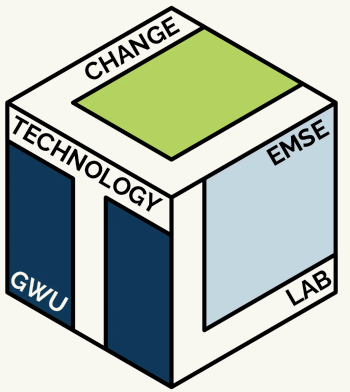
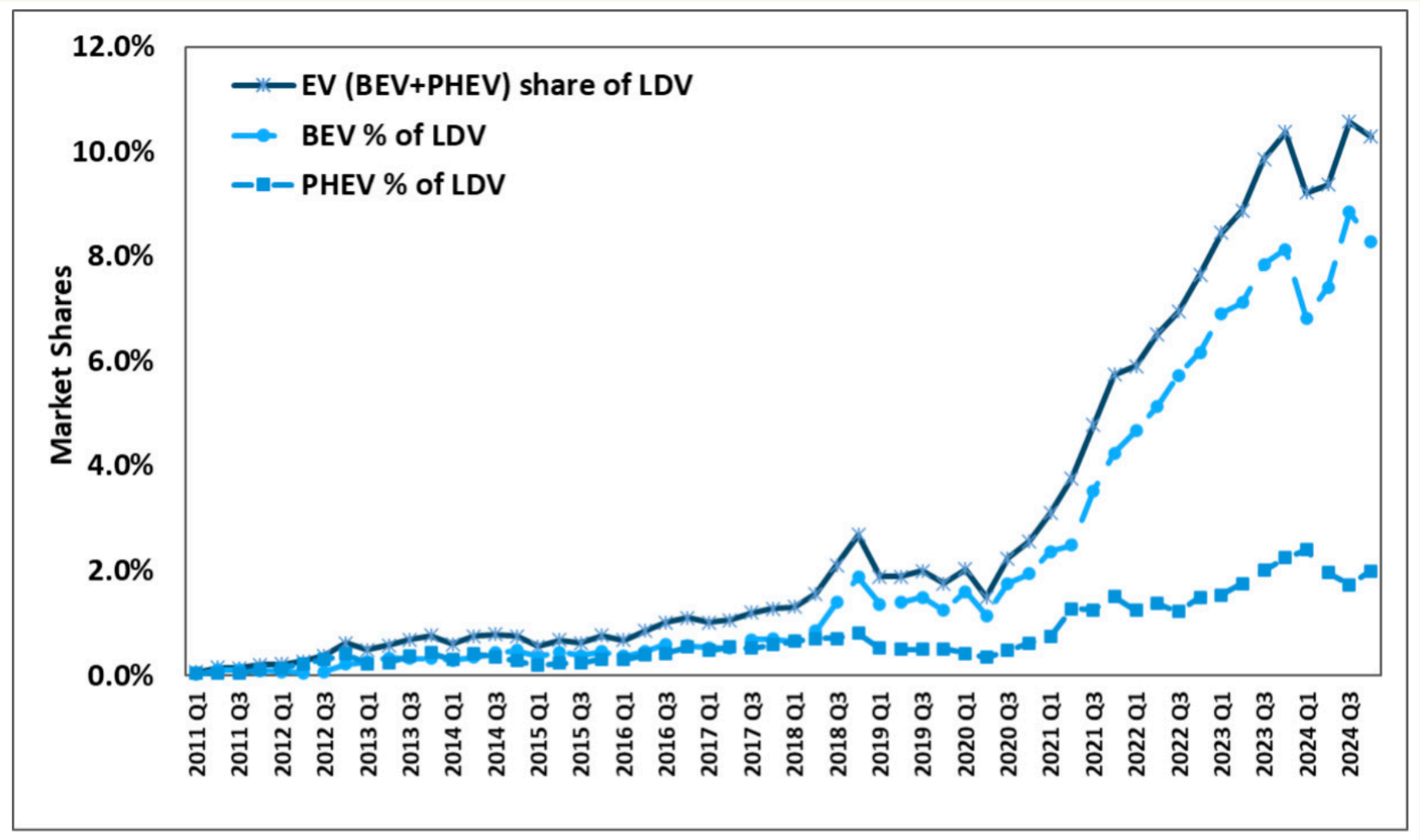
PhD Proposal Defense:

Electric Vehicle Smart Charging Adoption, Grid Peak-Shaving Quantification, and The surveydown Survey Platform



Pingfan Hu
George Washington University

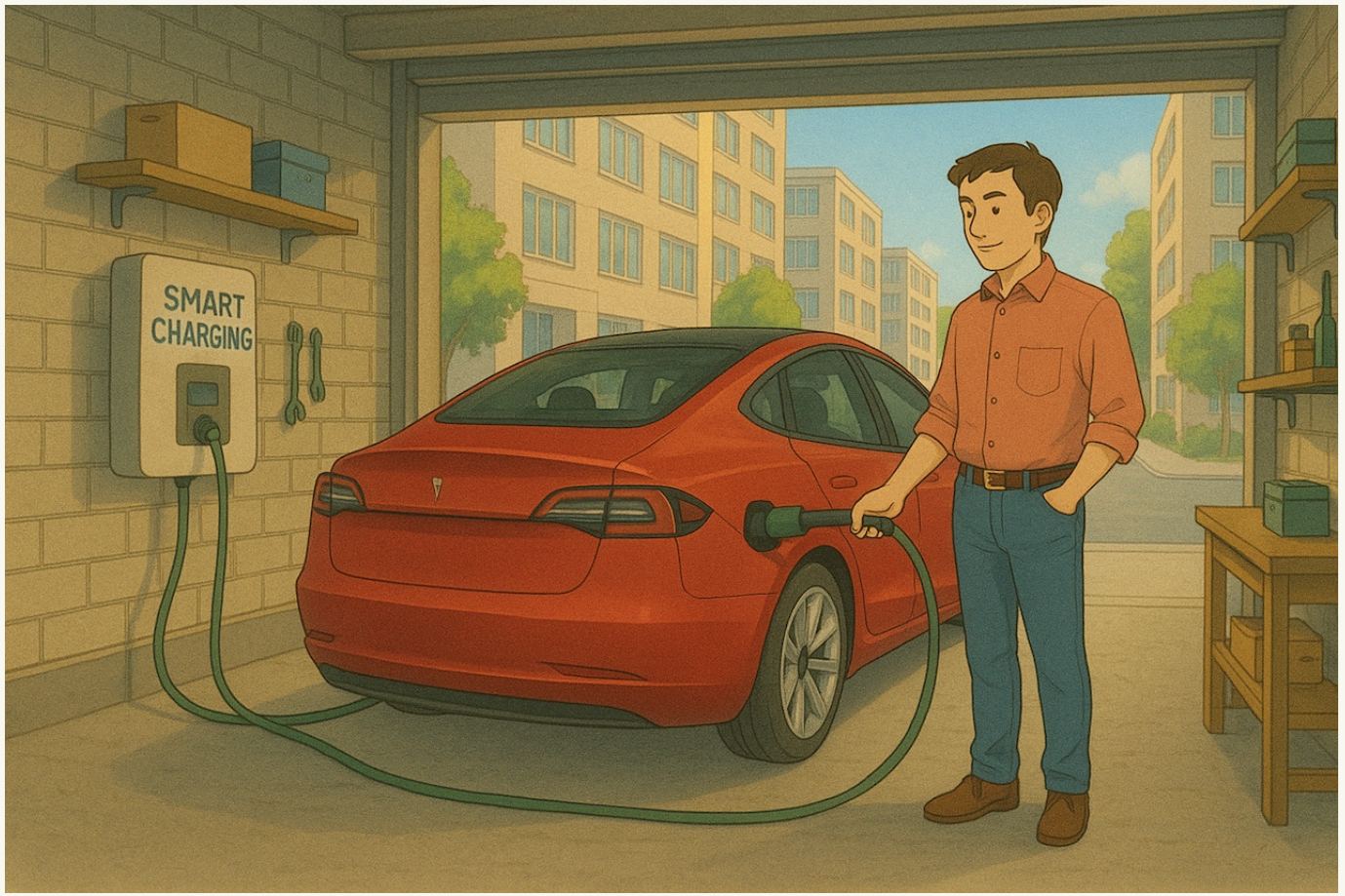
EV sales in US reaching ~10% of sales



Source: Argonne National Lab, www.anl.gov/ev-facts/model-sales

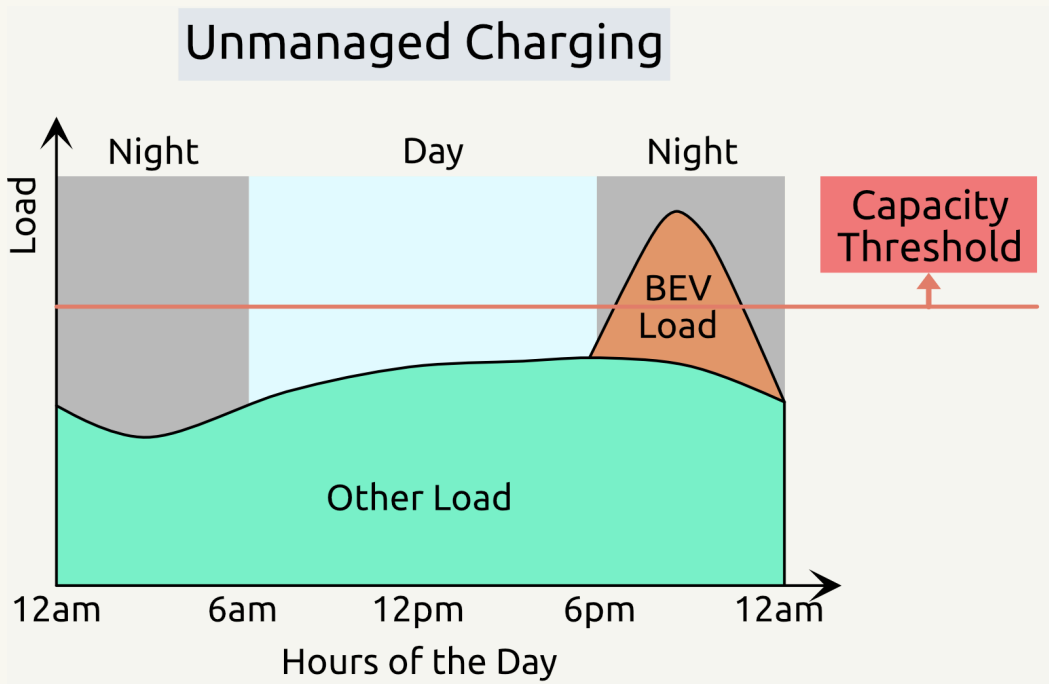
Introduction

- **Unmanaged** BEV charging is becoming a problem to the grid.
- **Managed** charging is cheaper and smoothes out the grid load.
- **Smart** charging: Supplier-Managed Charging (SMC) and Vehicle-to-Grid (V2G).



SMC - Supplier Managed Charging

- SMC smooths out EV charging spike (called “Peak-shaving”).
- Electricity demand is controlled below capacity threshold.
- It saves money and reduces pollution.



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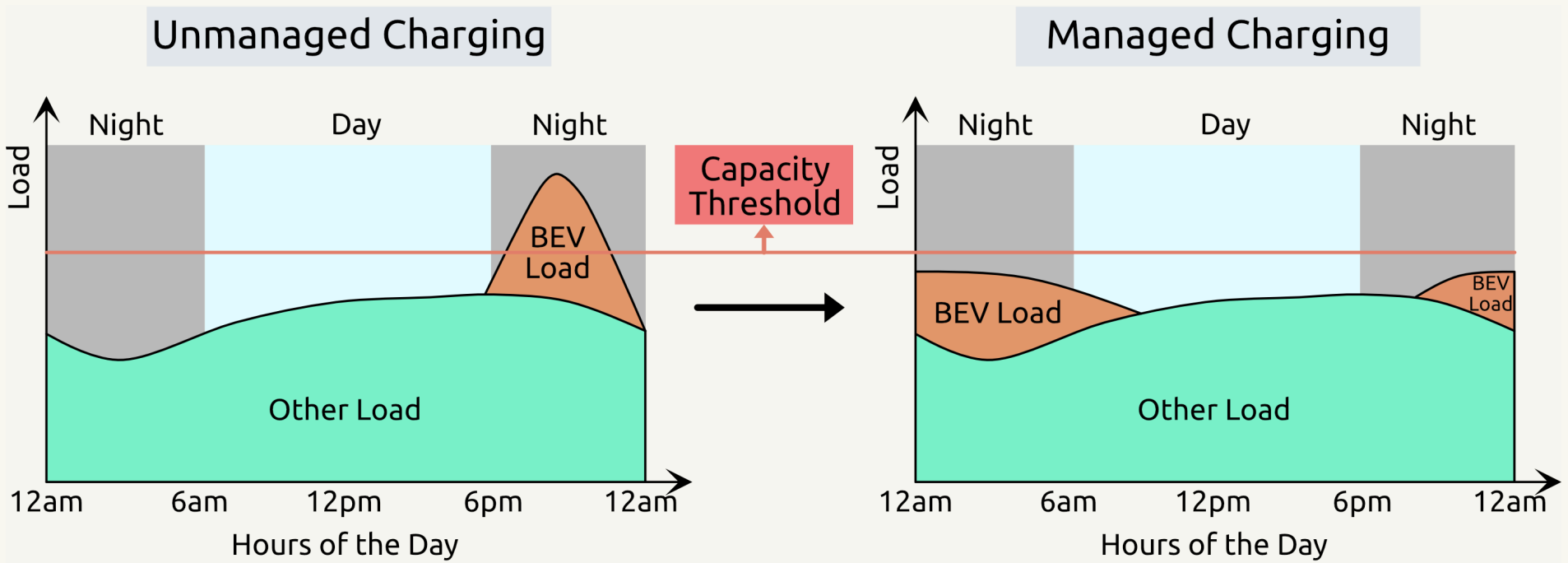


Managed charging avoids overload caused by BEV charging.

V2G - Vehicle-to-Grid

Non-V2G (Single Direction)

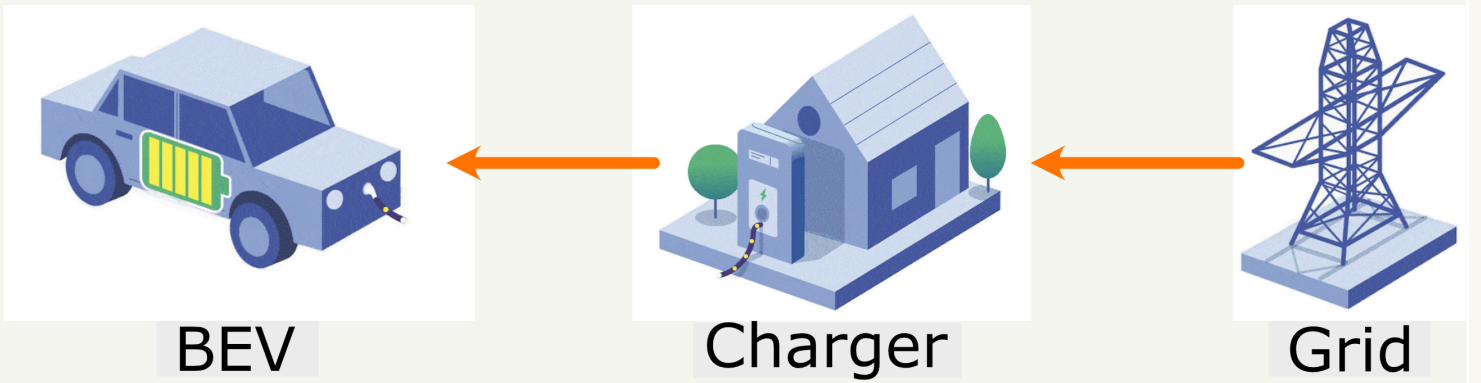
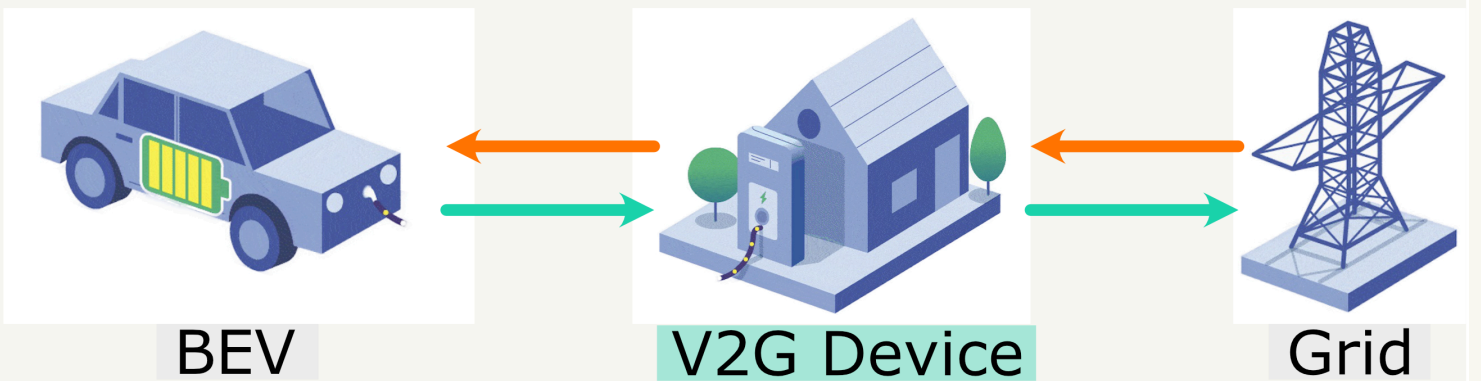


Figure Source: *wri.org*

V2G (Bi-direction)



In a V2G event, BEVs can charge the grid when necessary. BEVs are charged back eventually. Owners earn money.

Smart charging effectiveness depends on enrollment and peak-shaving.

Three Inter-connected Studies

Survey Research & Modeling

Electric Vehicle Smart Charging Adoption

Simulation Research

Grid Peak-Shaving Quantification

Software Development

The `surveydown` Survey Platform

Study 1
Electric Vehicle Smart Charging Adoption

Under second round of reviews:

Hu, Pingfan, Tarroja, B., Dean, M., Forrest, K., Hittinger, E., Jenn, A. & Helveston, J.P. (2024) "Measuring Electric Vehicle Owners' Willingness to Participate in BEV Smart Charging Programs" *Environmental Research Letters*.

Prior studies have few EV owners in sample

1. A survey-based study by Wong et al. (2023) examined **incentives** effect on EV owners' acceptance, but EV ownership in sample was only 19%.
2. A survey-based study by Philip and Whitehead (2024) found **range anxiety** matters, but EV ownership in sample was only 1.28%.
3. A survey-based study by Huang et al. (2021) indicates the importance of **fast charging**, but the sample size was only 157.

We need high EV ownership & large sample size.

Research Questions

1. **Sensitivity:** How do changes in smart charging program **features** influence BEV owners' willingness to opt in?

2. **Enrollment Rate:** Under what **combinations of features** will BEV owners be more willing to opt in to smart charging programs?

Conjoint survey to collect BEV owners' willingness.

Mixed logit model for utility simulations.

Survey Design

Conjoint Questions

1. Monetary Incentives
2. Charging Limitations
3. Flexibility

Demographic Questions

1. BEV Ownership
2. Personal Info
3. Household Info

Conjoint Question Explained

A Sample Conjoint Question

For example, if these were the only apples available, which would you choose? *

Option 1	Option 2	Option 3
		
Type: Fuji **Price**: $ 2 / lb **Freshness**: Average	**Type**: Pink Lady **Price**: $ 1.5 / lb **Freshness**: Excellent	**Type**: Honeycrisp **Price**: $ 2 / lb **Freshness**: Poor

1. Provide respondents with different **sets** of attributes.
2. Observe choices across random sets.
3. Estimate **utility** of each attribute.

