is being produced, this project aims to address the following research question:

- How can we encourage people to adjust the timing of high-power appliance usage based on renewable energy production?

It aims to address this question through the data-enabled design methodology [7]. Participants' energy usage patterns will be explored contextually. Insights from this contextual exploration will be a starting point for an informed exploration. During the informed exploration, an intervention will be deployed at the participants' homes. Data will be gathered on how this intervention affects their energy usage patterns.

Contextual exploration

Project scoping

This project is dedicated to sustainable development. Based on further exploration of the theme, we have focused our research on household energy consumption of high-power appliances. We aim to design a product that can motivate people to adjust the usage time of high-power appliances to periods when renewable energy is abundant, thereby optimising energy utilisation.

To understand people's awareness of sustainable energy use and which high-power appliances they are willing to adjust, we designed a questionnaire and distributed it among TU/e students and our acquaintances (see Appendix A). 26 individuals between the ages of 20 and 35 took part in it. We found that 22 people are aware of sustainable energy and know it is currently used (Figure 1). Additionally, the top two high-power appliances people are willing to

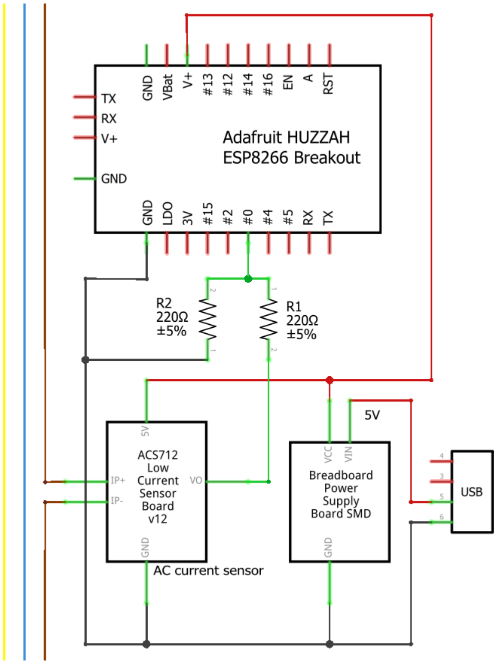

Figure 3: Schematics of our probe

Figure 4: Creation, testing and placing of probe

adjust are the washing machine and the dishwasher (Figure 2).

To better explore the energy consumption of high-power appliances, we need to create a probe to measure the usage patterns, which can only be done for one specific appliance. Considering that with washing machines, clothes need to be removed promptly after washing to prevent odours and mould growth [1]. Additionally, certain stains become harder to remove if left unwashed for too long, so washing dishes is more flexible. Dirty dishes can be temporarily stacked and washed when renewable energy is more available and do not need to be dried immediately after washing. Dishwashers offer greater flexibility regarding usage timing than washing machines, so we decided to focus on dishwasher usage.

Probe and data collection

We created two probes to measure the dishwasher's energy usage (Figure 4). They consist of an ESP8266 or ESP32 with Wi-Fi connectivity to upload the measurements to Data Foundry. The dishwasher is plugged into a 3-socket power bar, and we measure the AC current going through the cable towards the power bar using a hall-effect current sensor. This sensor outputs a voltage based on the amount of current flowing through it, which we can measure using the analog-to-digital converter (ADC) on the ESP. The current sensor outputs a voltage ranging between 0-5V, while the ADC pin on the ESP8266 can only measure between 0-1V and the ESP32 between 0-3.3V. Because of this, we used two resistors to create a voltage divider to reduce the 5V range to one that the microcontroller can measure (for the schematics, see Figure 3). After calibrating the sensor, we multiply the measured current by 230 (the standard AC voltage) to calculate the power usage in Watts. This value is uploaded to Data Foundry every 20 seconds, along with a Boolean value reflecting whether the dishwasher is running. To be able to update the software remotely if needed, we implemented over-the-air update functionality using OTAdrive.com, which checks for any new firmware every 20 minutes and updates when new firmware is available. Appendix B includes the latest firmware code.

We collected the dishwasher usage for two participants as our quantitative data. Further, after the dishwasher was finished, we automatically sent a message to the participant via a Telegram chatbot asking for a picture of the dishwasher's contents. This allowed us to understand how full the dishwasher is loaded, which could indicate how much the participants care about wasting energy.

PRINCIPLE 8: USE TECHNOLOGY CONSCIOUSLY AND BE TRANSPARENT AND CRITICAL ABOUT APPLIED DATA PRACTICES

We measure the current going through a 230V cable, so our probe needs to be safe. We use regular high-voltage cases to create safe connection between the cable and the current sensor, clamped the cables so they cannot be pulled out, and physically separated the high-voltage and low-voltage parts from each other so they cannot touch each other if something does break. The data tracking is made as low-effort as possible using a telegram bot.

PRINCIPLE 7: USE MODULAR AND REUSABLE SYSTEMS AND METHODS

We use a common microcontroller (ESP8266 and ESP32) with a regular current sensor to measure the energy. We implemented OTA functionality in the code on our probe so we can update the software later when needed without needing physical access.