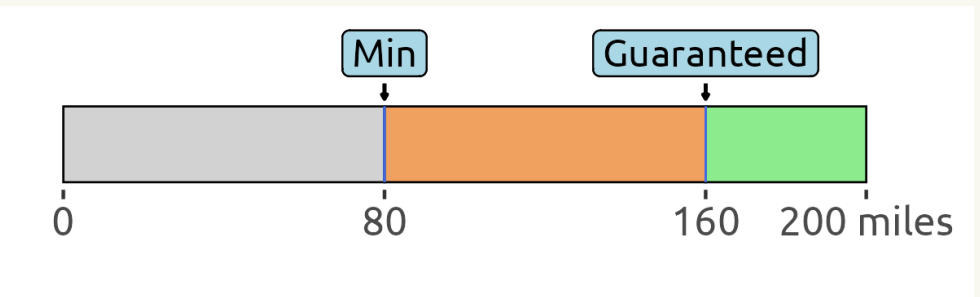
SMC Programs

Attributes

No.	Attributes	Range
1	Enrollment Cash	$50 to $300
2	Monthly Cash	$2 to $20
3	Monthly Override	0 to 5
4	Min Battery	20% to 40%
5	Guaranteed Battery	60% to 80%

Sample Program

Attributes	Values
Enrollment Cash	$300
Monthly Cash	$20
Monthly Override	5



(Range determined by stated vehicle they own)

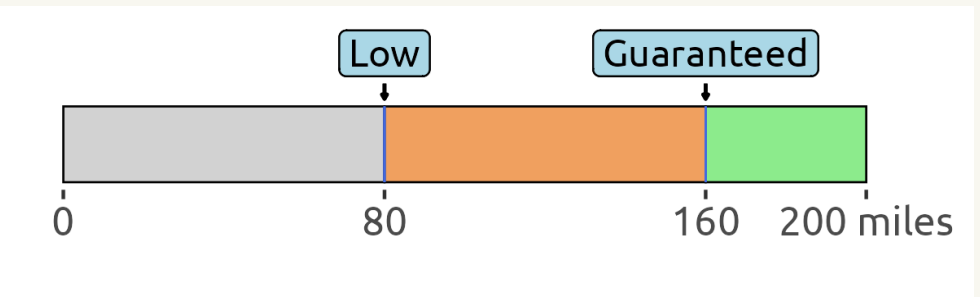
V2G Programs

Attributes

No.	Attributes	Range
1	Enrollment Cash	$50 to $300
2	Occurrence Cash	$2 to $20
3	Monthly Occurrence	1 to 4
4	Lower Bound	20% to 40%
5	Guaranteed Battery	60% to 80%

Sample Program

Attributes	Values
Enrollment Cash	$300
Occurrence Cash	$20
Monthly Occurrence	1

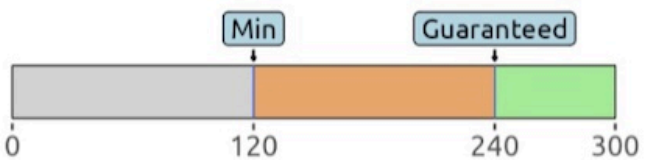


(Range determined by stated vehicle they own)

Sample SMC Question

(1 of 6) If your utility offers you these 2 SMC programs, which one do you prefer?
(Your BEV has maximum range of **300** miles.)

Access the SMC Attributes

Option 1	Option 2	Option 3
Enrollment Cash: $100 Monthly Cash: $20 Override Allowance: 1 per Month	Enrollment Cash: $200 Monthly Cash: $10 Override Allowance: 1 per Month	Not Interested
Battery Thresholds (in Miles): 	Battery Thresholds (in Miles): 	

Sample V2G Question

(1 of 6) If your utility offers you these 2 V2G programs, which one do you prefer?
(Your BEV has maximum range of **300** miles.)

Access the V2G Attributes

Option 1	Option 2	Option 3
Enrollment Cash: $100 Occurrence Cash: $5 Monthly Occurrence: 2 Battery Thresholds (in Miles):  	Enrollment Cash: $100 Occurrence Cash: $20 Monthly Occurrence: 2 Battery Thresholds (in Miles):  	Not Interested

Survey Fielding - 1,356 in Total

Meta Ads: Voluntary participants

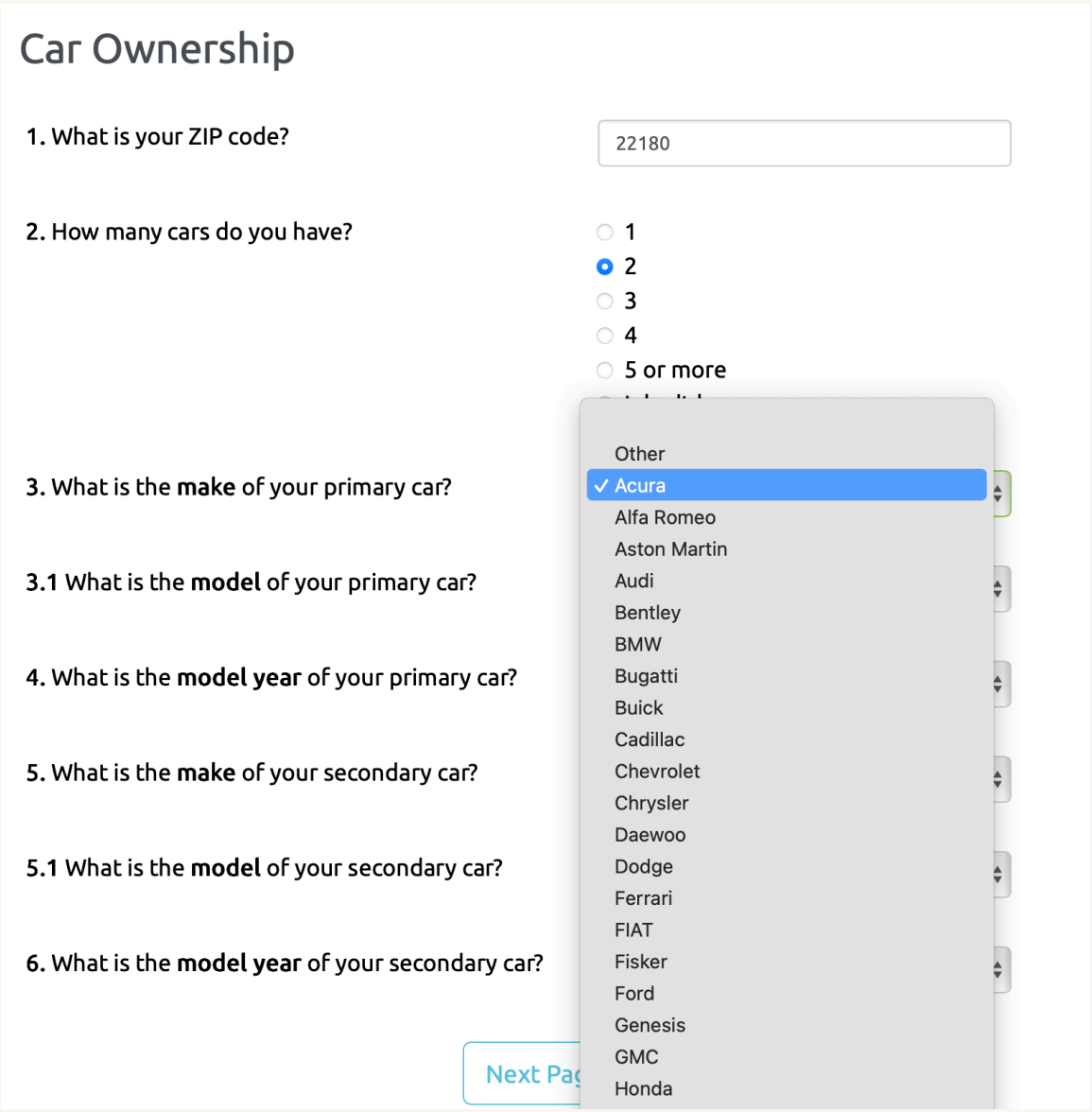
- 803 responses
- March to July in 2024

Dynata Recruitment: Paid survey

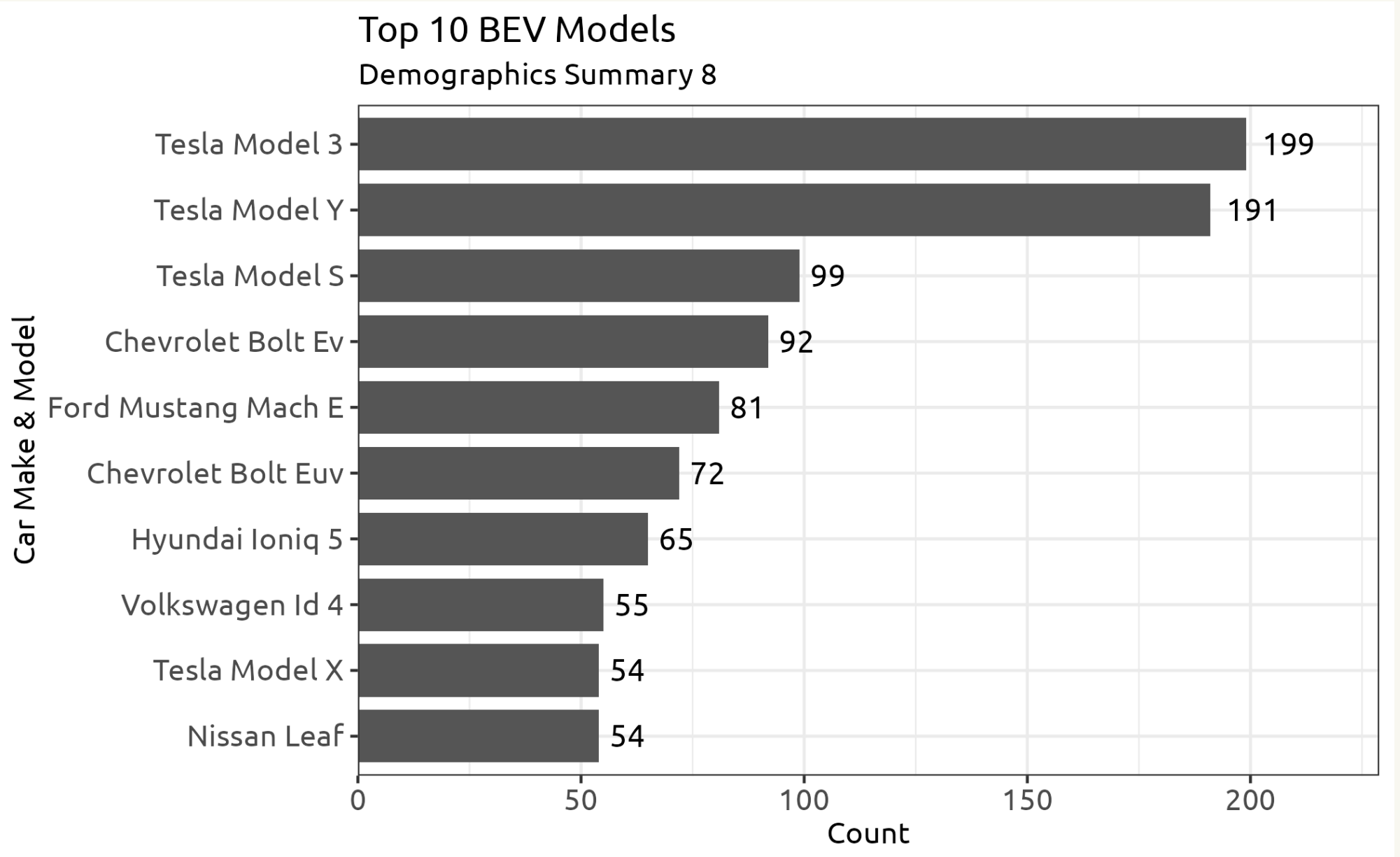
- 553 responses
- September to November in 2024

Facebook Messenger Instagram | dynata

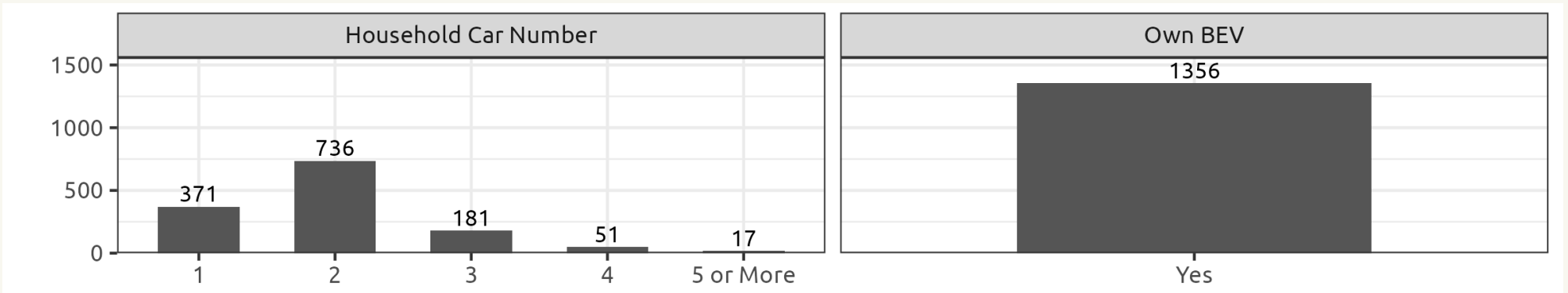
Survey Question - Car Ownership

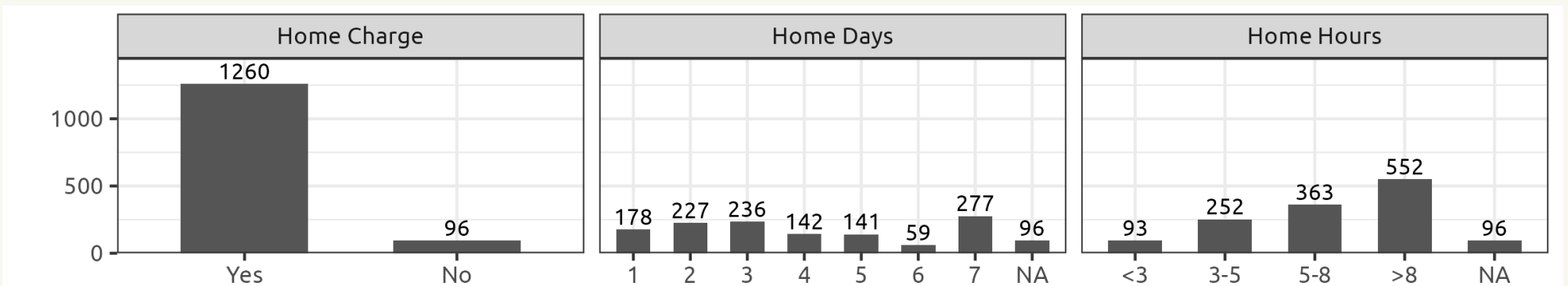


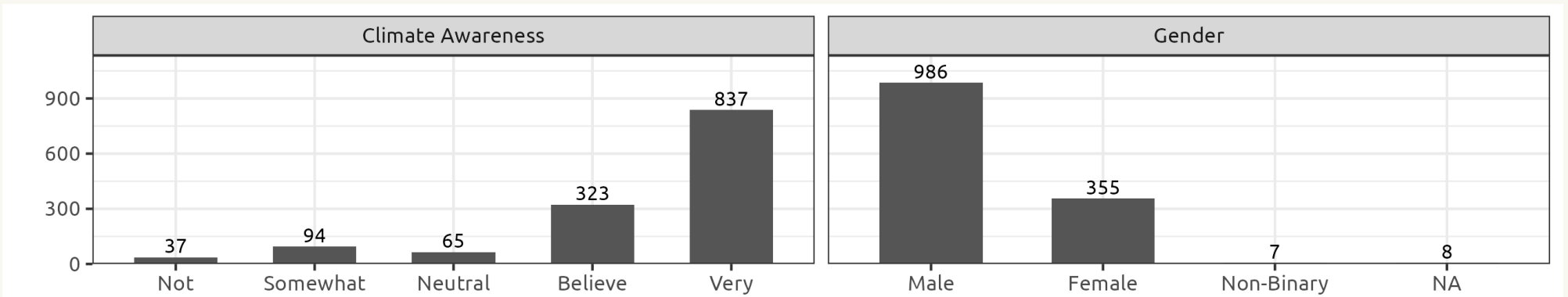
Survey Results - Top 10 BEV



Survey Results - Demographics







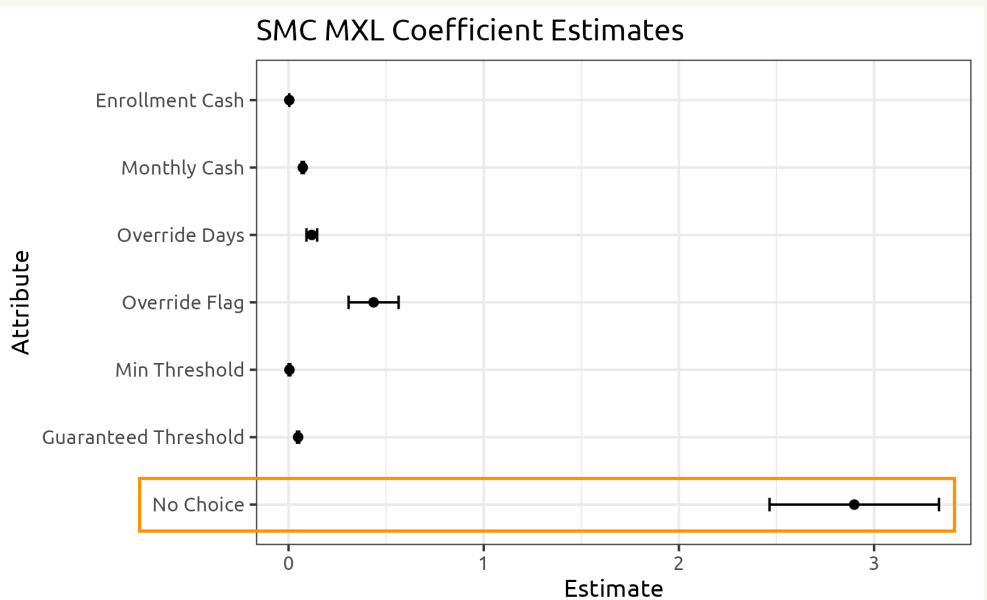
Survey Results - Willingness to Participate

Mixed Logit Models

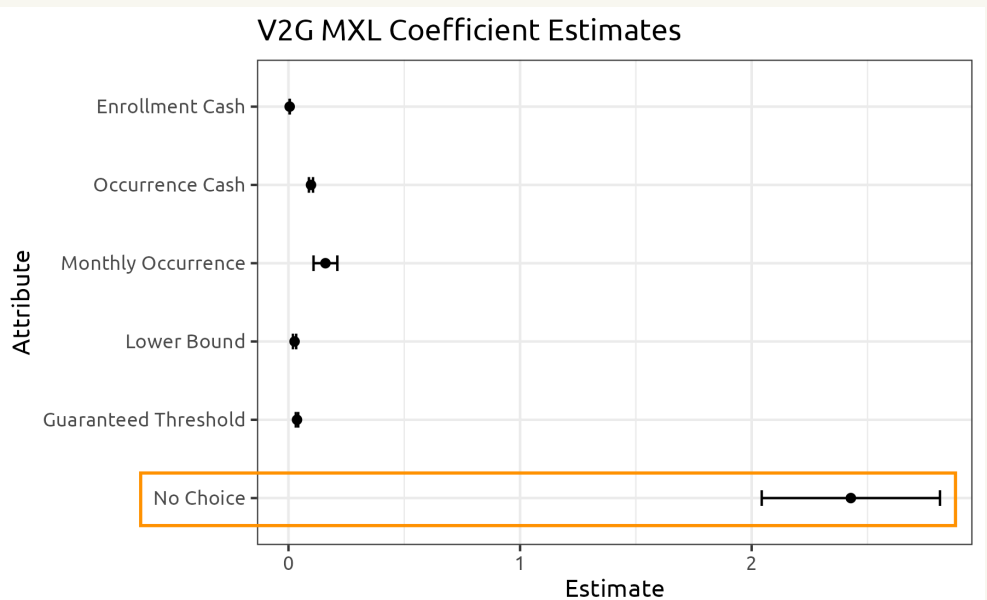
$$u_j = v_j + \epsilon_j = \beta' x + \epsilon_j \qquad P_j = \frac{e^{v_j}}{\sum_{k=1}^{J} e^{v_k}}$$

Utility esimated using maximum likelihood estimation (MLE).

SMC Estimates



V2G Estimates



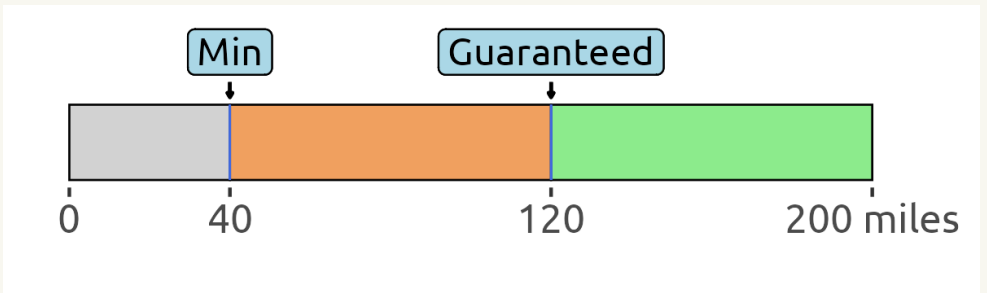
Without compensation, users will not participate.