Data Foundry

All the retrieved data has to be stored safely and preferably together in a clear manner. Data Foundry, a design-specific infrastructure for prototyping and designing with data [2], allowed us to collect and store data from various sources in a structured way while still being able to comply with the General Data Protection Regulation (GDPR), which enhances individuals' control and rights over their personal information. We created a project in Data Foundry in which we added 3 datasets during the contextual exploration phase and 4 datasets during the informed exploration phase.

Datasets contextual exploration:

1. Dishwasher usage:
   this dataset contains the energy measurements of the probes installed at the participants, showing when the dishwasher is turned on
2. Media Data:
   visual responses from the participants on the automated Telegram requests, such as pictures of the contents of the dishwasher when it was finished
3. Semi-structured interviews:
   Transcriptions of the interviews with the participants, including the Thematic Analysis

Datasets informed exploration:

1. Diary data:
   Textual responses from the participants on the automated Telegram requests. This contained motivations to turn on the dishwasher at a specific time and was added after the intervention
2. Renewable Energy UI:
   Embedded Figma Prototype showing the UI with available renewable energy
3. Dishwasher with intervention:
   Identical to dishwasher usage, but the data is only sent when the dishwasher is running to prevent a too-large dataset
4. Semi-structured final interviews:
   Transcriptions of the final interviews with the participants

The Diary and Media data datasets required participants' responses via push notifications. We created scripts that sent these push notifications during the contextual exploration phase.

We used Data Foundry to transcribe one interview, but it was inaccurate and did not differentiate between the researcher and the participant. Fixing it took extra time, so we transcribed further interviews in MS Word. We stored all transcripts and the thematic analysis in a separate dataset in Data Foundry called “Semi-structured interviews.”

PRINCIPLE 5: STAY IN CONSTANT CONTACT WITH THE CONTEXT WE DESIGN FOR
We used Data Foundry to act on the data and ask for qualitative data at the right time.

PRINCIPLE 9: Embrace automation to get close to reality
We automated requesting for additional information when the dishwasher starts or stops running.

Figure 5: Affinity diagramming

Figure 6: Coding

Semi-structured interview
We interviewed the participants a few days after the probes were installed to have some data to use in the interview. This semi-structured interview had two focus points. Firstly, the intensity of the dishwasher's use and the times at which it is used. The second focus was to be informed about the current knowledge about renewable energy and the willingness to adapt their current use to energy availability. The next step from these interviews was to analyse them using thematic analysis.

We used the thematic analysis method to analyse the qualitative data from the interview. We used an inductive approach for this thematic analysis, meaning there were no predefined codes or themes. We started structuring the data in an affinity diagram (Figure 5) from where the coding could start (Figure 6). Coding took place until no new codes emerged after iterative reviewing. This process also revealed relationships between the codes [11].

PRINCIPLE 3: FAVOUR DEEP, CONTEXTUAL DATA OVER WIDE BIG DATA
The interview gave us data which we used to understand the automated data.

We connected the quotes into themes and, within these themes, defined sub-themes:

- Convenience
  - Ignorance
- Use
  - Time of use
  - Responsible use
- Financial incentive

Ignorance is part of convenience because the items represent issues that can be easily resolved by just spending time delving into the subject. This is resembled by the answer to the question of whether it is hard to turn on the timer of the dishwasher:

> *"I don't even know how it works. OK, so I know it's possible."*

PRINCIPLE 1: DESIGN WITH STORIES AND ANECDOTES
We have only 2 participants and take their thoughts and opinions into account when designing and collecting data.