Enrollment Sensitivity

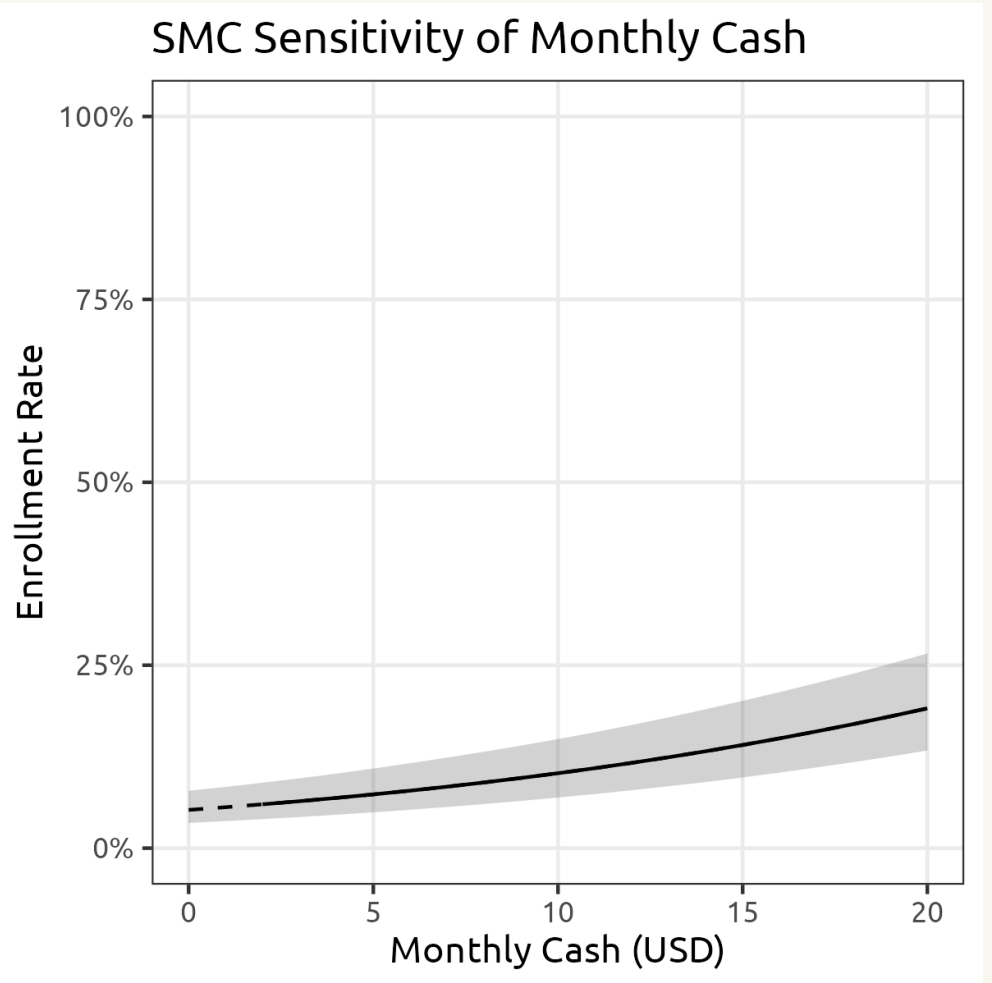
Baseline Simulation

Choice between "None" and this program:

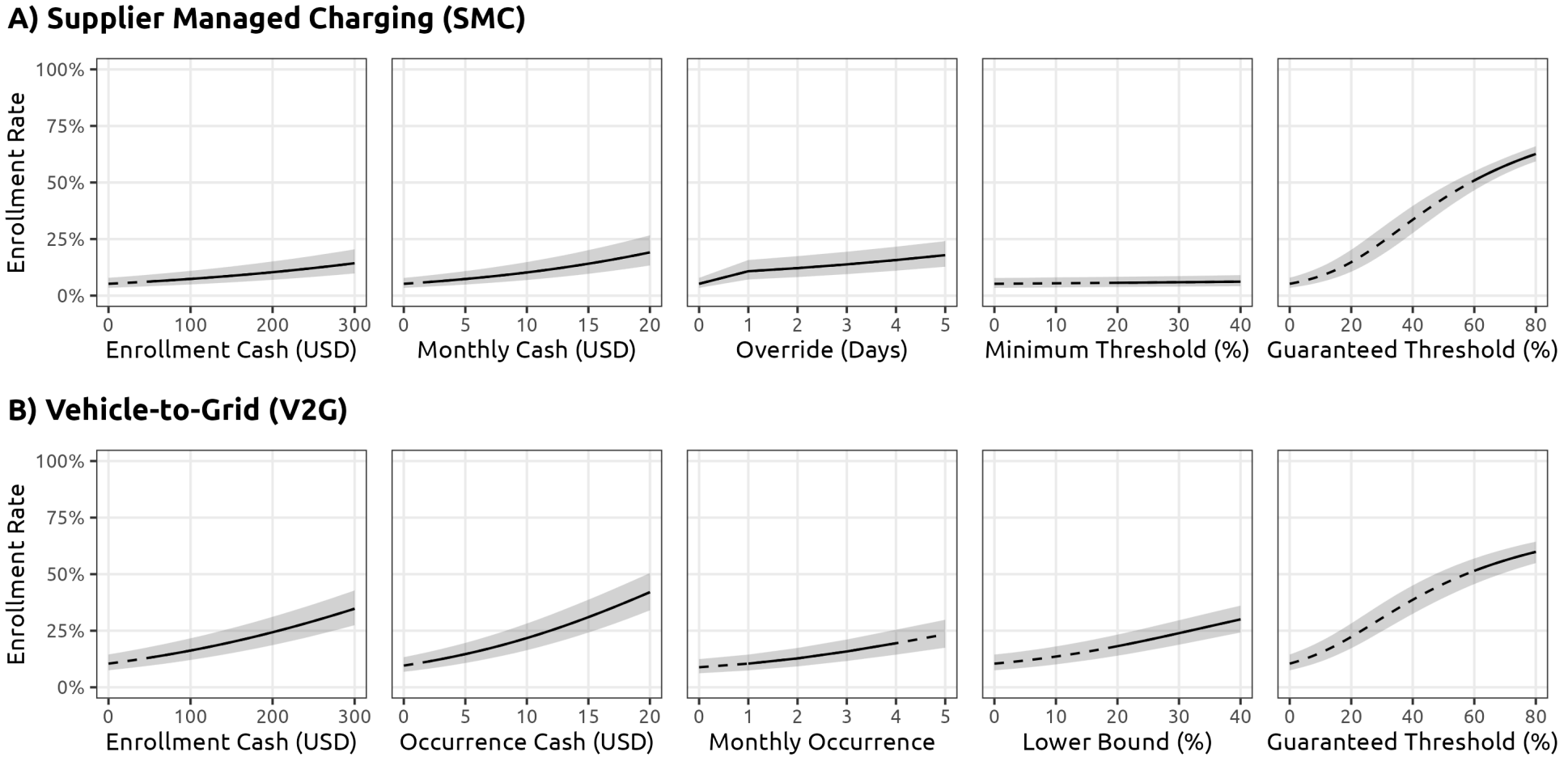
Attributes	Values
Enrollment Cash	$0
Monthly Cash	**$0 - $20**
Monthly Override	0



Sensitivity Plot



Enrollment Sensitivity



1. Steeper slope indicates higher sensitivity.
2. Diminishing returns exist.

Equivalencies of 5% Enrollment Increase

SMC

Attribute	Equivalence Value	Unit
Enrollment Cash	77.7	$
Monthly Cash	4.0	$
Override Days	2.5	Days
Minimum Threshold	65.5	%
Guaranteed Threshold	**6.3**	**%**

V2G

Attribute	Equivalence Value	Unit
Enrollment Cash	**55.7**	**$**
Occurrence Cash	**2.9**	**$**
Monthly Occurrence	1.9	Times
Lower Bound	11.7	%
Guaranteed Threshold	9.1	%

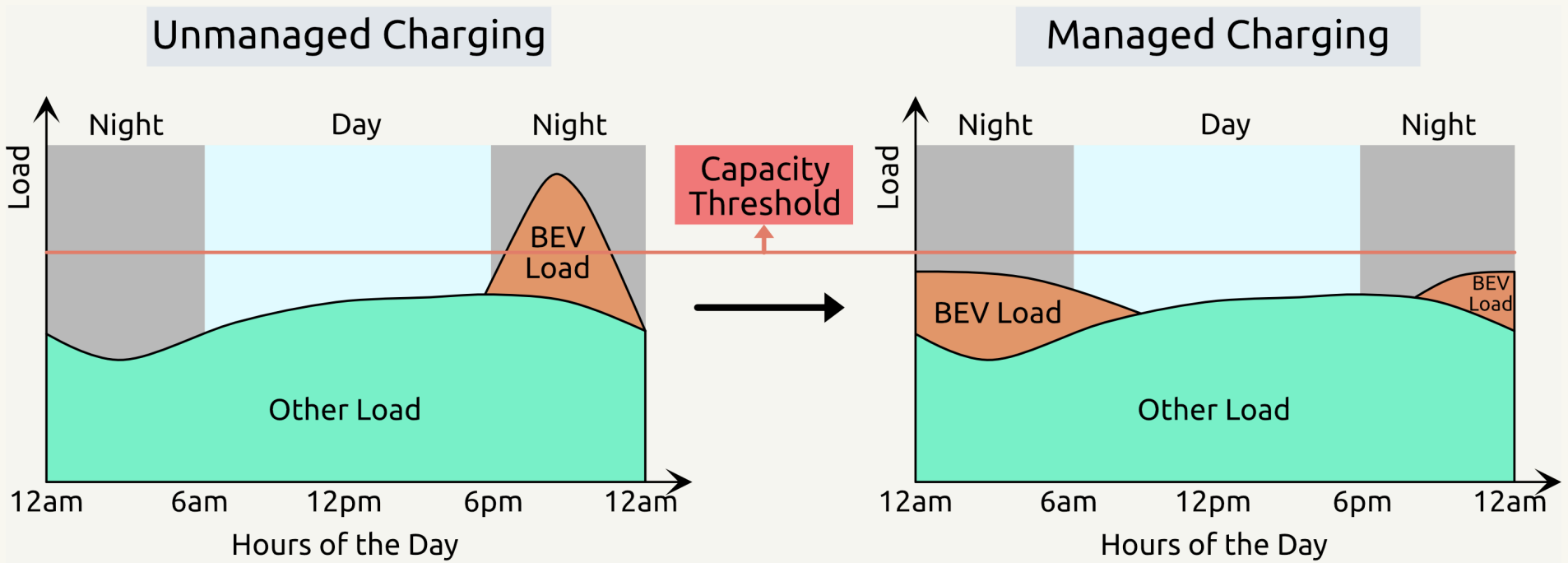
1. **Smaller** value indicates higher efficiency.
2. **Monetary** incentives are valued more in V2G than SMC.
3. **Guaranteed** thresholds are in high efficiency, indicating range anxiety.
4. Attribute equivalencies can be used to inform incentive design.

Study 2

Quantifying the supply of peak-shaving from controlled EV charging

Recall the SMC Peak-shaving

- SMC smooths out EV charging spike (called "Peak-shaving").
- Electricity demand is controlled below capacity threshold.
- It saves money and reduces pollution.



Managed charging avoids overload caused by BEV charging.

Research Questions

1. **Peak-shaving:** How much does peak-shaving from controlled EV charging cost utilities?

2. **Variations:** How do peak-shaving results change based on regions, seasons, EV-to-house ratios, and enrollment rates.

Data collection from NHTS, NREL, and U.S. Census.

Peak-shaving **simulation** using model from study 1.

Plan of Action

Step 1: Data Collection

- **NHTS:** Charging behavior data
- **NREL:** Household electricity consumption data
- **U.S. Census:** Count of single family households
- **Study 1:** MXL model of SMC enrollment utilities

Step 2: Simulation

- Simulate grid demand profiles with different EV charging loads
- Simulate peak load reduction under different levels of SMC enrollment

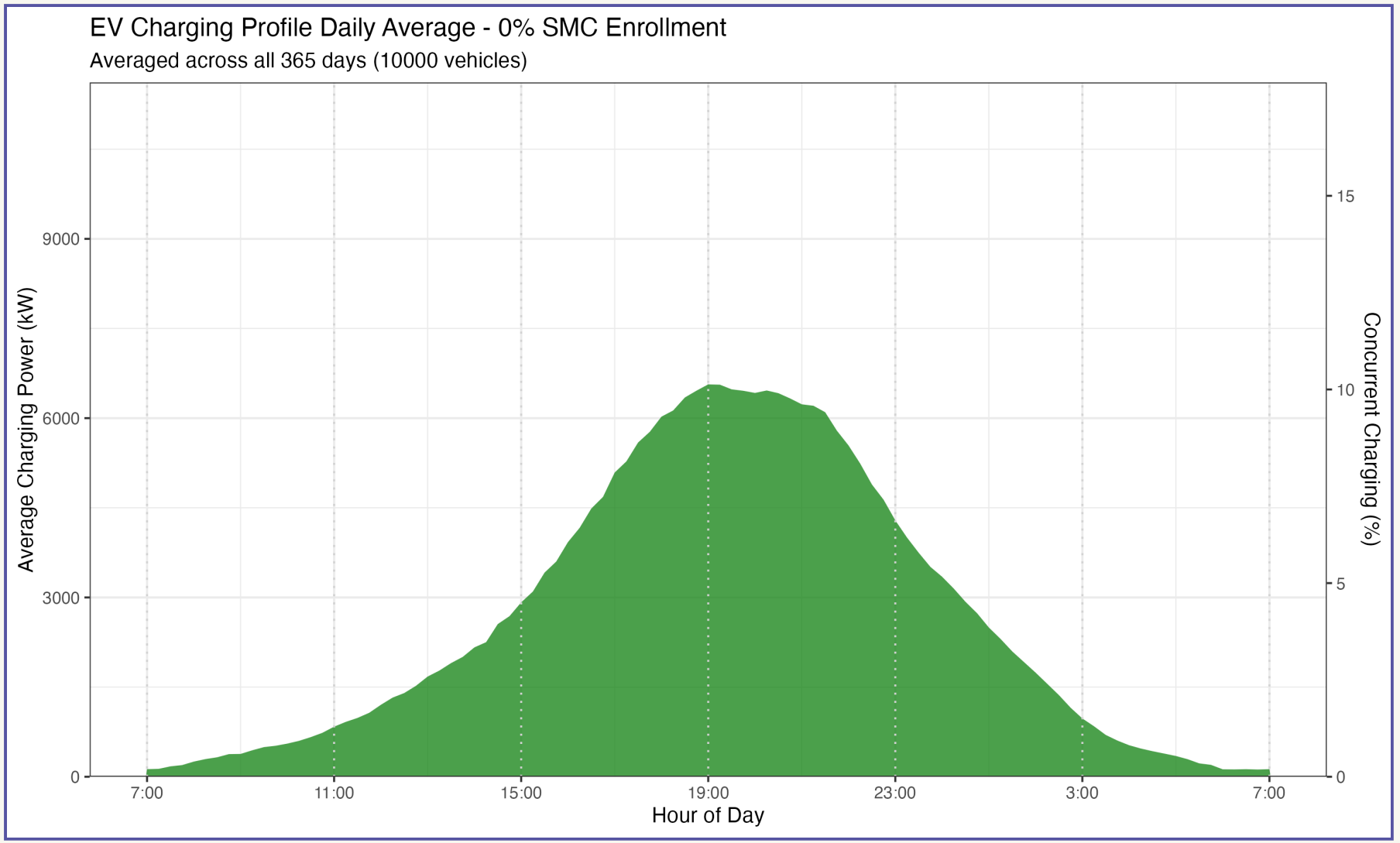
Step 3: Sensitivity Analysis

- Compare the peak-shaving results of different scenarios
- Summarize and provide policy implications

NHTS - National Household Travel Survey

Travel patterns of 26,000 vehicle owners.

Simulated EV Charging Profile

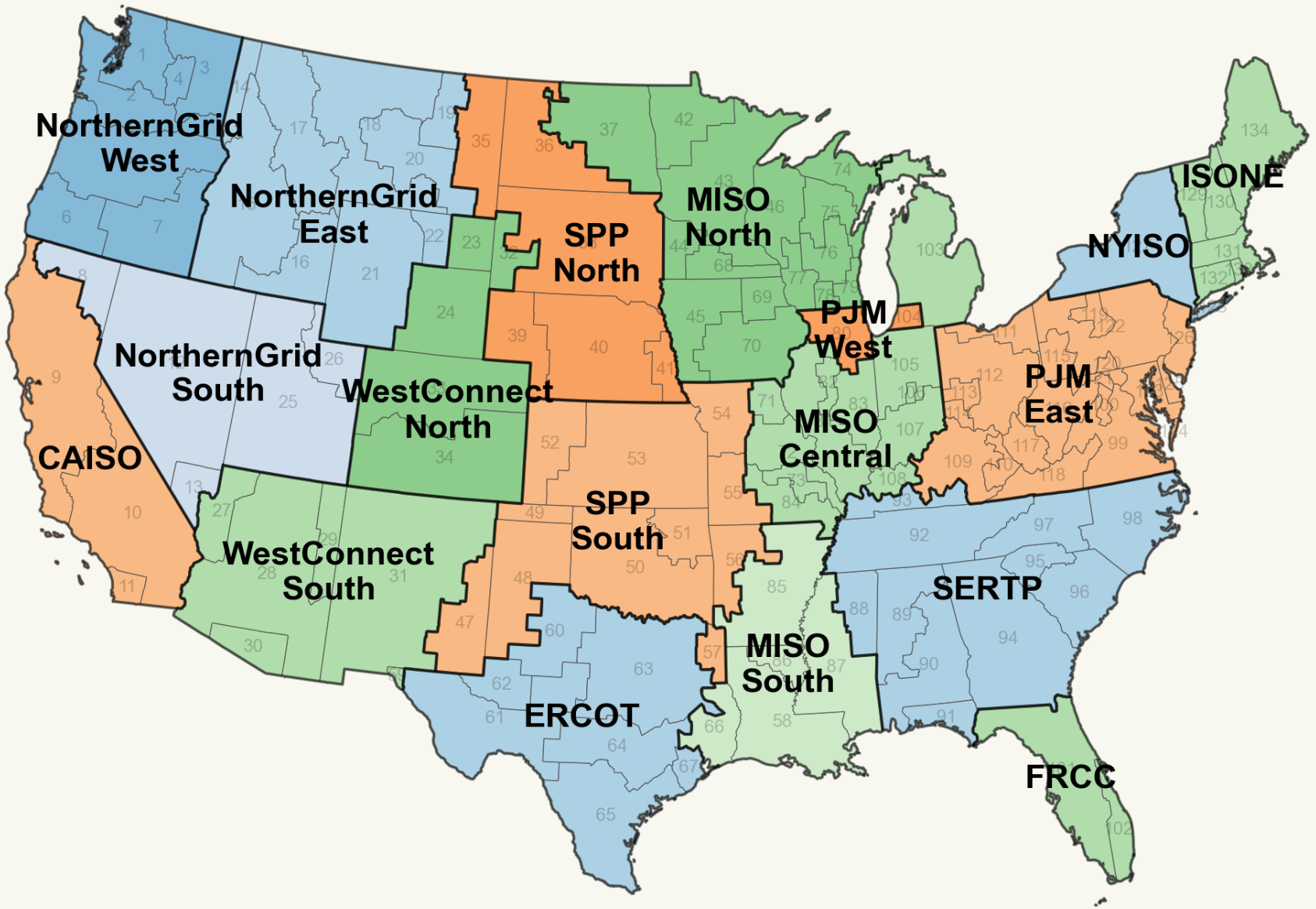


Energy consumption and concurrent charging % of 10,000 EVs.

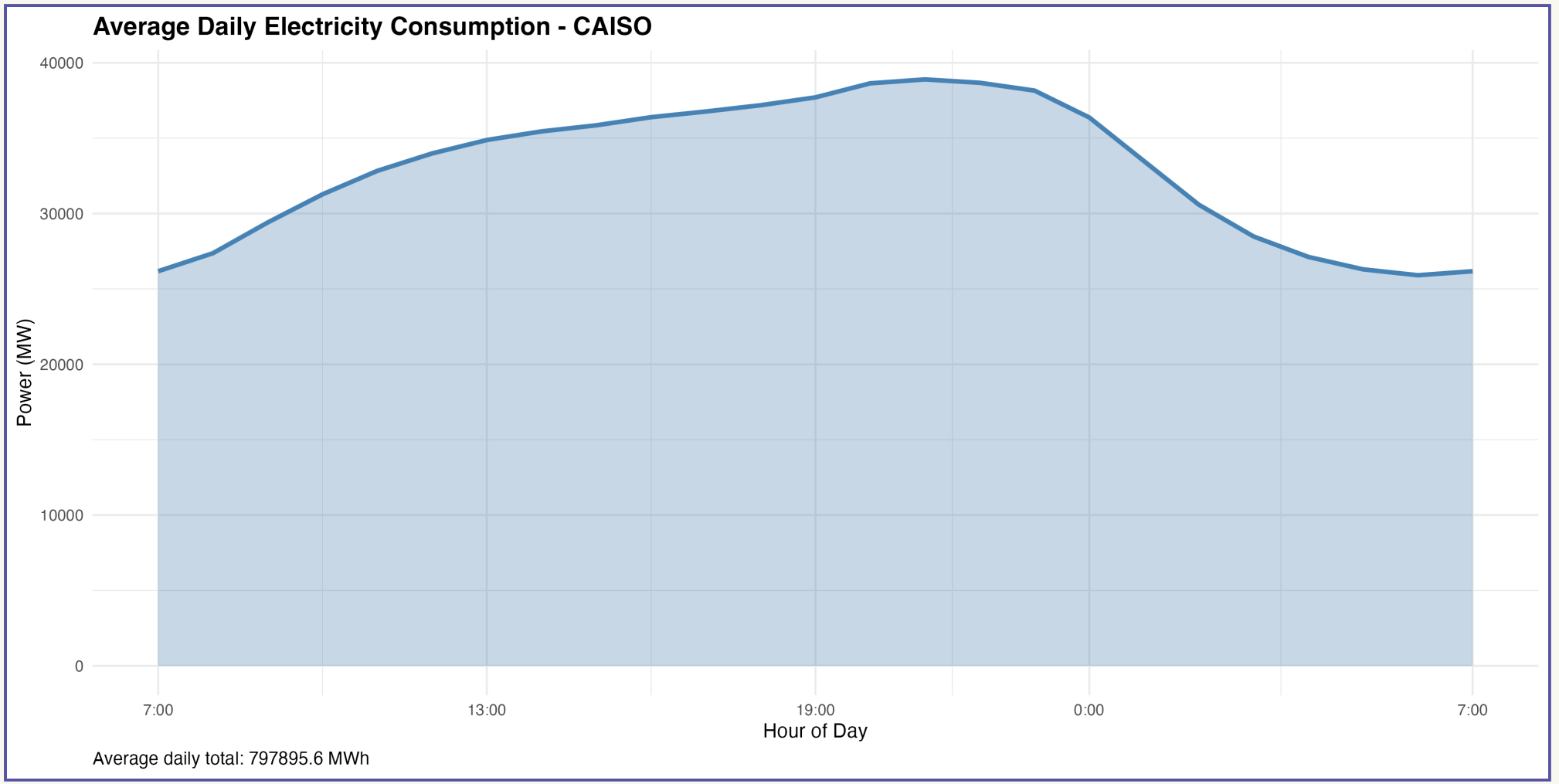
NREL - National Renewable Energy Lab

Data of household electricity consumption in each GEA region.

18 GEA Regions


NorthernGrid West
NorthernGrid East
NorthernGrid South
CAISO
WestConnect North
WestConnect South
SPP North
SPP South
MISO North
MISO Central
MISO South
PJM West
PJM East
NYISO
ISONE
ERCOT
SERTP
FRCC

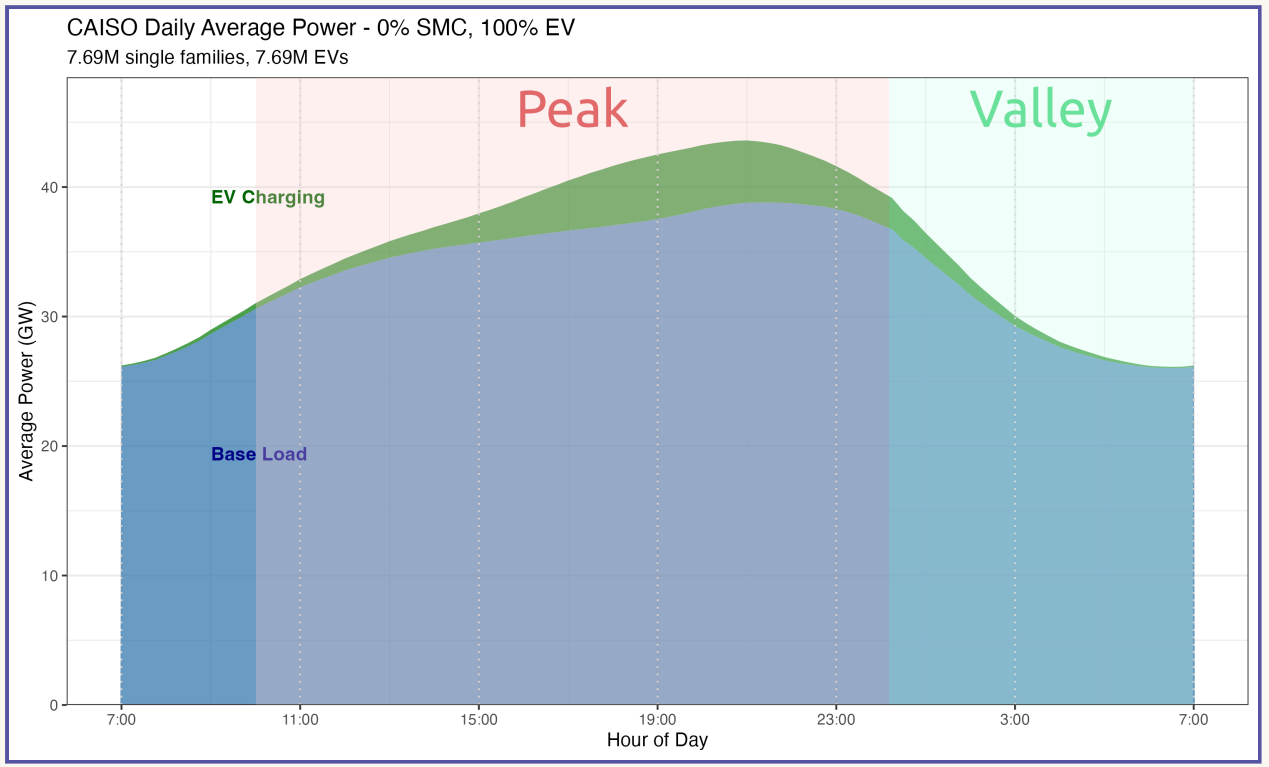
CAISO as an Example



7.69M single-family homes, collected from U.S. Census.

Peak-shaving Simulation

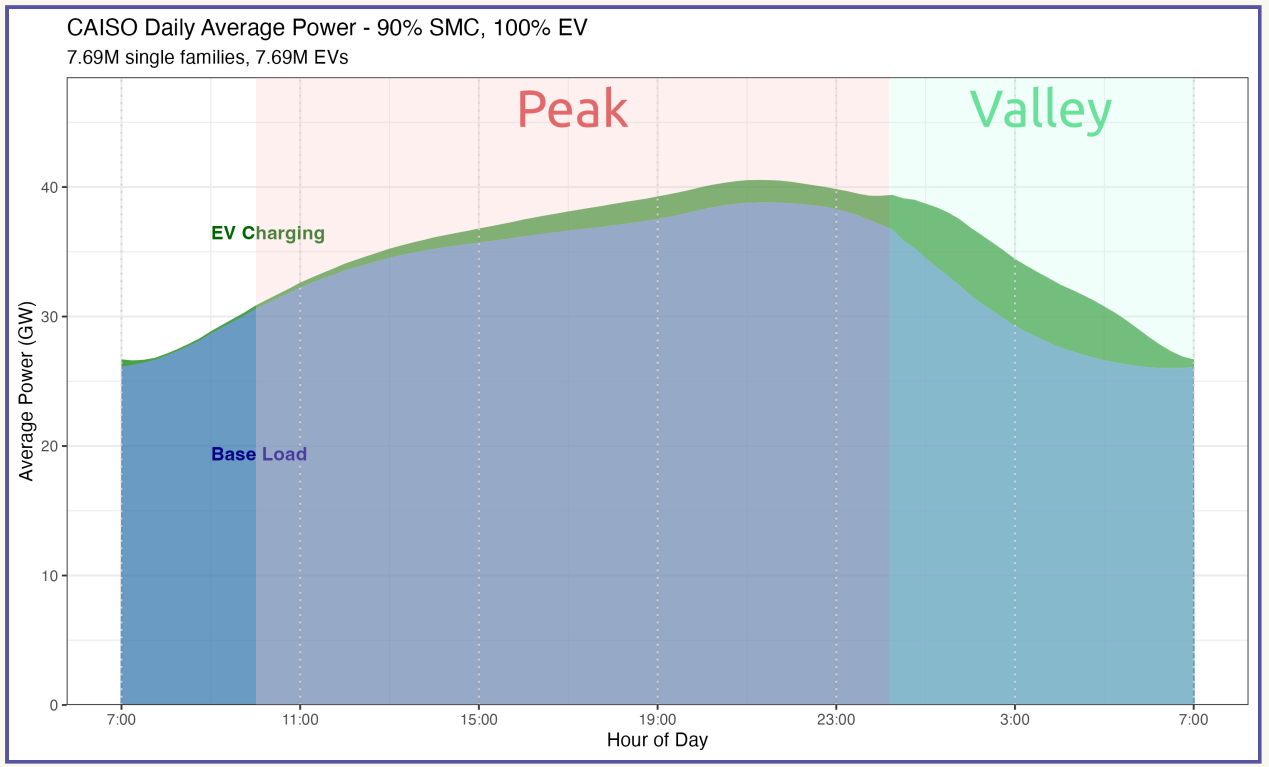
Original Consumption Profile



Assumptions

- 200-mile range BEV.
- Level 2 charger.
- Peak: 10AM-12:00AM.
- Valley: 12:00AM-7AM.
- Battery: 20%-80%.
- Auto-override.

Shifted Consumption with Peak-shaving



90% SMC enrollment, EV-to-house ratio 1:1.

Assumptions

- 200-mile range BEV.
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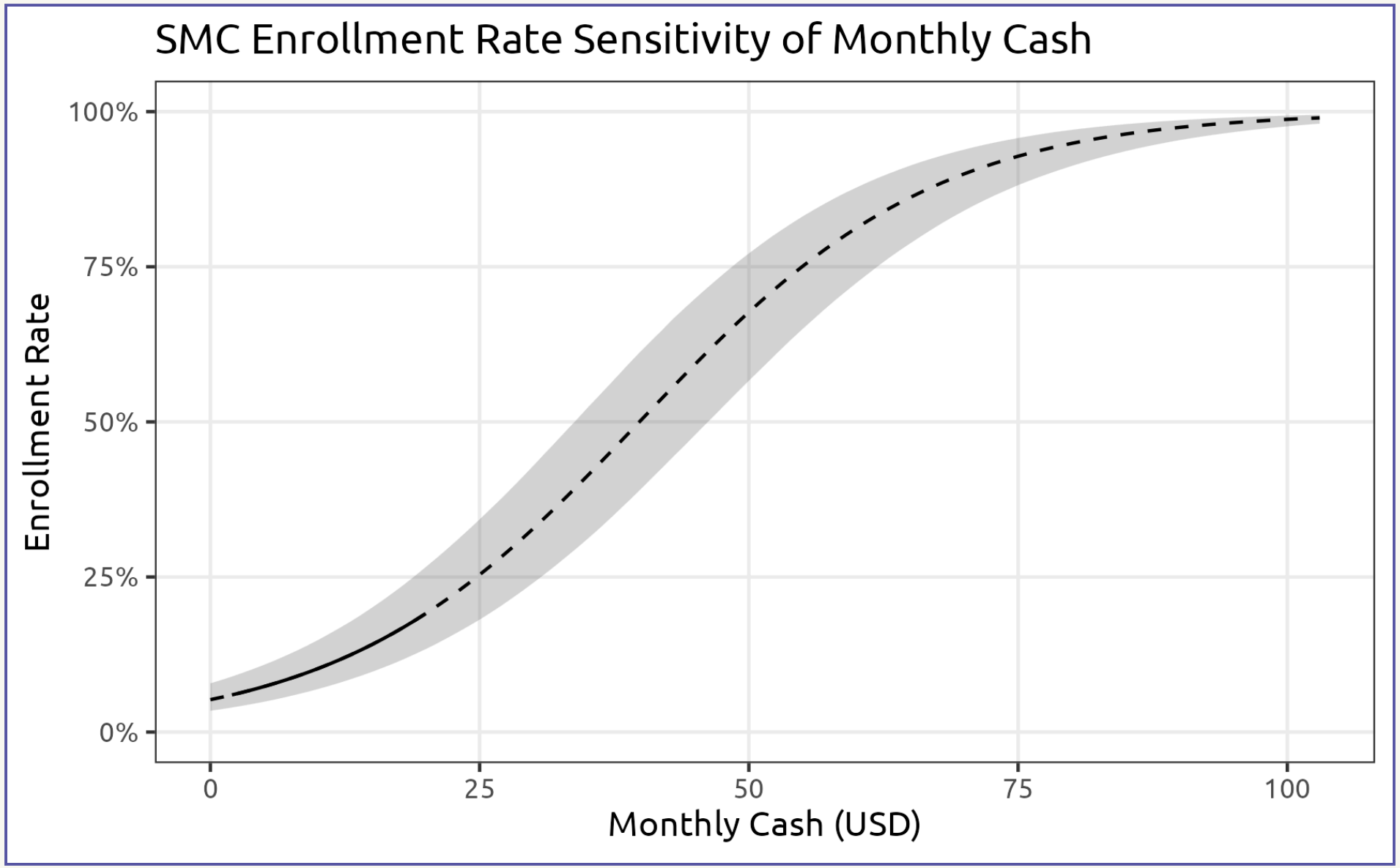
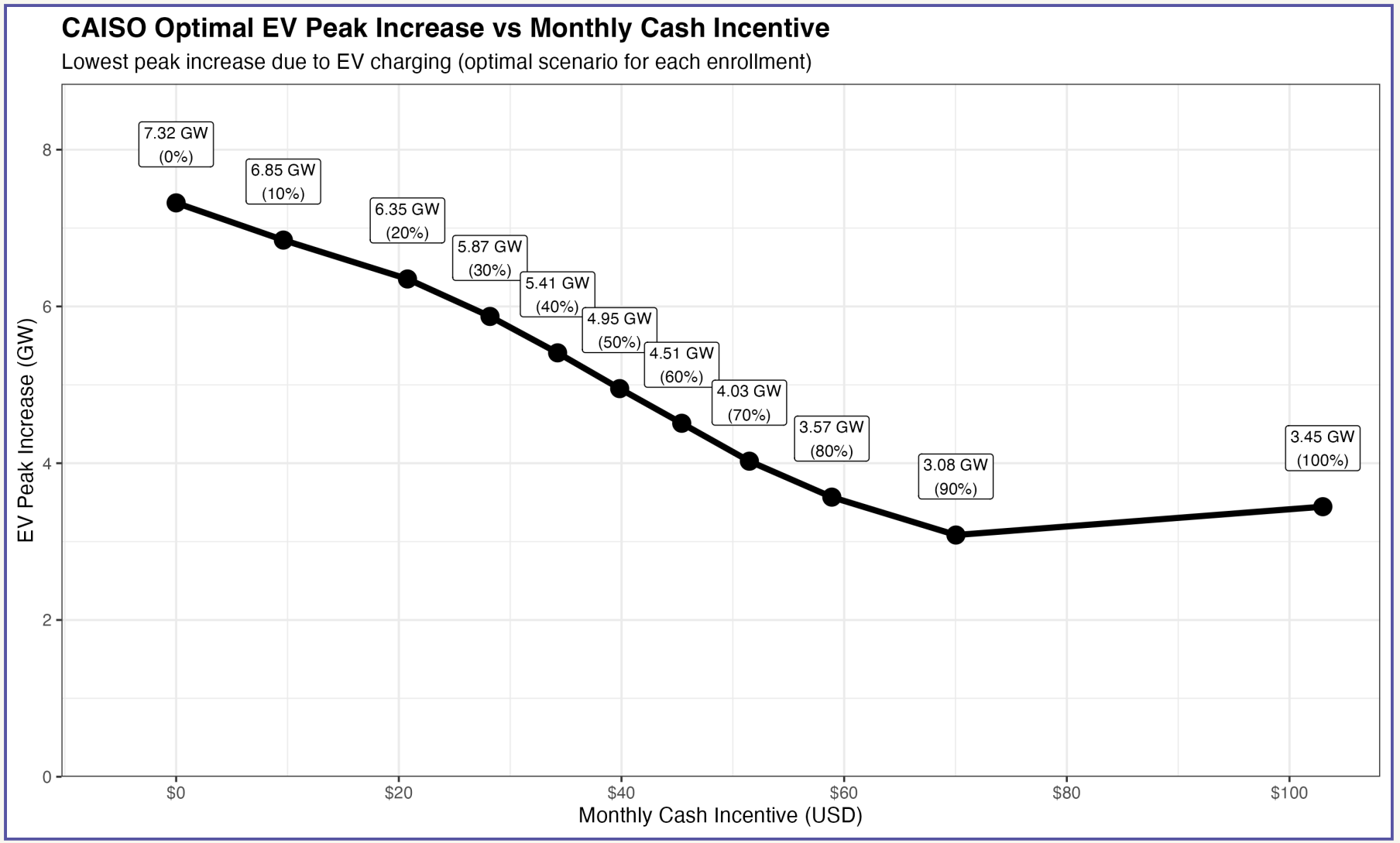
- Auto-override.

MXL Model of Monthly Incentives



EV Peak Increase vs Monthly Incentives



More incentives lead to higher SMC enrollment, thus more peak shaving.

Sensitivity Analysis

Different Scenarios

- All 18 GEA regions in all 4 seasons.
- Varying EV-to-house ratios (1:4, 1:2, 1:1).
- Varying SMC enrollment rates (from 0% to 100%).
- Varying peak and valley windows.

Policy Implications

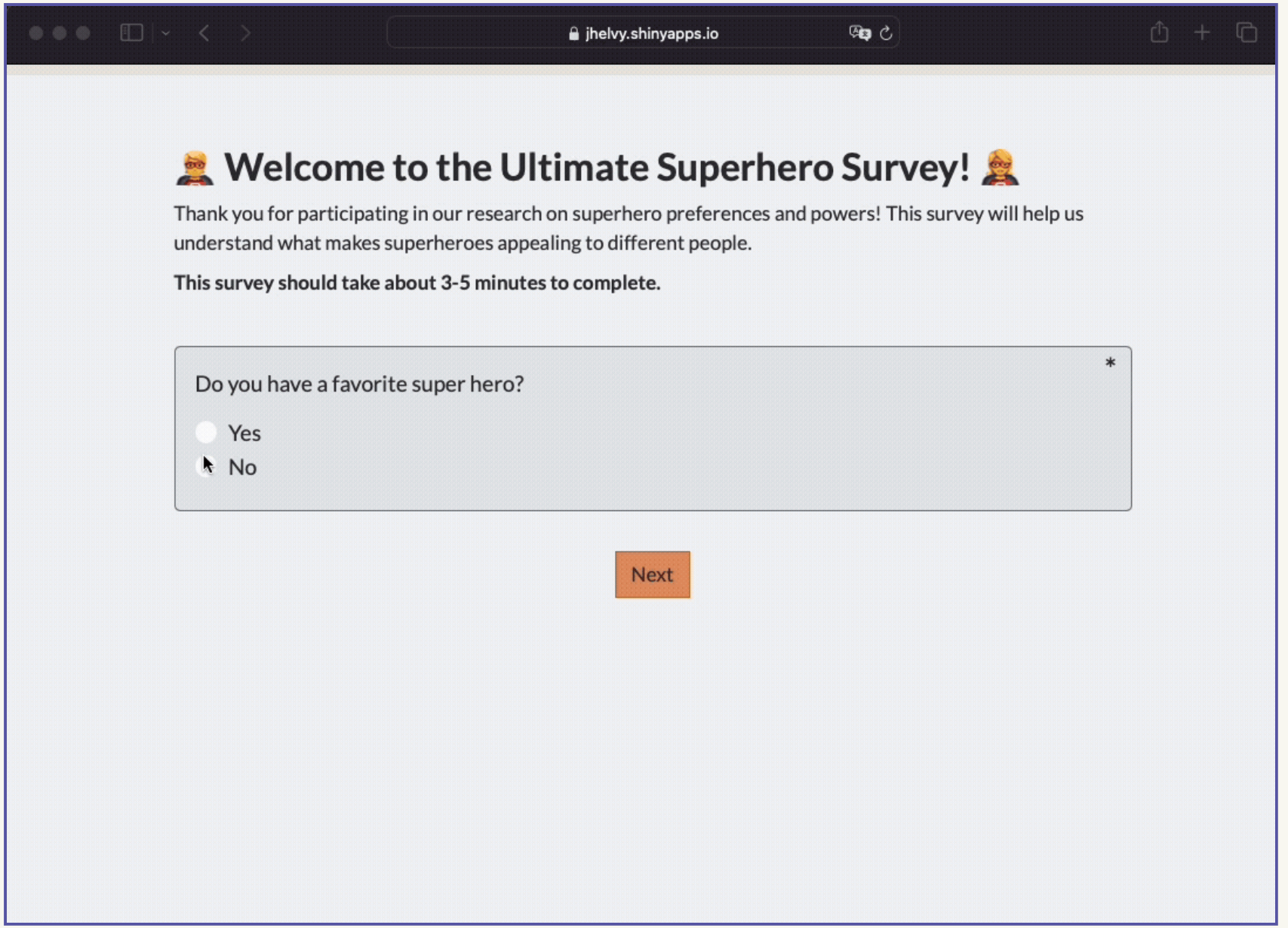
1. Utilities must plan a budget that scales with enrollment levels.
2. Governments could get engaged (e.g. provide subsidies to offset the cost).