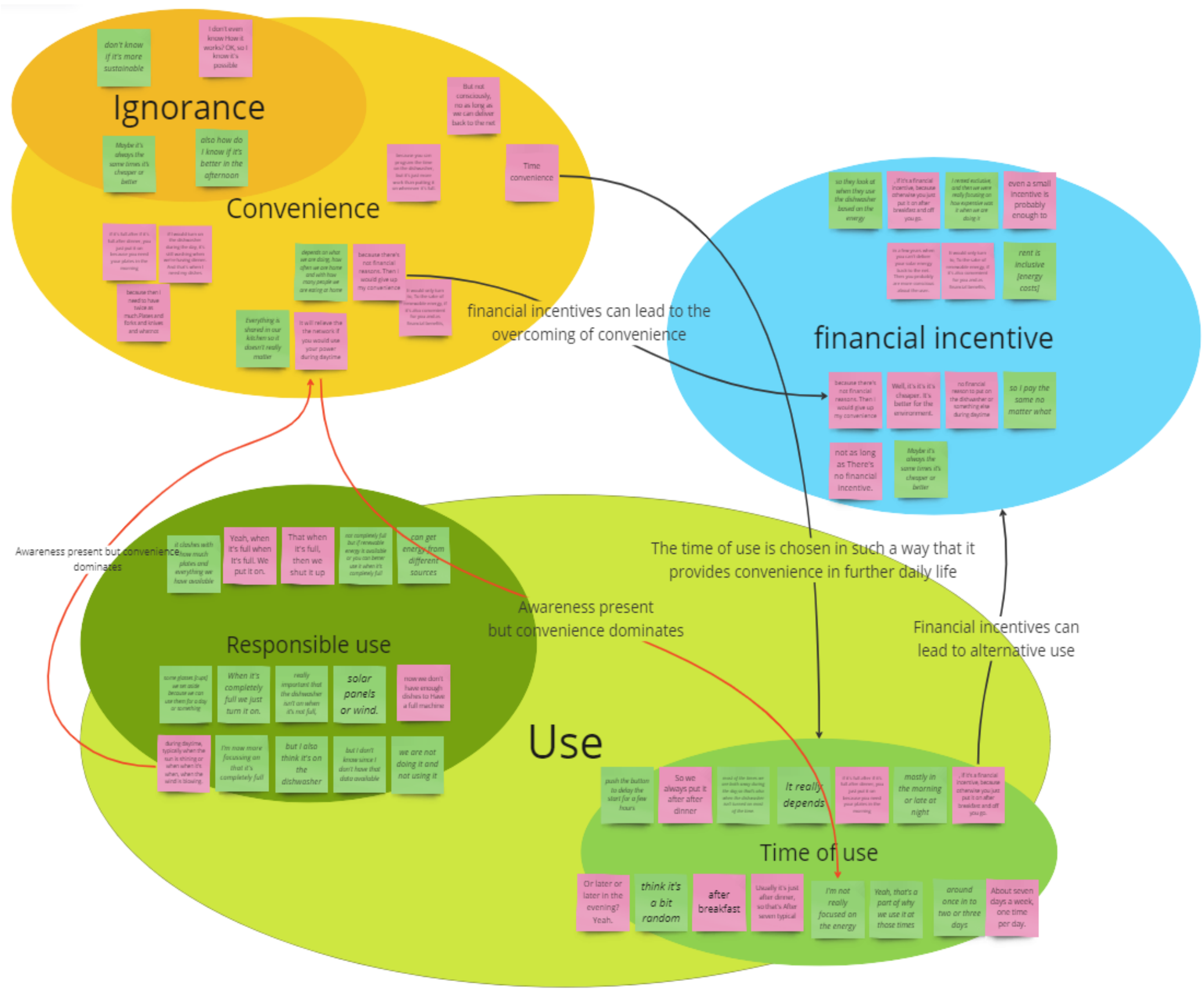

Figure 7: Thematic Analysis Map with themes, sub-themes and relationships

The relations between the different items could be identified and visualised when put into a Thematic Analysis Map (Figure 7).

- Financial incentives can lead to the overcoming of convenience
- The time of use is chosen in such a way that it provides convenience in further daily life
- Financial incentives can lead to alternative use
- Awareness is present, but convenience dominates

The last relation, awareness, shows the relation between responsible use and time of use, which is still dominated by convenience. The participants know that renewable energy can be used responsibly, but their awareness has not yet resulted in caring about energy use. This can be traced back to moments when the dishwasher is used.

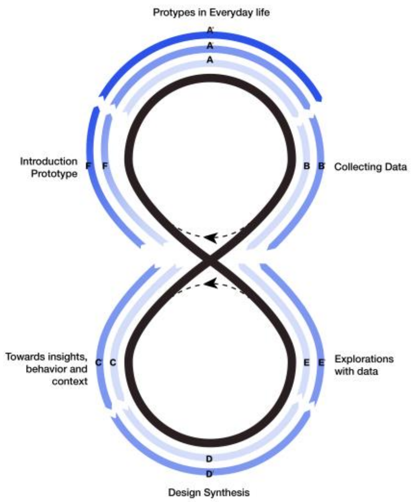

Figure 8: Data-Enabled Design loop

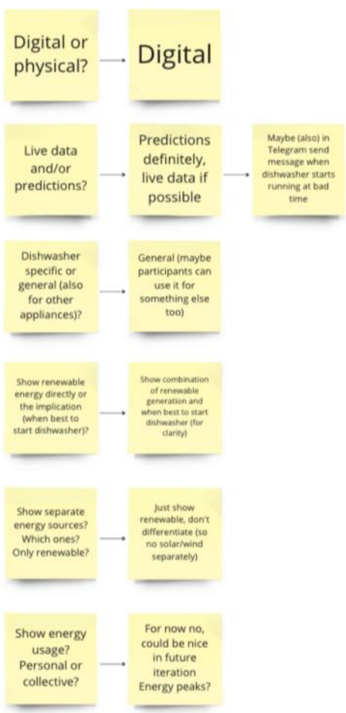

Figure 9: Brainstorming for first design iteration

Initial Findings

This first data exploration of the use of the dishwasher gave us two major insights, in which the quantitative and qualitative data support each other. The first is that the dishwasher is turned on during low renewable energy generation times. The graphs showing the use of late in the evening or early in the morning indicate this, and the interview backs this up by suggesting that this is the most convenient time to use it in the participants' daily lives. The second insight is that the participants are conscious about their dishwasher use regarding the environment because they mention in the interview that they only turn on the dishwasher when it is full, backed up by the media data. The pictures which were sent after each use showed full dishwashers.