Study 3
The surveydown Survey Platform

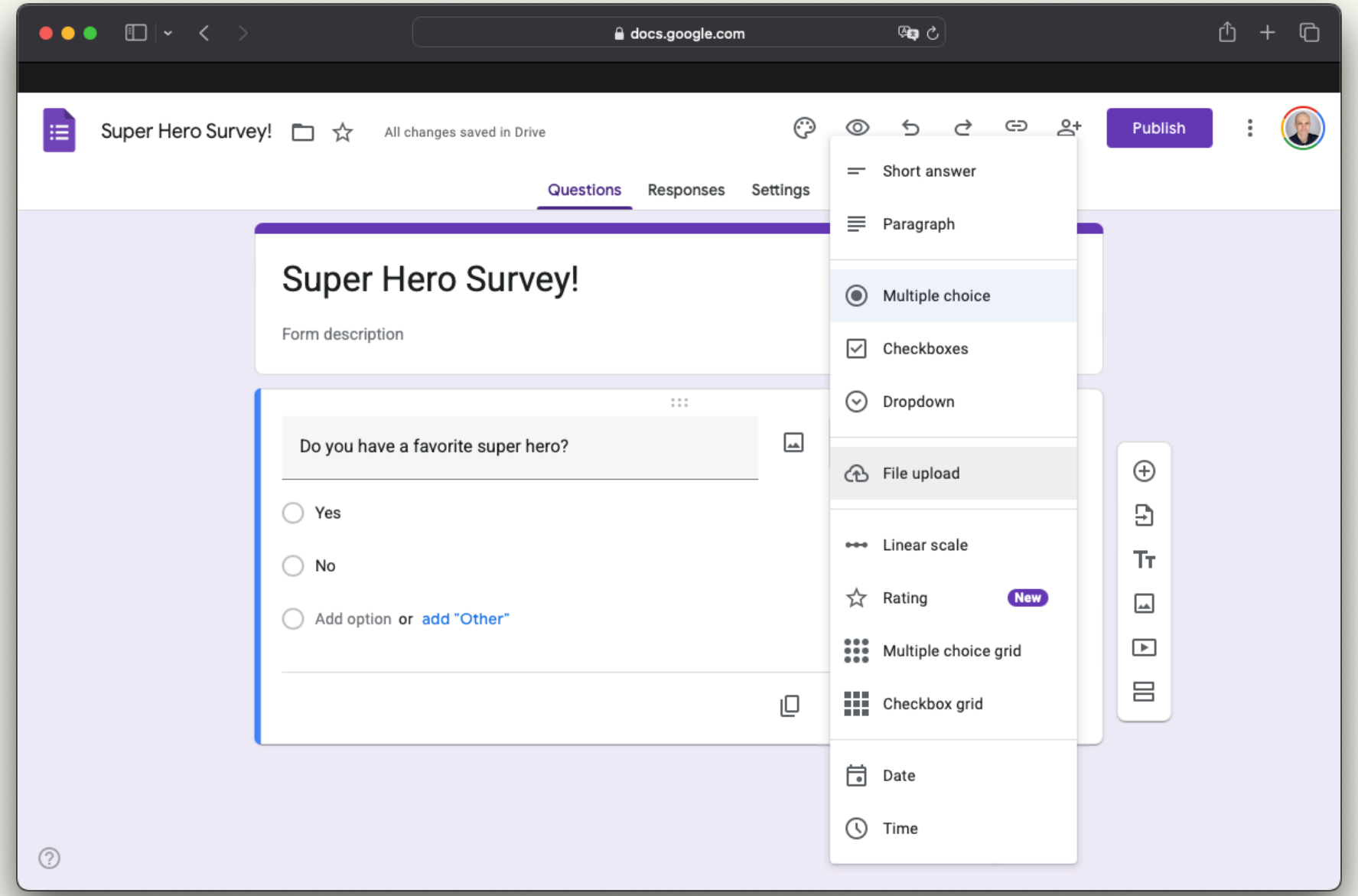
Published in *PLoS ONE*:

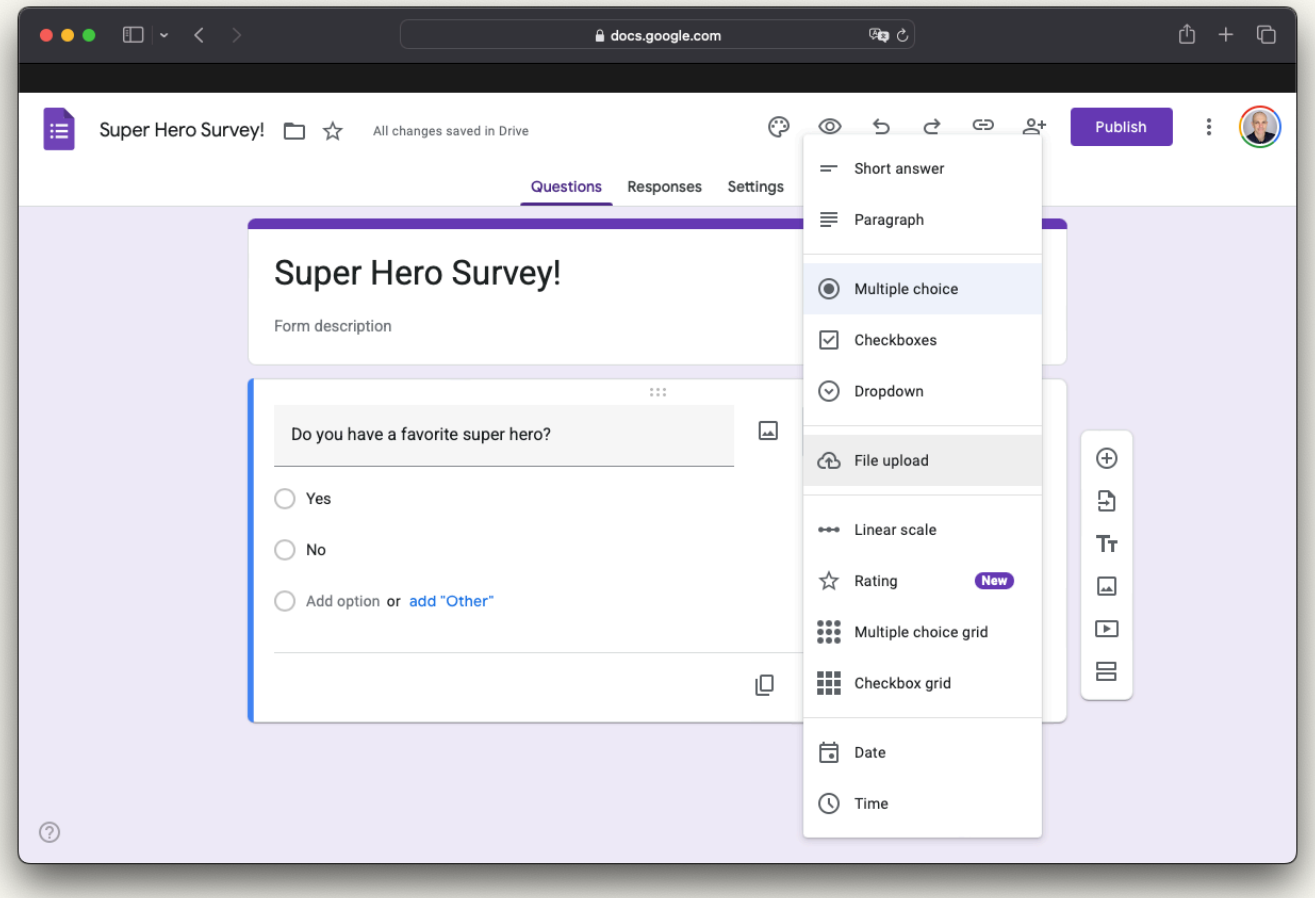
Hu, Pingfan, Bunea, Bogdan, & Helveston, J. P. (2025). "surveydown: An open-source, markdown-based platform for programmable and reproducible surveys" *PLOS ONE*, 20(8), e0331002. https://doi.org/10.1371/journal.pone.0331002

Typical Web Survey



Google Form - GUI Interface





Limitations

- ❌ Reproduciblity
- ❌ Version control
- ❌ Limited features
- ❌ Open source

Qualtrics - Commercial Platform

Qualtrics

Qualtrics makes sophisticated research simple and empowers users to capture customer, product, brand & employee experience insight. It is used to meas... Read more

Employee Engagement

Market Share of Qualtrics

Current Customer(s)	Market Share (Est.)	Ranking
81,701	57.68%	#1

Data captured from 6sense.com

Expensive!

Why not make surveys from `code`?

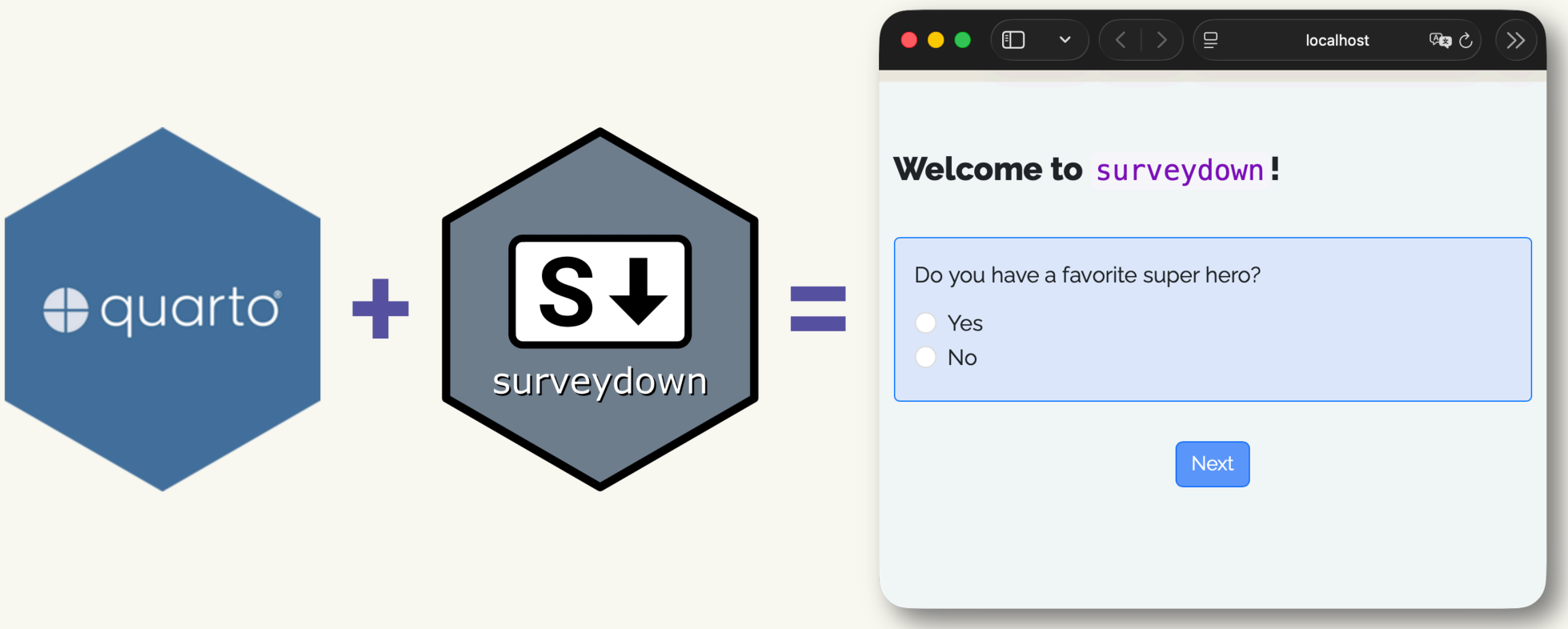
~~Limitations~~

Features

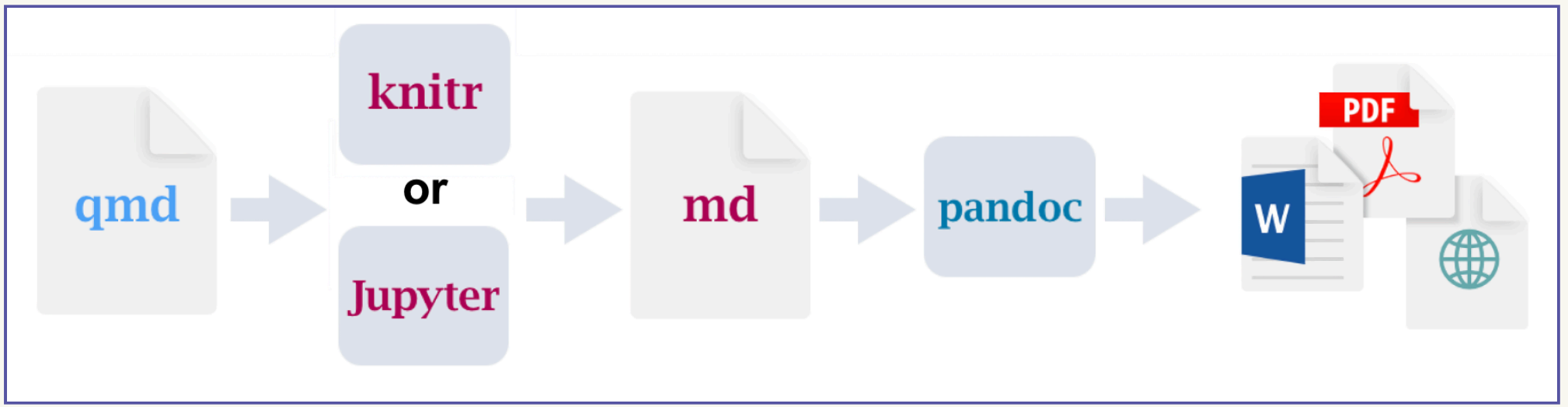
- ✅ Reproducibility
- ✅ Version control
- ✅ Lots of features
- ✅ Open source
- ✅ Free!

Introducing surveydown!

R package that renders Quarto files into surveys



Quarto is a publishing system

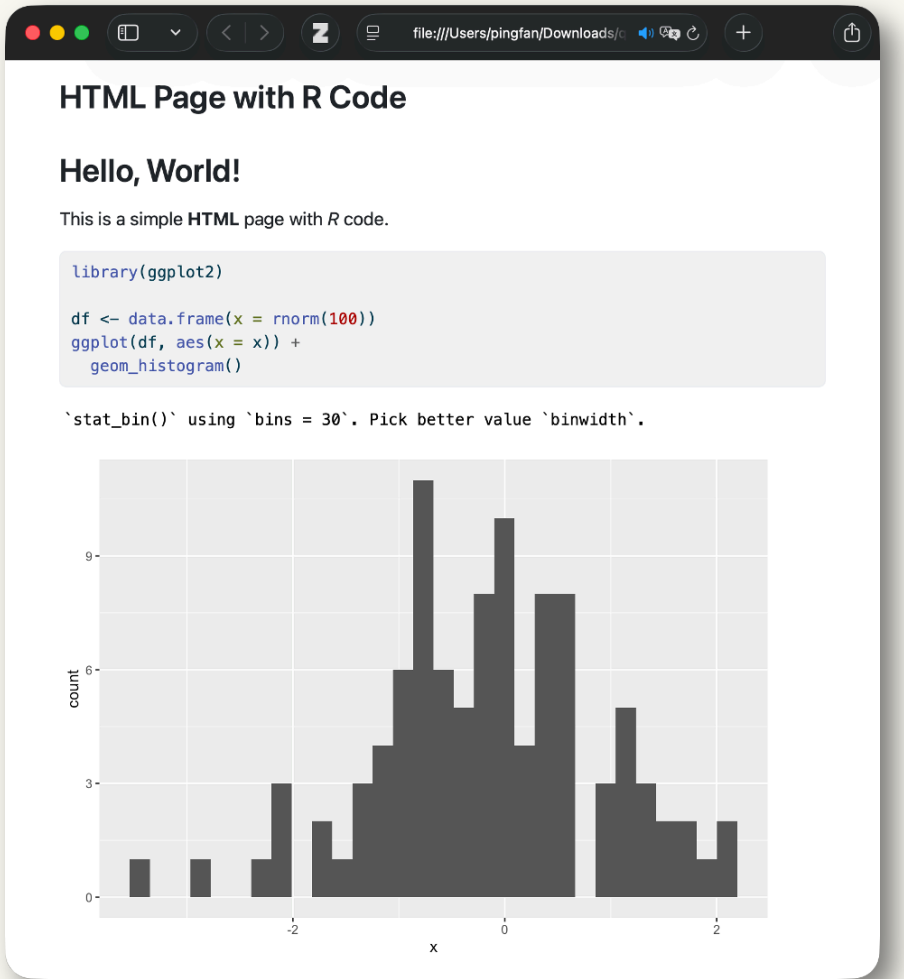


Original qmd file

Markdown + R code chunks

````
---
format: html
title: "HTML Page with R Code"
---

# Hello, World!

This is a simple **HTML** page with *R* code.

```{r}
library(ggplot2)

df <- data.frame(x = rnorm(100))
ggplot(df, aes(x = x)) +
  geom_histogram()
```
````

Rendered HTML



Original qmd file

Markdown + Python code chunks

````
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format: pdf
title: "PDF File with Python Code"
---

# Hello, World!

This is a simple **PDF** file with *Python* code.

```{python}
import matplotlib.pyplot as plt
import numpy as np

data = np.random.normal(0, 1, 100)
plt.hist(data)
plt.show()
```
````
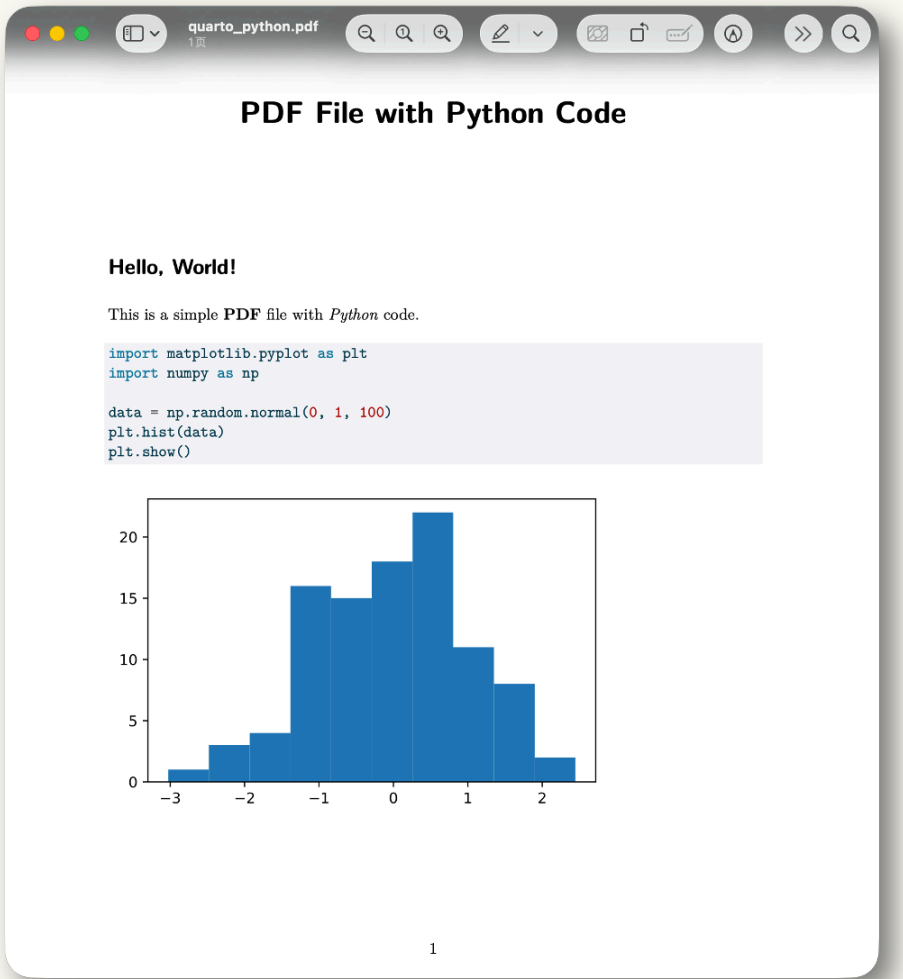
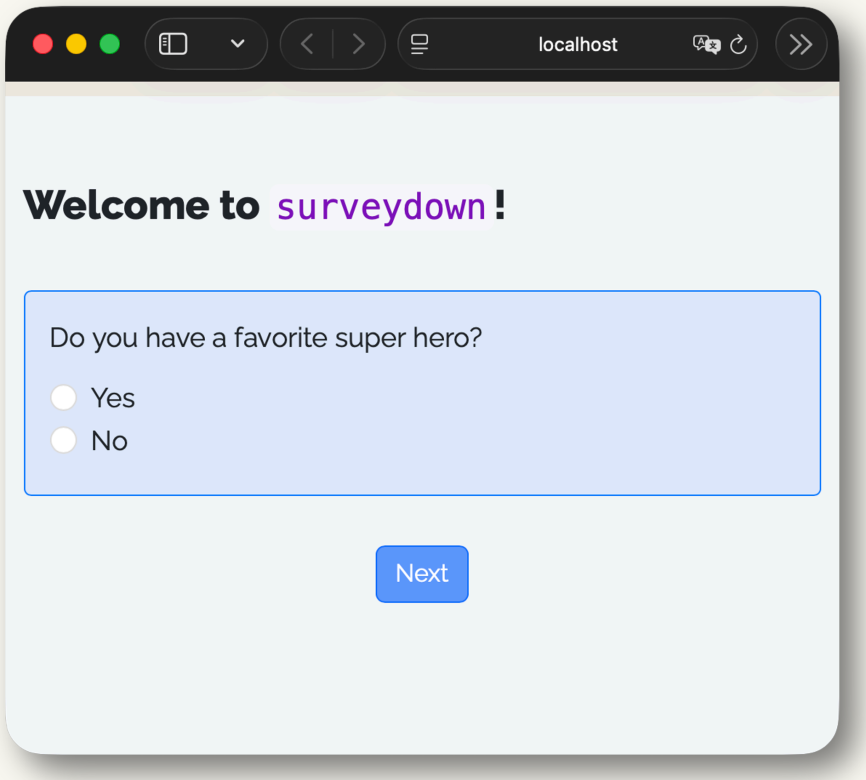

Rendered PDF



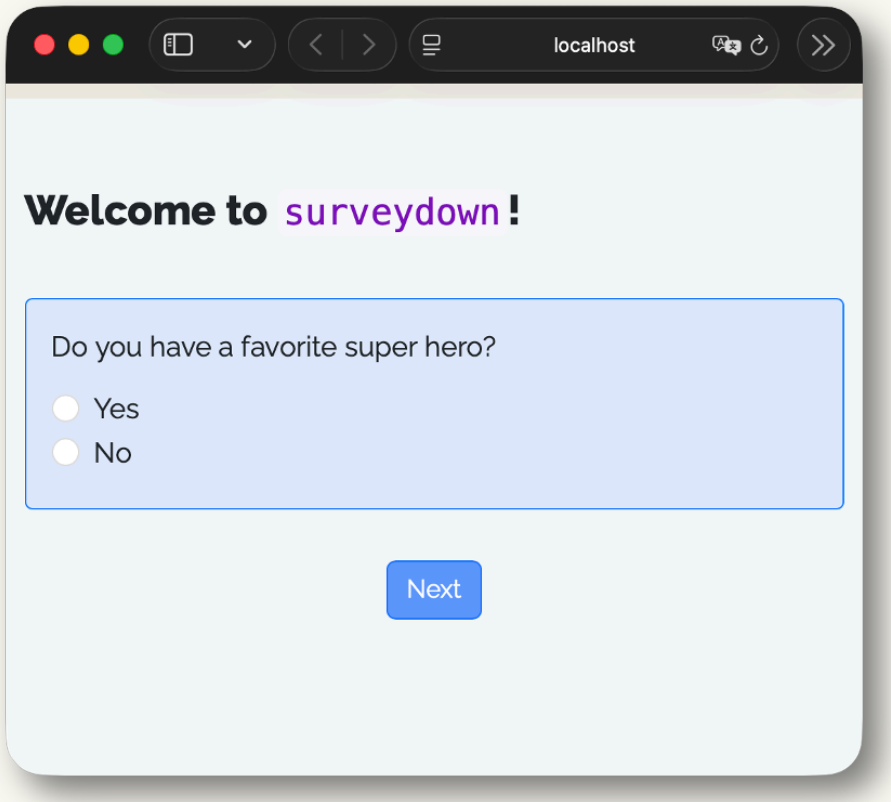

quarto
surveydown


localhost
Welcome to surveydown!
Do you have a favorite super hero?
Yes
No
Next

survey.qmd

````
---
format: html
echo: false
warning: false
---

```{r}
library(surveydown)
```

::: {#welcome .sd-page}

# Welcome to `surveydown`!

```{r}
sd_question(
  type  = "mc",
  id    = "has_fav_hero",
  label = "Do you have a favorite super hero?",
  option = c(
    "Yes" = "yes",
    "No"  = "no"
  )
)

sd_next()
```

:::
````

Rendered Survey



survey.qmd

````
---
format: html
echo: false
warning: false
---

```{r}
library(surveydown)
```

::: {#welcome .sd-page}

# Welcome to `surveydown`!

```{r}
sd_question(
  type  = "mc",
  id    = "has_fav_hero",
  label = "Do you have a favorite super hero?",
  option = c(
    "Yes" = "yes",
    "No"  = "no"
  )
)

sd_next()
```

:::
````

YAML header for a “clean” output

survey.qmd

````
---
format: html
echo: false
warning: false
---

```{r}
library(surveydown)
```

::: {#welcome .sd-page}

# Welcome to `surveydown`!

```{r}
sd_question(
  type  = "mc",
  id    = "has_fav_hero",
  label = "Do you have a favorite super hero?",
  option = c(
    "Yes" = "yes",
    "No"  = "no"
  )
)

sd_next()
```

:::
````

Load the surveydown Package

survey.qmd

````
---
format: html
echo: false
warning: false
---

```{r}
library(surveydown)
```

::: {#welcome .sd-page}

# Welcome to `surveydown`!

```{r}
sd_question(
  type  = "mc",
  id    = "has_fav_hero",
  label = "Do you have a favorite super hero?",
  option = c(
    "Yes" = "yes",
    "No"  = "no"
  )
)

sd_next()
```

:::
````

Use Quarto fences (:::)
to define survey pages

survey.qmd

````
---
format: html
echo: false
warning: false
---

```{r}
library(surveydown)
```

::: {#welcome .sd-page}

# Welcome to `surveydown`!

```{r}
sd_question(
  type  = "mc",
  id    = "has_fav_hero",
  label = "Do you have a favorite super hero?",
  option = c(
    "Yes" = "yes",
    "No"  = "no"
  )
)

sd_next()
```

:::
````

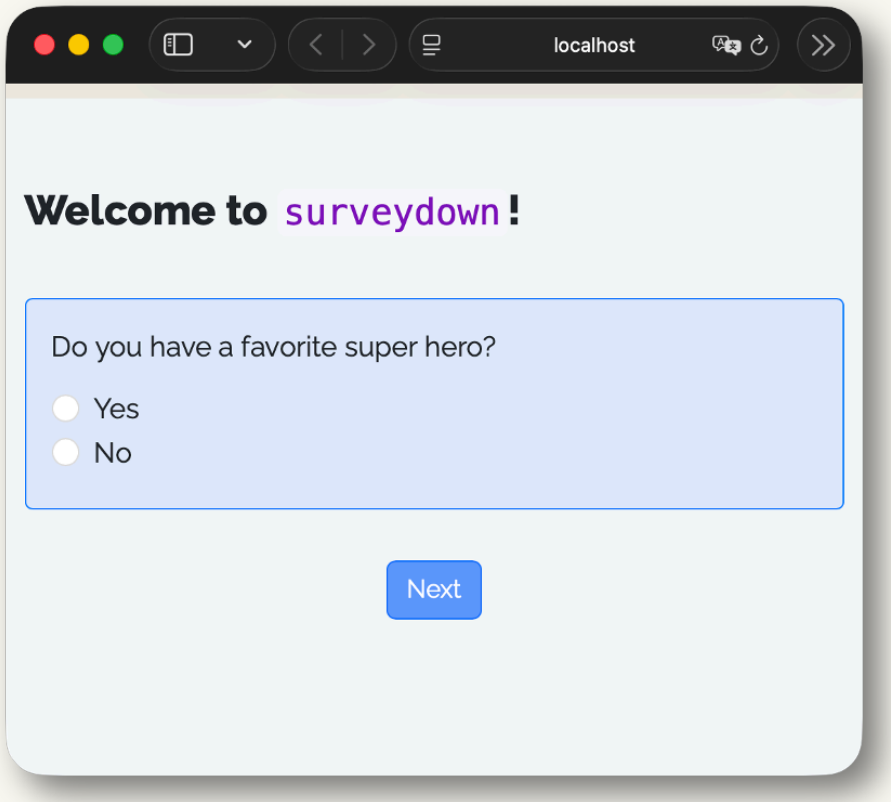
Page content

- Markdown for texts, images, etc.
- `sd_question()` for survey questions
- `sd_next()` for page navigation

survey.qmd

````
---
format: html
echo: false
warning: false
---

```{r}
library(surveydown)
```

::: {#welcome .sd-page}

# Welcome to `surveydown`!

```{r}
sd_question(
  type  = "mc",
  id    = "has_fav_hero",
  label = "Do you have a favorite super hero?",
  option = c(
    "Yes" = "yes",
    "No"  = "no"
  )
)

sd_next()
```

:::
````

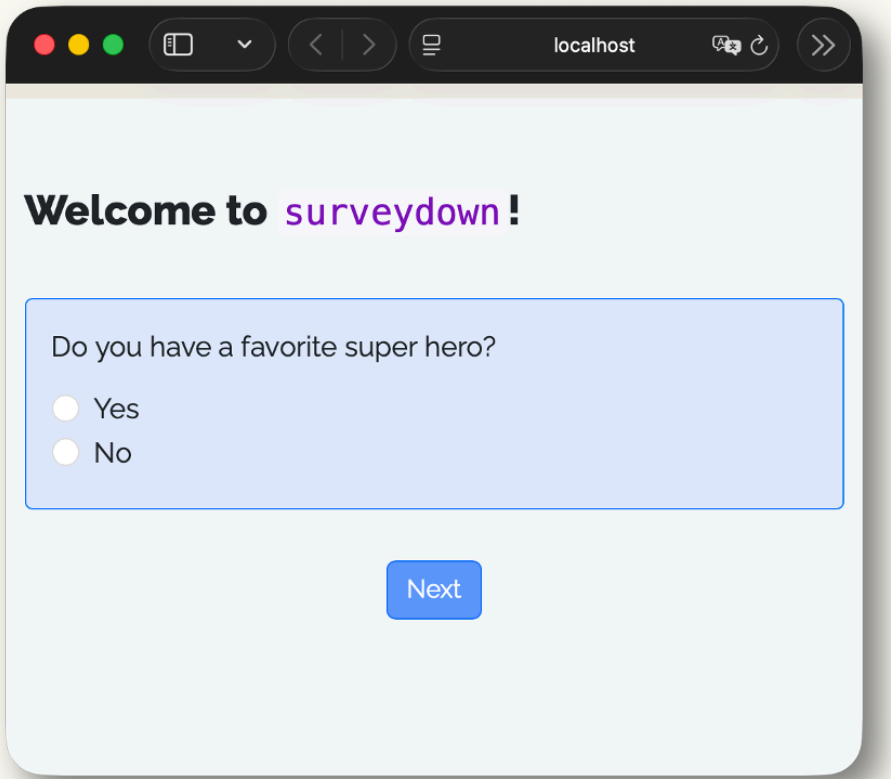
Rendered Survey



survey.qmd

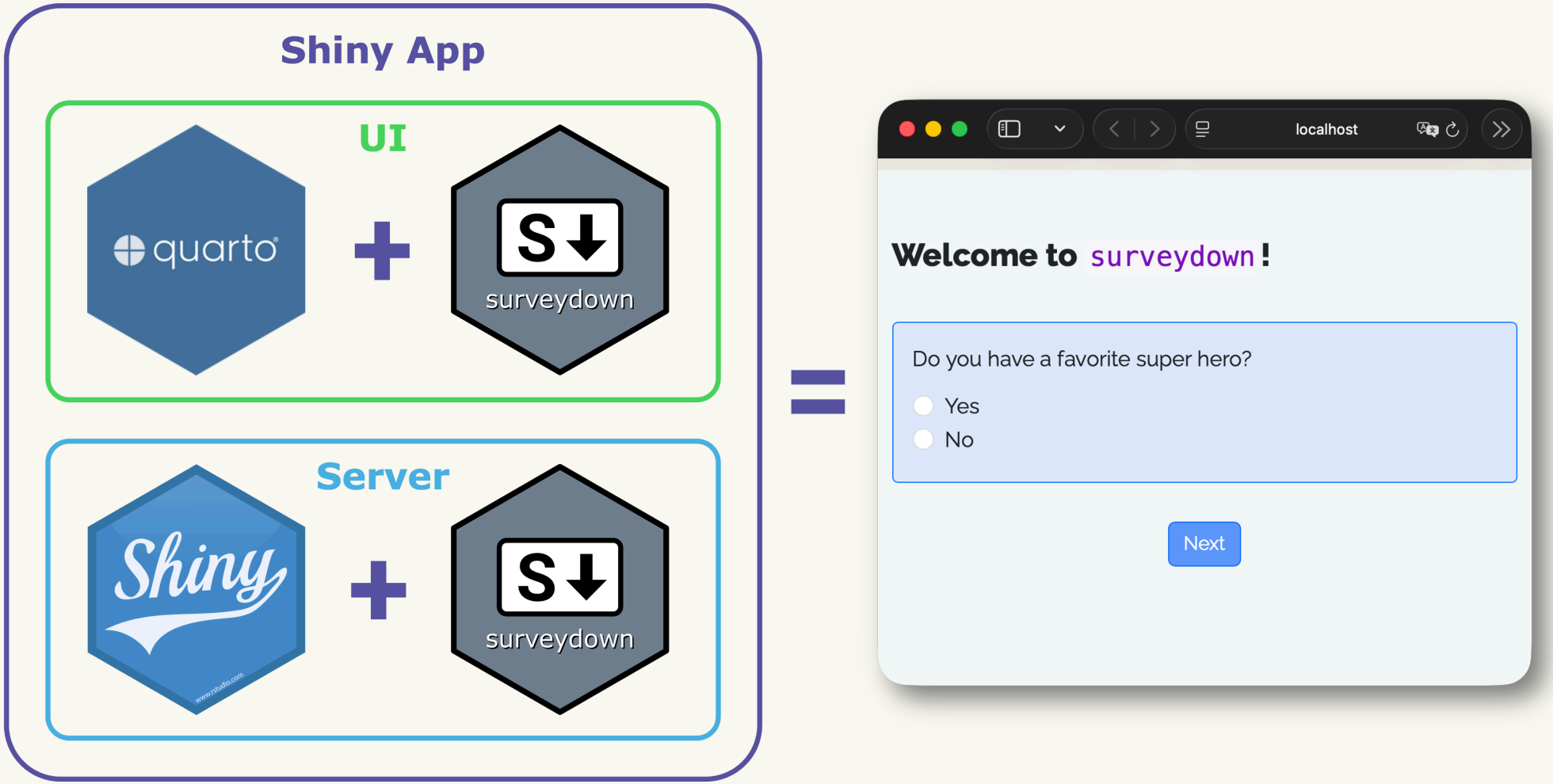
````
---
format: html
echo: false
warning: false
---

```{r}
library(surveydown)
```

::: {#welcome .sd-page}

# Welcome to `surveydown`!

```{r}
sd_question(
  type  = "mc",
  id    = "has_fav_hero",
  label = "Do you have a favorite super hero?",
  option = c(
    "Yes" = "yes",
    "No"  = "no"
  )
)

sd_next()
```

:::
````

Rendered Survey



has_fav_hero
yes
no
no
yes

Quarto renders to static html pages. Shiny turns them interactive.


Shiny App
UI
quarto
surveydown
Server
Shiny
surveydown
localhost
Welcome to surveydown!
Do you have a favorite super hero?
Yes
No
Next

A complete surveydown survey

`survey.qmd`

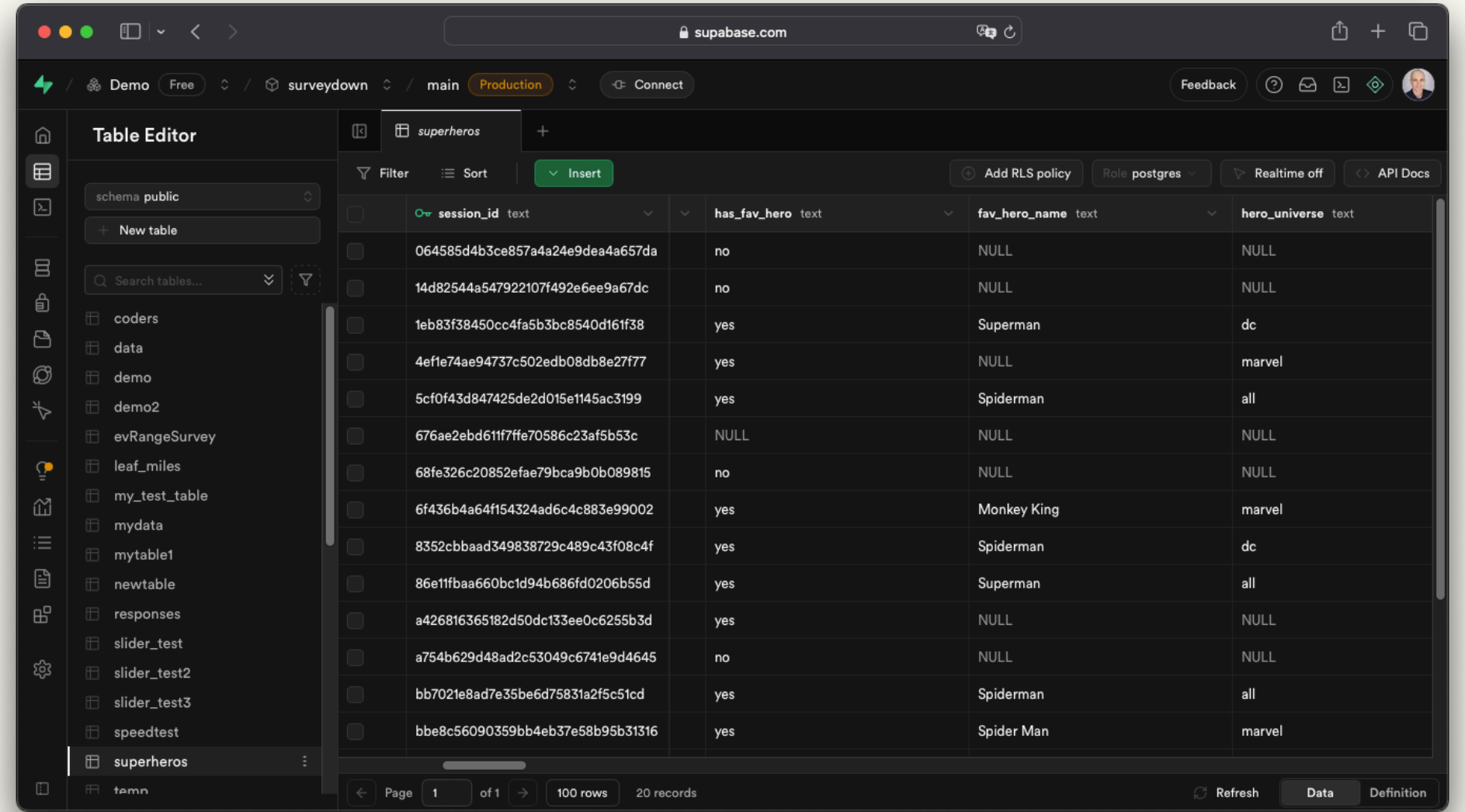
A **Quarto doc** defining the survey content (pages, texts, images, questions, etc).