Informed exploration

Design Process

The second stage of the process was the informed exploration [6], in which we analysed the data gathered in the contextual exploration and started to work towards the first prototype of our design.

While applying Data-Enabled Design, we went through the design loop multiple times after the second stage (Figure 8), and the users went through these multiple explorations while continuing to collect data from the participants. Going through the process loop in series where possible allowed us to provide the participants with a structured process in which they could easily understand and follow the steps without a forced obligation to change the dishwasher usage. They had the chance to gain more insights themselves, while at the same time, the information about the use remained rich to the project because we could detect if the proposals would change the time of use.

PRINCIPLE 11: USE DATA AWARENESS IN A CREATIVE DESIGN PROCESS
We used and combined all collected data to get insights into the situation from where we created the design

Data Plumbing

We used the collected data in the conceptual exploration to build up and gather insights for the design. In this activity called data plumbing [6, 9], we analysed the received data, retrieved new data and insights, and channelled them towards our first design. Data from the probe and the survey were compared to the data from the diary, media, and interview, leading to the design we presented to the users later.

The qualitative data from the interview led to the context in which we could place the quantitative data from the measurements. From the measurements, we can conclude that the dishwashers were turned on early in the morning and late in the evening, which is in contrast to the times when renewable energy was available (for the recommended starting times, see Figure 11Figure 10: Clock and data screens showing timeslot). From the interviews, we concluded that these

PRINCIPLE 2: TREAT QUALITATIVE DATA AND QUANTITATIVE DATA WITH EQUAL RIGOUR
We used qualitative data and quantitative data for mutual verification and to gain a deeper understanding of reasoning.

times are mainly chosen out of convenience but also partly out of ignorance. Convenience, because this best fits into the daily lives and routines of the participants who are not at home during the day and therefore do not have the opportunity to turn on the dishwasher but also to have clean dishes when needed, for example, for the next meal. Ignorance, because on the one hand, they have not studied the best times to use renewable energy; on the other hand, they do not want to make an effort to look into it, although they may want to change their use if given information.

First design iteration

After collecting two weeks of data on dishwasher energy consumption and usage frequency and conducting a brainstorming session with the team (Figure 9), we decided to design an app.

First, we planned to display renewable energy generation and the optimal times to start appliances. An interface prototype can help us design and test this information display method, ensuring it is intuitive and useful for users. Second, we aim to apply the interface to dishwashers and other household appliances. Additionally, through the interface prototype, we can more easily add and test new features in future iterations, ensuring they integrate smoothly into the existing interface. Overall, the interface prototype can improve design quality and user experience, reducing rework caused by changing requirements or design flaws, thereby saving time and costs.

The app primarily includes two sections: "timeslot" and "data" (Figure 10). The "timeslot" section visually displays the recommended time for using high-power appliances, which is from 9:00 AM to 9:00 PM. At the same time, the "data" section clearly shows real-time generated sustainable energy.

Users can start their high-power appliances during the recommended time slots. Additionally, it is important to note that the recommended time slots are not during the peak production of renewable energy but 2-2.5 hours earlier. This is because dishwashers typically have long run times. Notifying users in advance allows them to start their dishwasher as renewable energy production begins to rise, ensuring that the high-energy consumption phases of the wash cycle coincide with peak renewable energy output periods. This approach can maximise the use of renewable energy.

Figure 10: Clock and data screens showing timeslot

Principle 4: Visualise data in understandable and transparent ways

While we do not show the collected data to the participants, we do show renewable energy predictions to them, together with what this information means for them. In interviews, we asked how this information was received.

Principle 10: Build data and prototypes for research and for solutions in parallel

The first UI we made was based on an interview with a participant, who expressed they would need information on renewable energy predictions to adjust their dishwasher usage.