`app.R`

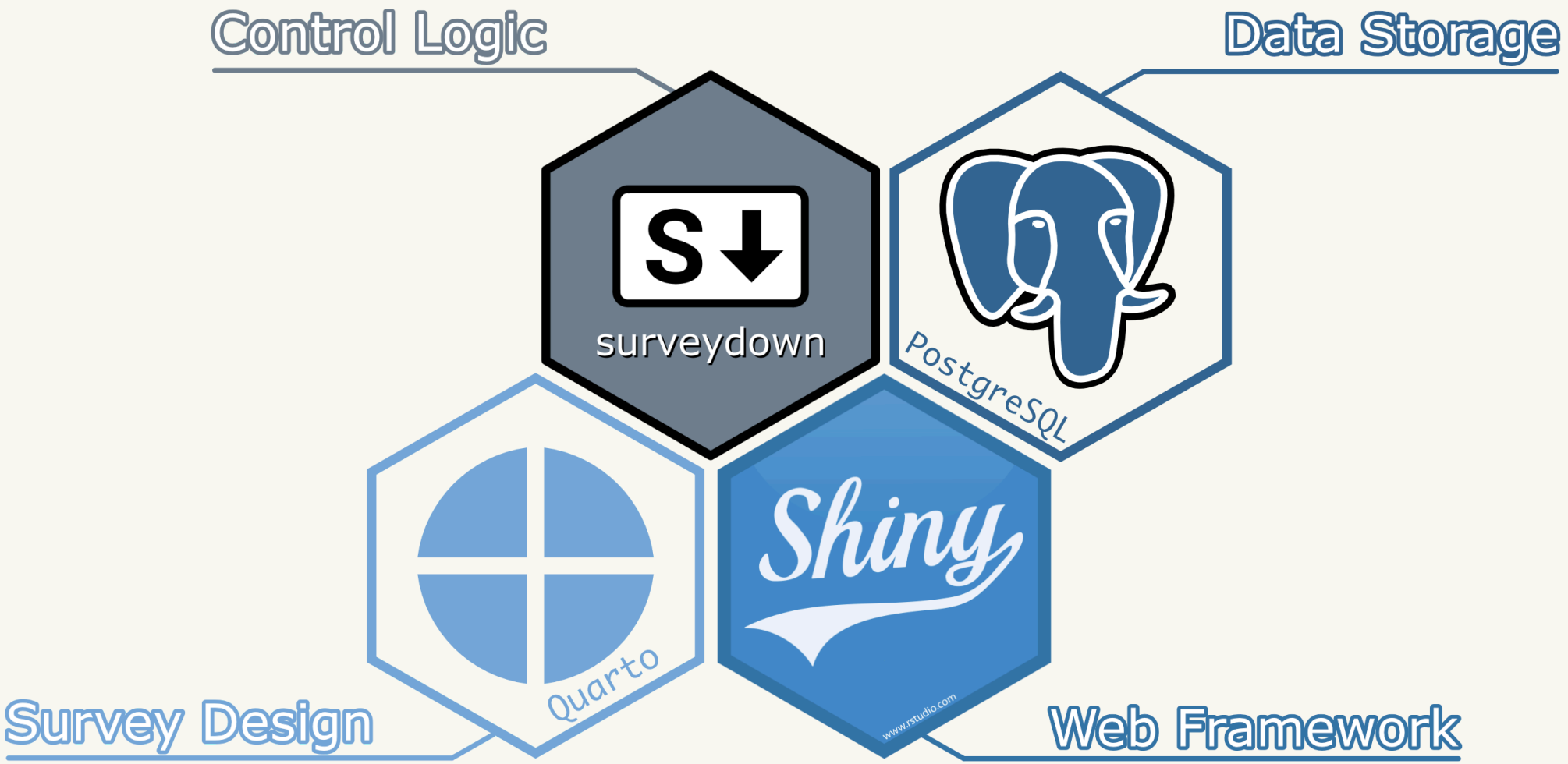
An **R script** defining the survey Shiny app.

PostgreSQL for response data storage.

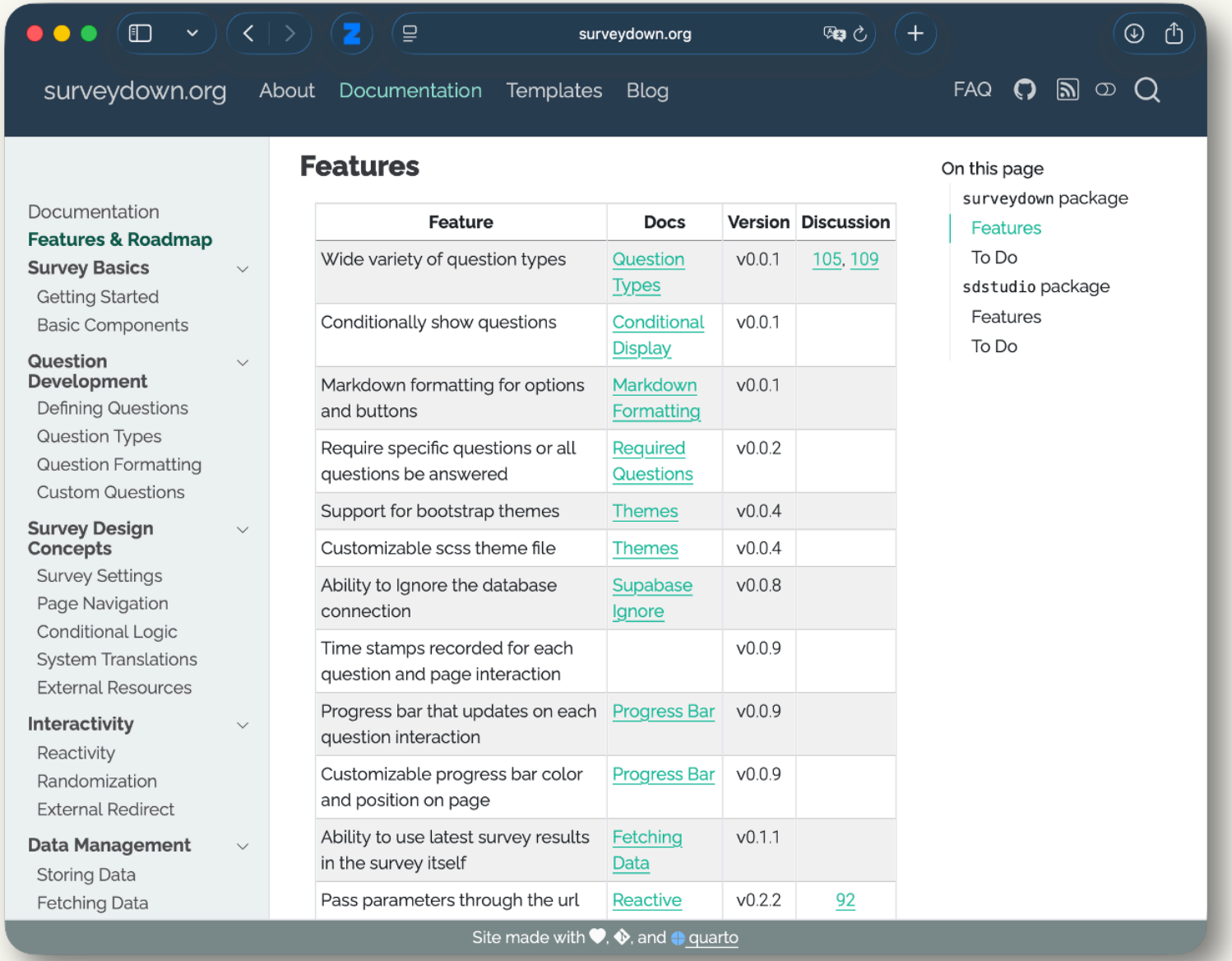
supabase.com



Technologies of surveydown



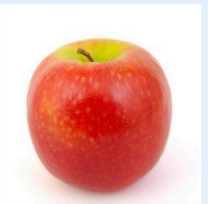
surveydown is feature-packed!



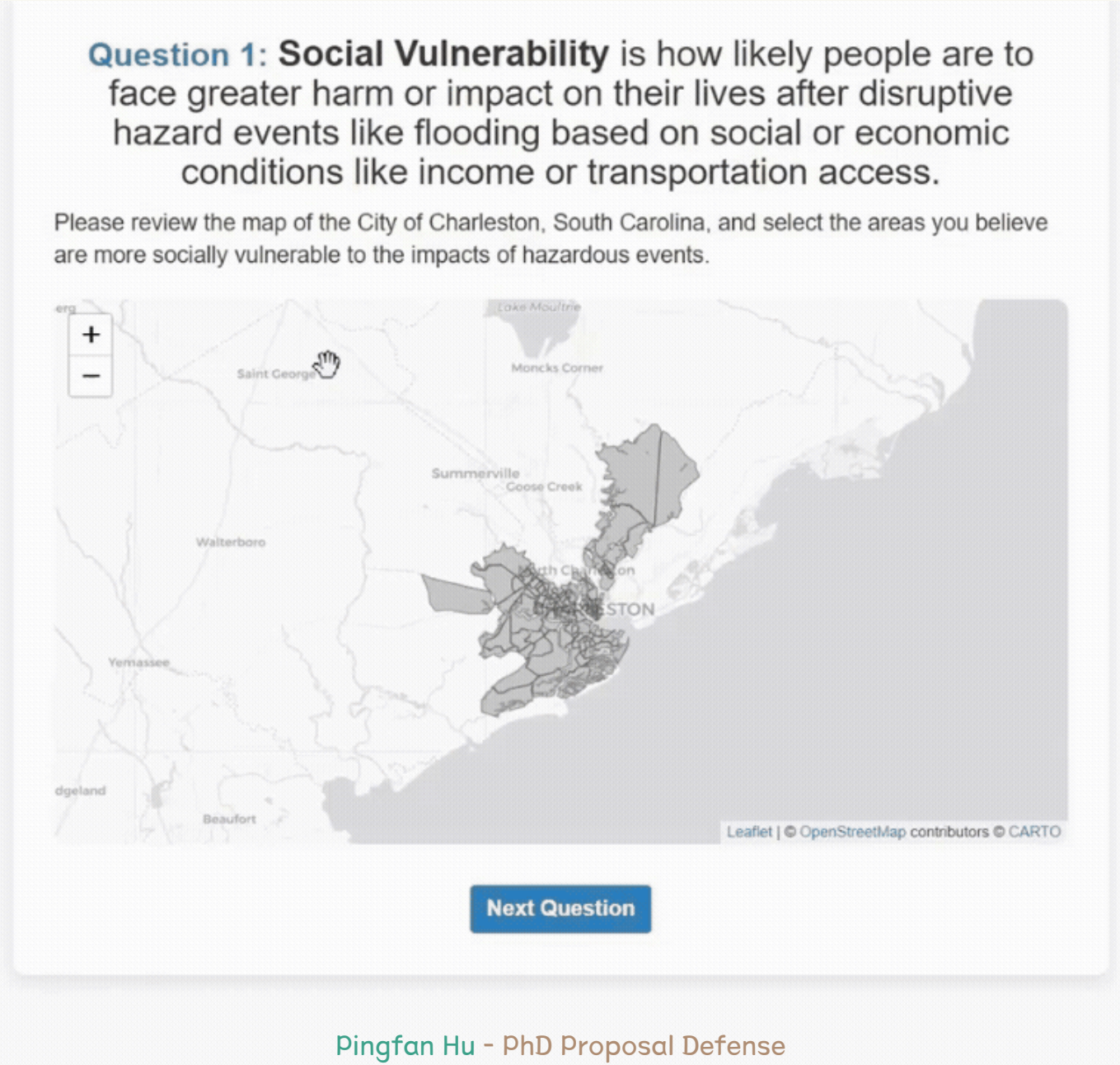
`surveydown` is highly flexible and customizable to user needs

Randomization: Conjoint question

For example, if these were the only apples available, which would you choose? *

Option 1	Option 2	Option 3
		
Type: Fuji **Price**: $ 2 / lb **Freshness**: Average	**Type**: Pink Lady **Price**: $ 1.5 / lb **Freshness**: Excellent	**Type**: Honeycrisp **Price**: $ 2 / lb **Freshness**: Poor

Shiny compatibility: `leaflet` map

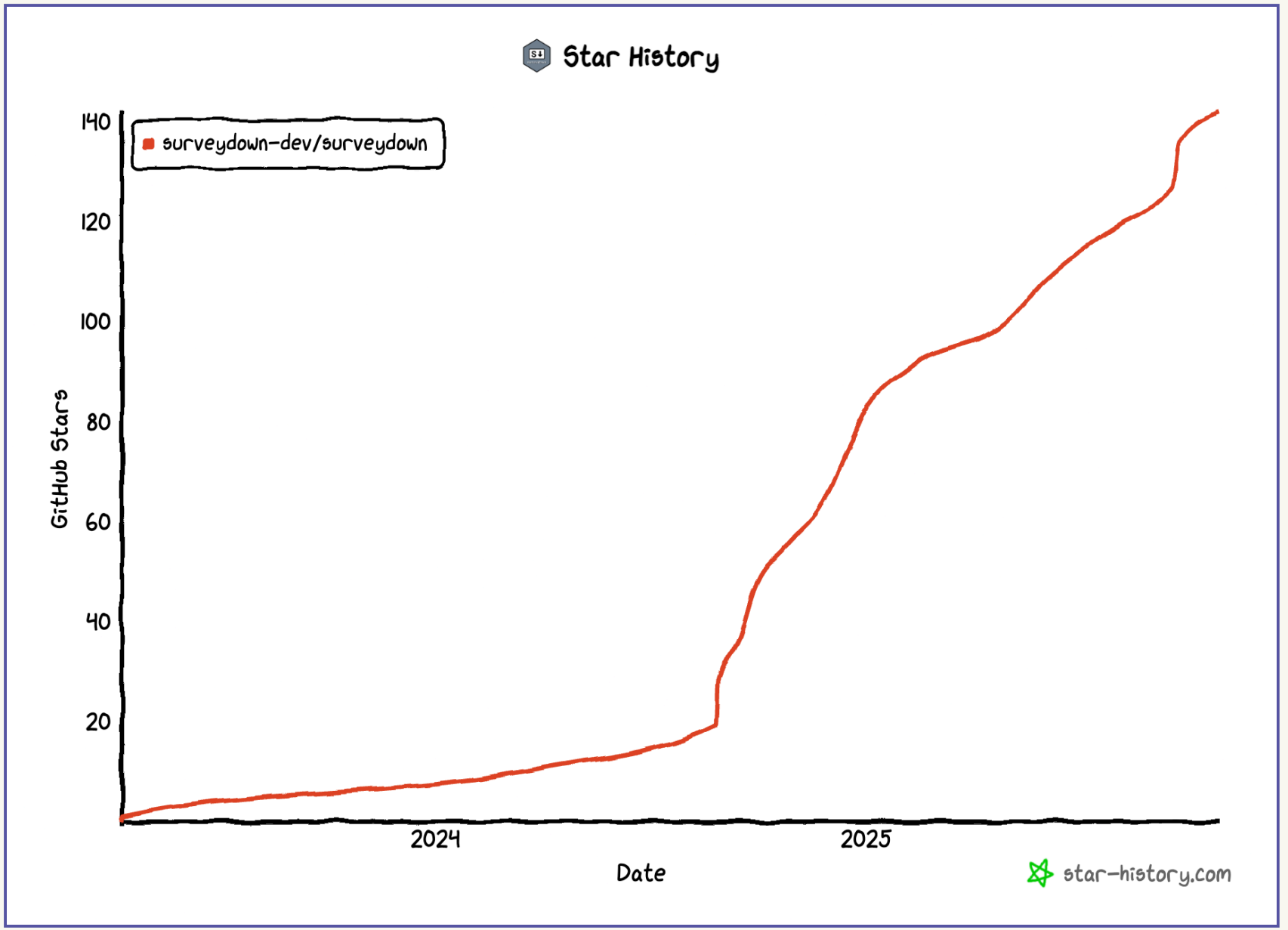


surveydown vs other platforms

Platform	User Interface	Cost	Reproducible	Open Source	Data Control	Programmable
Google Forms	GUI	Free	☐	☐	☐	☐
REDCap	GUI	Free/Paid	◪	☐	■	■
Qualtrics	GUI	Paid	◪	☐	☐	■
Sawtooth	GUI	Paid	◪	☐	◪	■
CASIC Builder	GUI	Paid	☐	☐	◪	☐
SurveyCTO	GUI	Paid	◪	☐	◪	■
QDS	GUI	Paid	☐	☐	☐	☐
LimeSurvey	GUI	Free/Paid	◪	■	☐	■
Open Data Kit	XLSForms	Free/Paid	◪	■	◪	■
oTree	GUI, Python	Free/Paid	■	■	■	■
SurveyJS	GUI, JavaScript	Free/Paid	◪	■	■	■
formr	XLSForms, markdown, R	Free	◪	■	◪	■
shinysurveys	R, CSV	Free	■	■	■	☐
surveydown	markdown (Quarto), R	Free	■	■	■	■

Legend: ■ = Yes, ◪ = Partially, ☐ = No

Star Count on GitHub



surveydown.org

Research Contributions

- **Study 1:** First *large N* survey study of EV owner *preference sensitivities* to smart charging. Introduces *attribute equivalencies* for incentive design.
- **Study 2:** Quantifies grid supply curves for *peak-shaving*, considering regions, seasons, EV-to-house ratios, and enrollment rates.
- **Study 3:** `surveydown`, a free open-source survey platform for programmable, reproducible survey designs.

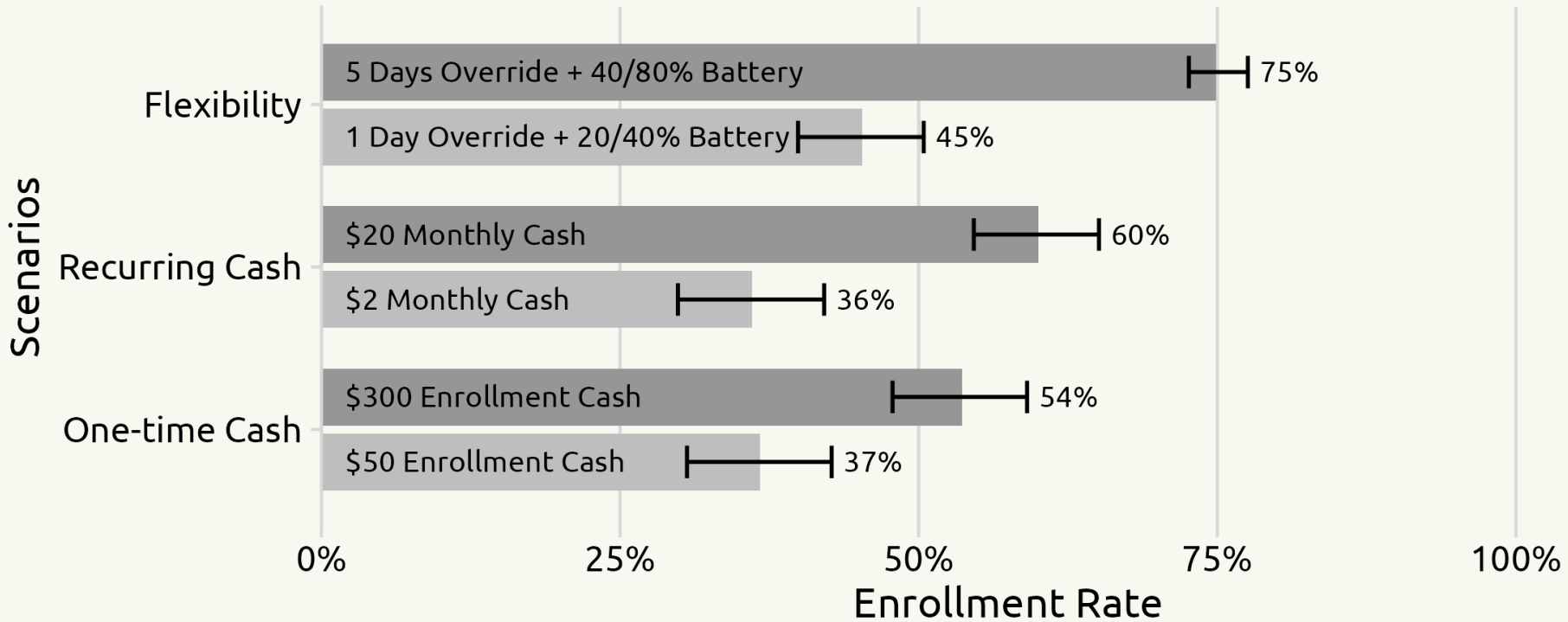
Timeline of Study 2

- **Nov 2025:** Sensitivity analysis on various scenarios.
- **Dec 2025:** Complete & submit manuscript for peer review.
- **Mar 2026:** Defend dissertation.

Thanks for listening!