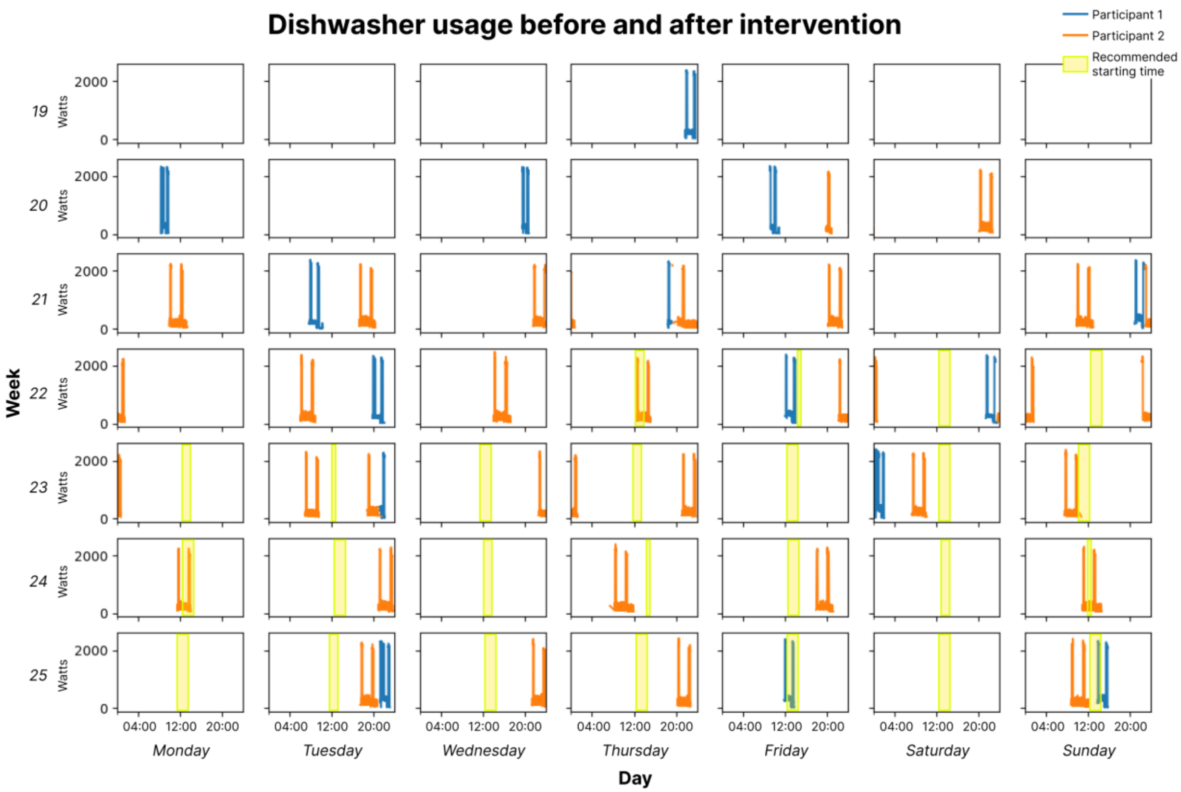

Figure 11: Dishwasher usage of both participants before and after intervention

Method

The push notifications in the telegram bot sent requests to the participants to reflect on the reason for turning on the dishwasher when it started and to send a picture of the contents when it was finished. This interaction between the user and the telegram bot, in combination with the data from the probe, can be considered as solution data [7]. This is the base of the collected data because it reflects when the participants use the dishwasher, why they use it at that time and how they use it.

Results

Figure 11 displays the dishwasher usage of both participants and the starting time we recommended during the intervention. Based on this data, participant 1 only started their dishwasher near the recommended timeslot 3 out of 7 times, and participant 2 for 5 out of 18 times. However, it is worth noting that our probe installed at participant 1 was disconnected during week 24, resulting in missing data. According to this participant's diary entries, they used the timer function on their dishwasher to delay the start three times this week, including once delaying it for 17 hours.

Based on these findings and the second interviews conducted later, we can state that the first design iteration was ineffective at adjusting the dishwasher usage to more sustainable times. It depends per person, with participant 1 trying to use the interface at least a few times, unlike participant 2.

The dishwasher is an appliance made for convenience, making convenience one of the most important aspects of using the dishwasher. This also came forth from our results, which indicate that spending effort to use the dishwasher at a more sustainable time takes away from this convenience. Because of this, we decided to make a new iteration to make it more convenient to use the dishwasher at a sustainable time.

PRINCIPLE 6: DESIGN WITH THE DATA THAT WE GATHER IN REAL-TIME
We can see data coming in to Data Foundry live, and first used it to see the participant's current behaviours. After implementing a design, we also ask for the reason for turning on the dishwasher at the time when they turned it on.

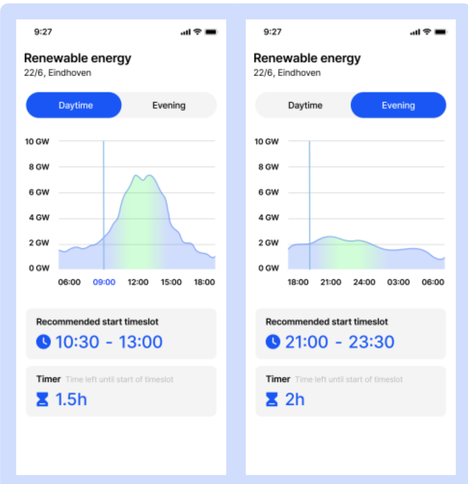

Figure 12: Daytime and evening timeslots with timer

Final Design

The new interface design will divide the system into "Daytime" and "Evening" sections (Figure 12). Both will display a graph with a recommended timeslot for using high-power appliances, with a real-time countdown showing how long until the recommended time begins. This design aims to help users select a timeslot that works for them. Additionally, the timer function simplifies the process, allowing users to set the dishwasher without manually calculating the start time, thus reducing the effort required.

The new interface adds a time dimension compared to the previous design. It shows the recommended usage time and provides a countdown to that period. Users do not need to check frequently; they only need to occasionally glance at the countdown to know the ideal time window for starting high-power appliances.

Closing Interview

The first interview in the contextual exploration phase showed many similarities and slight differences between the 2 participants. In the final interview, we still noticed the same similarities, but the differences expanded, indicating a diversification in the participants' approaches.

The similarities in dishwasher use were still based on convenience, and for both participants, this was also leading. They both want to turn the dishwasher on in the evening or when it starts to smell, and they want it ready when they need the contents.

One of the participants felt no incentive to change their behaviour towards using renewable energy. The dishwasher is still turned on at a convenient time, and setting a timer takes too much effort. They did not notice the notifications from the telegram bot, which could have been caused by distractions from their business trip. They care about the environment, but if that would be an incentive, they would wash by hand, saving more energy. The only incentive would be financial when they could save €0,11 per turn. This can only happen when they get a new energy contract.

The other participant was willing to change their behaviour, but getting out of the routines would take some effort. Setting a timer would not be a problem, but they did not know which time, especially in the evening. The provided timeslots were not always clear, and they discovered a pattern of good slots between 12:00 and 15:00, which made them doubtful. This feeling was extravagated when they wanted to turn the night before because the long timer setting felt unnatural. They stated it would work much better if a countdown to the slot were provided in the app and if this time was only for a few hours. They liked being part of the project, which made them aware of the dishwasher and, therefore, energy use, and it fed nice discussions they had with their roommate.

Both participants mentioned that this project made them aware of the dishwasher's energy use, but it did not provide sufficient incentive or ease to give up their pattern of dishwasher use, which was and still is led by convenience.

Ideal Future

While our final design concept is expected to make it easier to use the dishwasher at more sustainable times, making sustainability more convenient, it is not what we expect would be ideal in the future. As also came forth from the closing interviews, it would be most convenient if the dishwasher automatically started running at the most sustainable time. It should also allow the user to set a time at which it needs to be finished. On the one hand, we think there is an opportunity to do this in an app on a smartphone. Still, it can also be valuable if the time can be set on the dishwasher itself, after which it automatically selects the best moment to run its program.

Discussion

Although this project's approach was based on the Data-Enabled Design approach, it could have been more thoroughly implemented. For instance, the project's scope was relatively narrow, and it could have started much broader to explore the context from different angles to get inspired, only to start becoming more specific later on during the project.

Additionally, due to the nature of the process, bias might have been introduced to our participants. For instance, the first interview with our participants took place about a week after the deployment of the energy meters. As a result, they might have become more conscious about the topic of the study already and might have altered their power consumption behaviour as a result.

PRINCIPLE 12: SHIFT PERSPECTIVES AS NEEDED
By looking at the perspective from the user, we learned that the dishwasher is often used for convenience, at a convenient time. If it takes effort to change the usage time, it is not convenient anymore. Therefore, the intervention should be as convenient and low-effort as possible.

Another limitation is that the type of quantitative data that we collected was rather low-frequency, as a dishwasher is typically used at most once per day, typically less. As a result, we have to wait relatively long to gather enough data to analyse and discuss with our participants meaningfully. Furthermore, one of the probes was disconnected for about a week, meaning that some of the data collection is missing. However, as we combine quantitative with qualitative data, we have still been able to get a rough view of the participant's power consumption patterns during that period.

Future work in this area could expand on the insights gathered during this project by exploring angles that were not considered yet. For example, the energy usage patterns of participants could be investigated more broadly. When do participants use different kinds of household appliances, and what are the underlying reasons to do so? Furthermore, it would be interesting to explore how to effectively communicate with users and how to select a suitable starting time for their appliances.

Conclusion

In conclusion, this project aimed to answer the following question:

- How can we encourage people to adjust the timing of high-power appliance usage based on renewable energy production?

We have been working towards answering this question through two distinct phases: a contextual exploration, in which we familiarised ourselves with participants' dishwasher usage patterns and underlying motivations, and an informed exploration, during which a digital user interface was deployed as an intervention to help the participants gain insight into the most sustainable timeslots to use their dishwasher.

Through these explorations, we discovered participants' willingness to adopt more sustainable behaviours and some key factors that keep them from switching to these behaviours. For instance, the lack of a clear financial incentive prohibits this switch, as does the increased effort participants have to put in if they want to use their dishwasher at a less convenient time.

Through this work, steps have been taken to gain insights into participants' power consumption and what could motivate them to adapt their power consumption patterns to fit the availability of renewable energy. We hope that this can contribute to a more sustainable society.

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Appendix

A: Questionnaire Questions: Sustainable Energy and High-Power Appliance Usage

Thank you for participating in our survey! Your feedback is crucial for us to understand attitudes and behaviours towards the use of sustainable energy and high-power appliances. Please select the options that best represent your views and provide your opinions when necessary.

1. Your age
    - Under 20 years old
    - 20-35 years old
    - 35-50 years old
    - Over 50 years old

2. Are you aware that renewable energy sources (such as wind and solar power) are being used for electricity production in the Netherlands?
    - Yes
    - No

3. What percentage of electricity do you think comes from renewable sources in the Netherlands in 2023?
    - Less than 30%
    - Approximately 50%
    - Approximately 70%
    - Over 90%

4.How did you learn about the use of renewable energy sources? (Select all that apply)
    - Social media
    - News reports
    - Government campaigns
    - Friends or family
    - School

5. Do you know at what time of the day renewable energy sources (such as solar, wind power) are most abundant?
    - 6:00 - 11:00
    - 11:00 - 16:00
    - 16:00 - 20:00
    - 20:00 - 24:00
    - 24:00 - 6:00

6. Would you be willing to adjust the high-power electrical appliances usage time based on the availability of renewable energy?
    - Yes
    - No

7. For which home appliance would you like to adjust the usage time based on the daily production of renewable energy?

- Oven
- Microwave
- Dishwasher
- Washing machine
- Dryer
- None

8.What are your reasons for being willing to make such changes? (Select all that apply)

- Reduce dependence on fossil fuels
- Support the development of sustainable energy
- Save energy costs
- Reduce environmental impact

9. If no, what are your reasons for not being willing to make such changes? (Select all that apply)

- Don't know how to adjust the time
- Unwilling to change existing lifestyle habits
- Concerned about impacting quality of life

10. Apart from the reasons mentioned above, are there any other factors you would like to add?

11. Apart from the reasons mentioned above, are there any other factors you would like to add for not being willing to change?

B: Code used for probe

```
/**********************************************************************
   This code lets an ESP8266 measure AC current going through a cable,
   calculates the power in Watts, and sends it to an IoT dataset in
   Data Foundry.
   This works only with an existing account, project and dataset on
   Data Foundry (https://data.id.tue.nl)
   This file allows remote updating via OTAdrive.com

   Made by Jochem Verstegen for the course Data-Enabled Design at TU/e
 **********************************************************************/

#include "DFDataset.h"
#include <Arduino.h>
#include <ESP8266httpUpdate.h>

#define ProductKey "xxxxxxx-1234-5x67-xx89-01234567xxx890" // Replace with your own OTAdrive APIkey
#define Version "0.1.0.2"
#define MakeFirmwareInfo(k, v) "&_FirmwareInfo&k=" k "&v=" v "&FirmwareInfo_&"

// MAC Address: 84:f3:eb:b3:15:99
// SSIDs of Wifi networks
const char* ssid[] = {    "p1" ,"Laptop van Jochem","iotroam",   "ESP_temporary","xxxxxx"};
// Passwords of Wifi networks.
const char* password[] = {"xxx","xxxxxx",           "3qPcGvjYRq","r8zZ6eL75M",   "xxxxxx"};
// Amount of wifi cridential stored
const int amountWifi = 5;

// Various settings:
const int runningThreshold = 30; // Watts | After this value, we consider the dishwasher to be running
const int runningSensitivity = 16; // Only tells DF if it's running when this amount occurs in the array
const int dataFoundryTimer = 20; // Send data to DF every x seconds
const int updateTimer = 20; // Minutes | once every x minutes check for new update

// put the adress of Data Foundry here
const char* datafoundry = "data.id.tue.nl";

// create connection to dataset with server address, dataset id, and the access token
DFDataset iot(datafoundry, 10959, "aUUwbmhVNDhrdDRPZFJGbVhTYks3aFM4MlFvSGNFak4vQVZmN1lrOTJhZz0=");

// Pin setup:
const int sensorIn = A0;

// Variables for measurement
int mVperAmp = 100;
int Watt;
int prevWatt = 0;
bool changedWatt = false;
double Voltage = 0;
double VRMS = 0;
double AmpsRMS = 0;

bool running = false;
bool prevRunning = false;
bool certain = false;
bool runningHist[20] = {false,false,false,false,false,false,false,false,false,false,false,false,false,false,false,false,false,false,false,false};
```

```
int runningArrayLength = 20;

// timer to not spam DF too much
long timer_start = 0;
bool send_data = true;

void update();

// put your setup code here, to run once:
void setup() {
  Serial.begin(115200);

  pinMode(LED_BUILTIN, OUTPUT);

  connectWifi();

  update();

  pinMode(sensorIn, INPUT);

  // you can also already set the device and activity here,
  // if they don't change throughout the program execution
  iot.device("xxxxxxxxxxxxx");
  iot.activity("idle");

  iot.addString("action", "program_started");
  send_data = true;
}

uint32_t updateCounter = 0;

void loop() {
  // Serial.println(WiFi.status());
  if (WiFi.status() != WL_CONNECTED) {
    iot.addString("action", "wifi_disconnected");
    send_data = true;
    Serial.println("Wifi disconnected, connecting again now...");
    connectWifi();
  }
  Voltage = getVPP();
  VRMS = (Voltage/2.0) * 0.707;
  AmpsRMS = (VRMS * 1000)/mVperAmp - 0.19; // 0.19 to make sure it measures 0 with no load
  AmpsRMS = AmpsRMS * 0.825; // 0.825 is a calibration factor for better accuracy
  if (AmpsRMS < 0.05) AmpsRMS = 0; // Make sure it stays at 0 if it's a very low measurement
  Watt = (AmpsRMS * 230);
  if ((Watt - prevWatt > 500 || Watt - prevWatt < -500) && !changedWatt) {
    int savePrevWatt = prevWatt; // Avoid sudden large measurements when (un)plugging something
    prevWatt = Watt;
    Watt = savePrevWatt;
    changedWatt = true;
  } else {
    prevWatt = Watt;
    changedWatt = false;
  }

  if (millis() >= timer_start + dataFoundryTimer*1000) {
    running = checkRunning();
```

```

    if (certain) {
      iot.addBool("running", running); // record in DF whether dishwasher is running

      if (!prevRunning && running) {
        iot.addString("action", "start_running"); // tell DF diswasher started
        iot.activity("running");
        send_data = true;
      } else if (prevRunning && !running) {
        iot.addString("action", "stop_running"); // tell DF dishwasher stopped
        iot.activity("idle");
        send_data = true;
      }
      prevRunning = running;
    }

    iot.addInt("power", Watt); // record the current measured power in DF
    if (send_data || running) iot.logItem(); // avoid sending data when dishwasher is not running to reduce dataset size
    digitalWrite(LED_BUILTIN, LOW);
    delay(200);
    digitalWrite(LED_BUILTIN, HIGH);
    timer_start = millis();
    send_data = false;
  }

  if (WiFi.status() == WL_CONNECTED) { // this function checks for updates every 20 minutes
    updateCounter++;
    if (updateCounter > updateTimer*60) {
      updateCounter = 0;
      update();
    }
  }
}

float getVPP() {
  float result;
  int readValue;                // value read from the sensor
  int maxValue = 0;             // store max value here
  int minValue = 1024;          // store min value here

  uint32_t start_time = millis();
  while((millis()-start_time) < 1000) //sample for 1 Sec
  {
    readValue = analogRead(sensorIn);
    // see if you have a new maxValue
    if (readValue > maxValue)
    {
      /*record the maximum sensor value*/
      maxValue = readValue;
    }
    if (readValue < minValue)
    {
      /*record the minimum sensor value*/
      minValue = readValue;
    }
  }

```

```
  // Subtract min from max
  result = ((maxValue - minValue) * 5.0)/1024.0;
  return result;
}

bool checkRunning() {
  int countTrue = 0;
  int countFalse = 0;

  for (int i = 0; i < runningArrayLength-1 ; i++) {
    runningHist[i] = runningHist[i+1];
  }

  if (Watt >= runningThreshold) runningHist[runningArrayLength-1] = true;
  else runningHist[runningArrayLength-1] = false;

  for (int i = 0; i < runningArrayLength; i++) {
    if (runningHist[i]) countTrue++;
    else if (!runningHist[i]) countFalse++;
  }

  if (countTrue >= runningSensitivity) {
    certain = true;
    return true;
  } else if (countFalse >= runningSensitivity) {
    certain = true;
    return false;
  } else {
    certain = false;
    return false;
  }
}

void update() {
  Serial.println("checking for updates now...");
  String url = "http://otadrive.com/deviceapi/update?";
  url += MakeFirmwareInfo(ProductKey, Version);
  url += "&s=" + String(ESP.getChipId());

  WiFiClient client;
  ESPhttpUpdate.update(client, url, Version);
}

void connectWifi() {
  // establish Wifi connection, loop through all wifi networks stored
  int wifiAttempts = 0;
  int wifiNetwork = 1;

  while (WiFi.status() != WL_CONNECTED) {
    if (wifiAttempts == 0 && wifiNetwork == 1) {
      Serial.print("Connecting to WiFi with SSID: ");
      Serial.println(ssid[wifiNetwork-1]);
      WiFi.begin(ssid[wifiNetwork-1], password[wifiNetwork-1]);
    } else if (wifiAttempts > 15) {
      WiFi.disconnect();
      wifiAttempts = 0;
      wifiNetwork++;
```

```
      if (wifiNetwork > amountWifi) wifiNetwork = 1;
      Serial.print("Failed, now trying WiFi with SSID: ");
      Serial.println(ssid[wifiNetwork-1]);
      WiFi.begin(ssid[wifiNetwork-1], password[wifiNetwork-1]);
    }
    digitalWrite(LED_BUILTIN, LOW);
    delay(500);
    Serial.print('.');
    digitalWrite(LED_BUILTIN, HIGH);
    delay(500);
    wifiAttempts++;
  }
  digitalWrite(LED_BUILTIN, HIGH);

  Serial.print("Connected to the WiFi network: ");
  Serial.println(ssid[wifiNetwork-1]);
}

```

C: Questions first semi-structured interview

1. How often do you use the dishwasher, for example, how many times a week do you typically use it?
2. Are there specific times of the day or week when you prefer to use the dishwasher?
3. What are the reasons for choosing these particular times?
4. What factors influence your decision to use the dishwasher? For example, if there are a lot of dirty dishes to wash.
5. What do you know about renewable energy and when it is available?
6. Do you know the advantages of renewable energy?
7. Would you be willing to adjust the dishwasher usage time based on the availability of renewable energy? Why?

D: Questions Closing interview

1. Thank you for helping us with this research. What do you think was the hardest part for you as a participant?
2. After a few weeks you were informed about the best time to put on the dishwasher. You didn't seem to follow this advice consistently. Why?
3. Since this week you were informed of 2 options to set your timer. What do you think about this option?
4. Did these options help you in being more sustainable?
5. What helped you in changing the time your dishwasher runs, or why didn't the proposals help you?
6. Will you continue to be more aware of your use of the dishwasher?