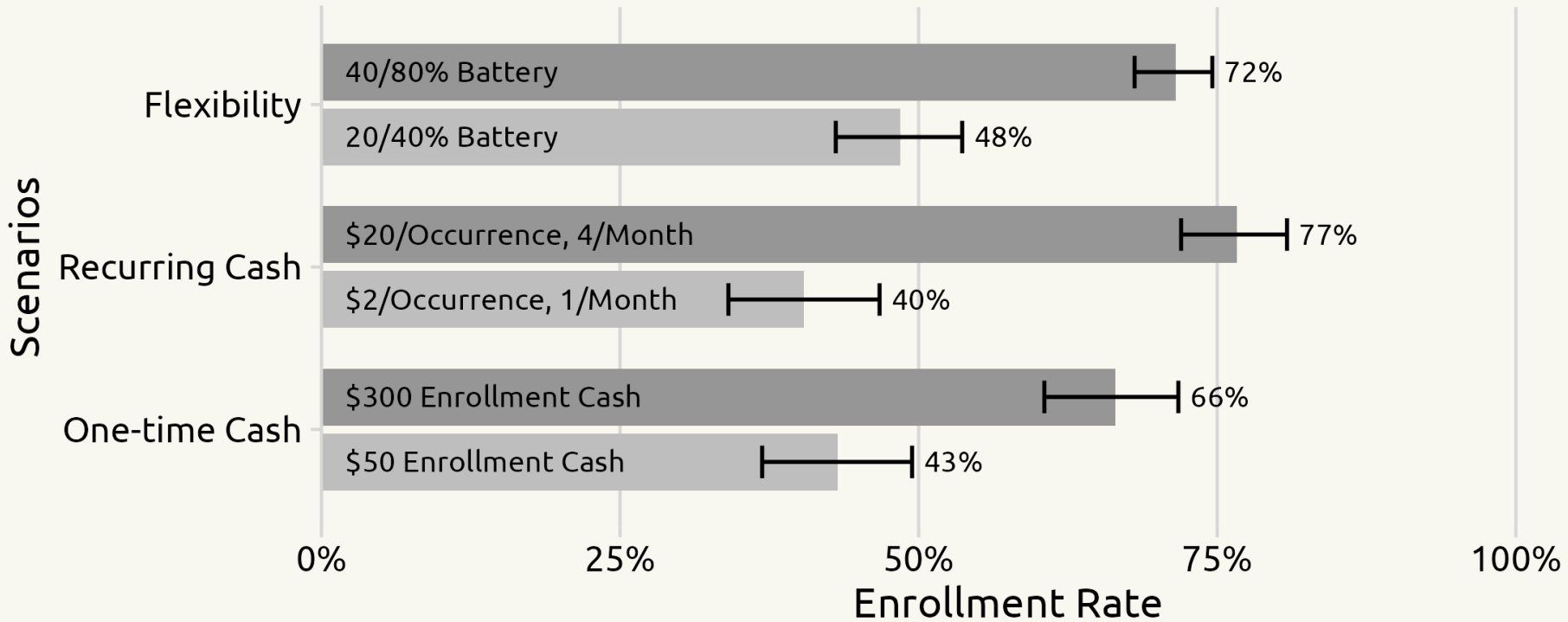
Appendix

SMC Scenario Analysis



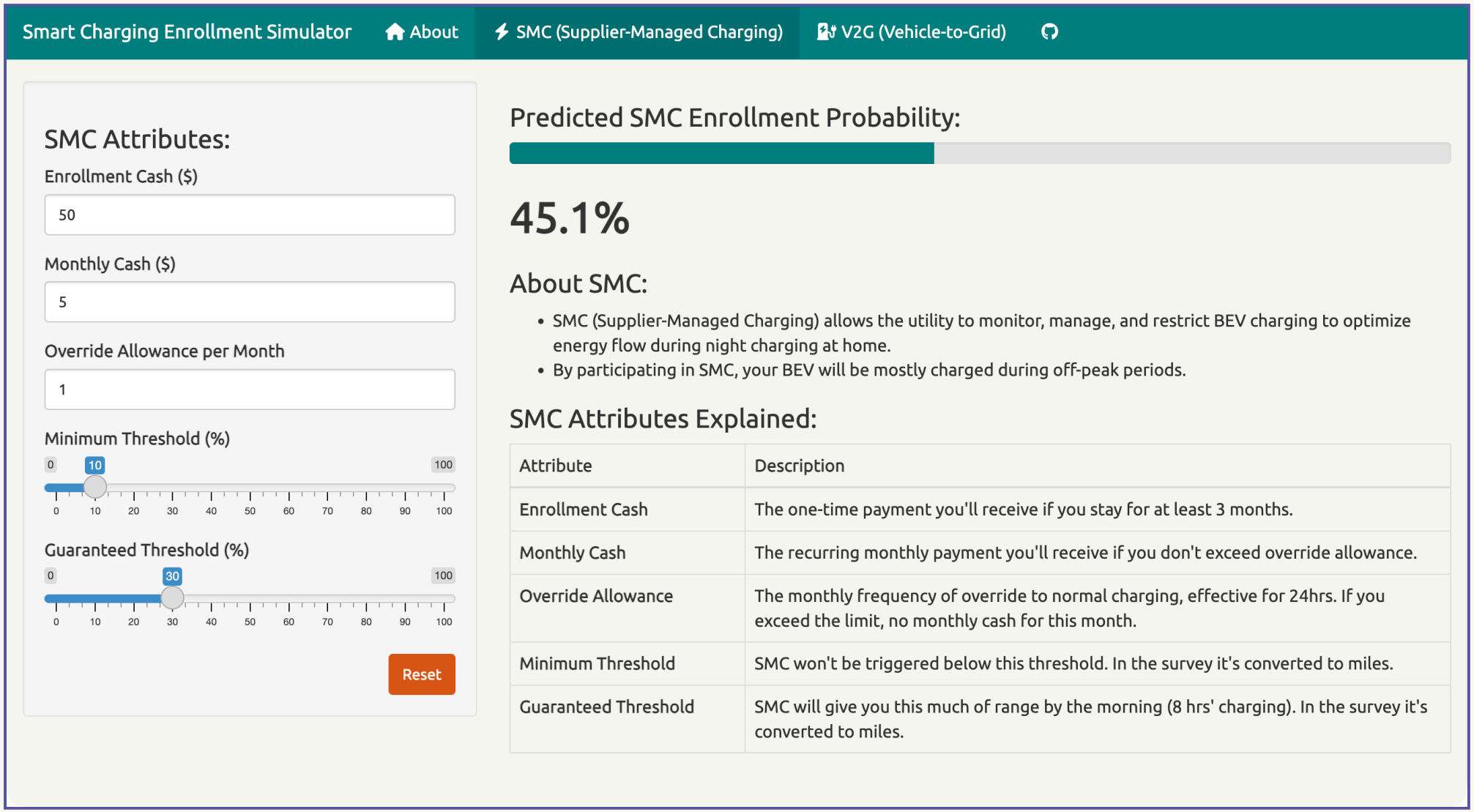
1. **Flexibility** is highly valued.
2. **Recurring** incentives are more important than one-time.
3. Payment alone is not enough.

V2G Scenario Analysis



1. Still, **recurring** incentives are more important than one-time.
2. But **flexibility** is not as important compared with SMC.
3. Owners are willing to leverage BEV as a source of income.

Smart Charging Enrollment Simulator



SMC Logit Model

$$u_j = \beta_1 x_j^{\text{enroll\_cash}} + \beta_2 x_j^{\text{monthly\_cash}} + \beta_3 \delta_j^{\text{override\_allowed}} + \beta_4 x_j^{\text{num\_overrides}} + \beta_5 x_j^{\text{min\_threshold}} + \beta_6 x_j^{\text{guaranteed\_threshold}} + \beta_7 \delta_j^{\text{no\_choice}} + \epsilon_j$$

Attribute	Coef.	Est.	SE	Level	Unit
Enrollment Cash	β_1	0.0037	0.0002	50, 100, 200, 300	USD
Monthly Cash	β_2	0.0728	0.0031	2, 5, 10, 15, 20	USD
Override Days	β_3	0.1191	0.0140	0, 1, 3, 5	Days
Override Flag	β_4	0.4357	0.0654	Yes, No	-
Minimum Threshold	β_5	0.0044	0.0023	20, 30, 40	%
Guaranteed Threshold	β_6	0.0490	0.0028	60, 70, 80	%
No Choice	β_7	2.8984	0.2215	-	-

V2G Logit Model

$$u_j = \beta_1 x_j^{\text{enroll\_cash}} + \beta_2 x_j^{\text{occur\_cash}} + \beta_3 x_j^{\text{num\_occurrences}} + \beta_4 x_j^{\text{lower\_threshold}} + \beta_5 x_j^{\text{guaranteed\_threshold}} + \beta_6 \delta_j^{\text{no\_choice}} + \epsilon_j$$

Attribute	Coef.	Est.	SE	Level	Unit
Enrollment Cash	β_1	0.0051	0.0003	50, 100, 200, 300	USD
Occurrence Cash	β_2	0.0972	0.0045	2, 5, 10, 15, 20	USD
Monthly Occurrence	β_3	0.1595	0.0262	1, 2, 3, 4	Times
Lower Threshold	β_4	0.0263	0.0036	20, 30, 40	%
Guaranteed Threshold	β_5	0.0368	0.0037	60, 70, 80	%
No Choice	β_6	2.4283	0.1964	-	-

surveydown Feature Highlights

Question types

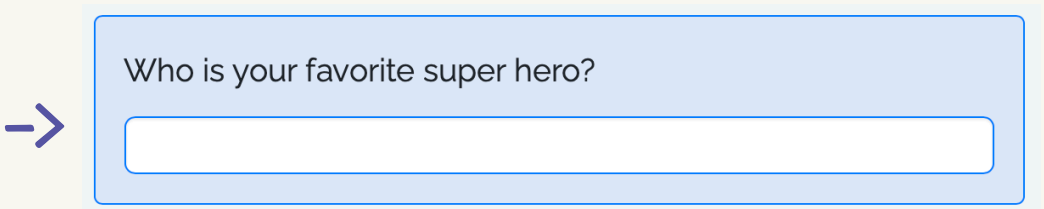
Conditional logic

12 Built-in Question Types

`text`	`textarea`	`numeric`	`mc`
`mc_multiple`	`mc_buttons`	`mc_multiple_buttons`	`select`
`slider`	`slider_numeric`	`date`	`daterange`

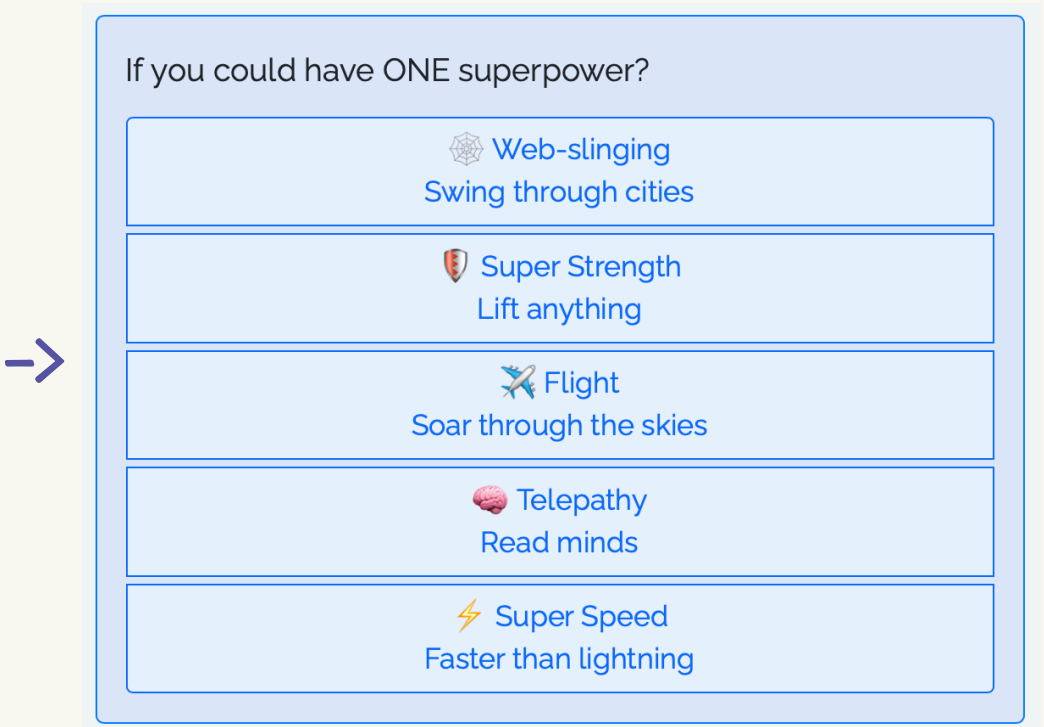
Question Type: `text`

```
sd_question(
  type  = "text",
  id    = "fav_hero_name",
  label = "Who is your favorite super hero?"
)
```



Question Type: mc_buttons

```
sd_question(
  type  = "mc_buttons",
  id    = "dream_power",
  label = "If you could have ONE superpower?",
  option = c(
    "🕸️ Web-slinging"   = "webslinging",
    "🛡️ Super Strength" = "strength",
    "✈️ Flight"         = "flight",
    "🧠 Telepathy"      = "telepathy",
    "⚡ Super Speed"    = "speed"
  ),
  direction = "vertical"
)
```



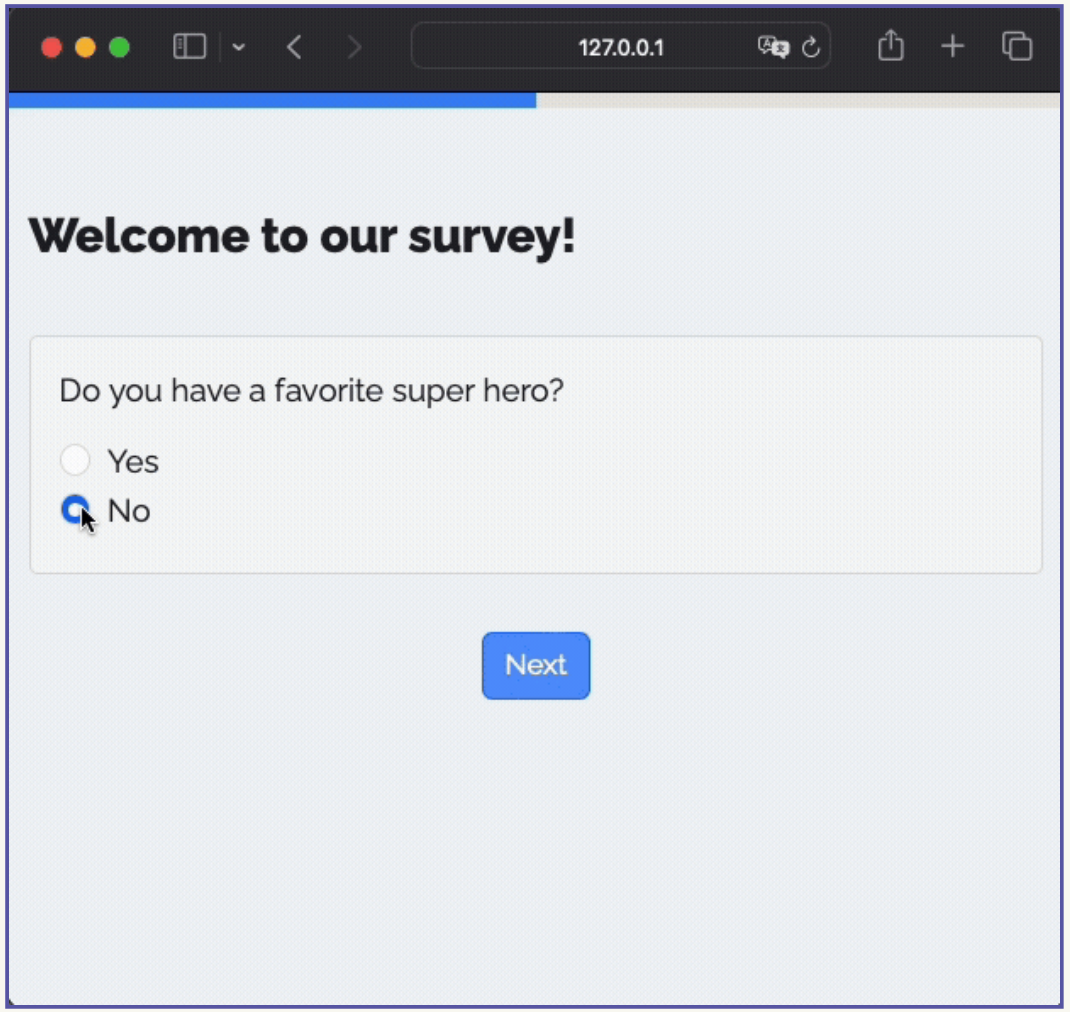
Conditional logic

Conditional showing

Conditional skipping

Conditional stopping

Conditional showing - `sd_show_if()`



Conditional showing - sd_show_if()

survey.qmd

```qmd
# Conditional Question
sd_question(
  type  = "mc",
  id    = "has_fav_hero",
  label = "Do you have a favorite hero?",
  option = c("Yes" = "yes", "No" = "no")
)

# Target Question
sd_question(
  type  = "text",
  id    = "fav_hero",
  label = "Who is your favorite super hero?"
)
```

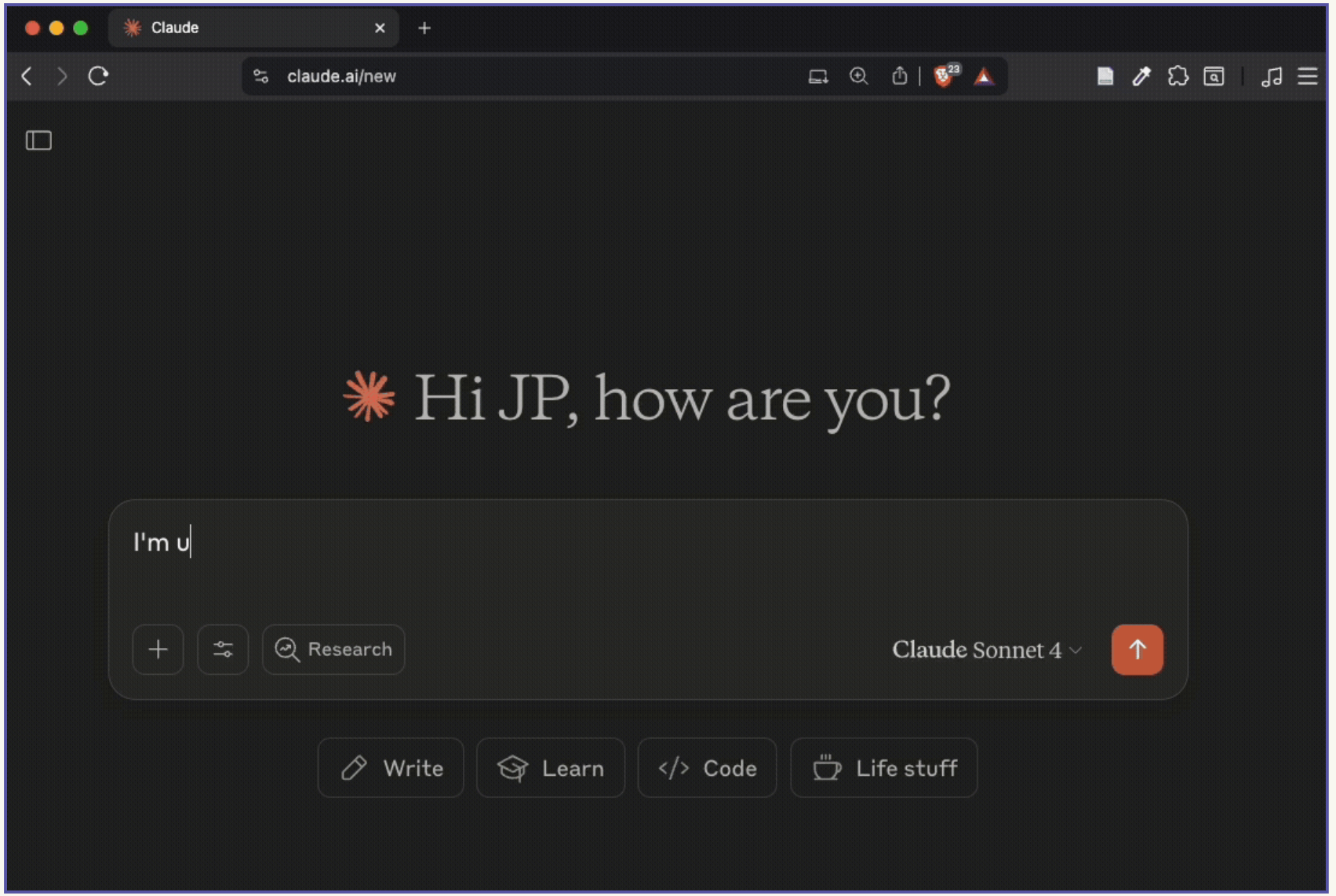
app.R

```r
# Inside server
sd_show_if(
  input$has_fav_hero == "yes" ~ "fav_hero"
)
```

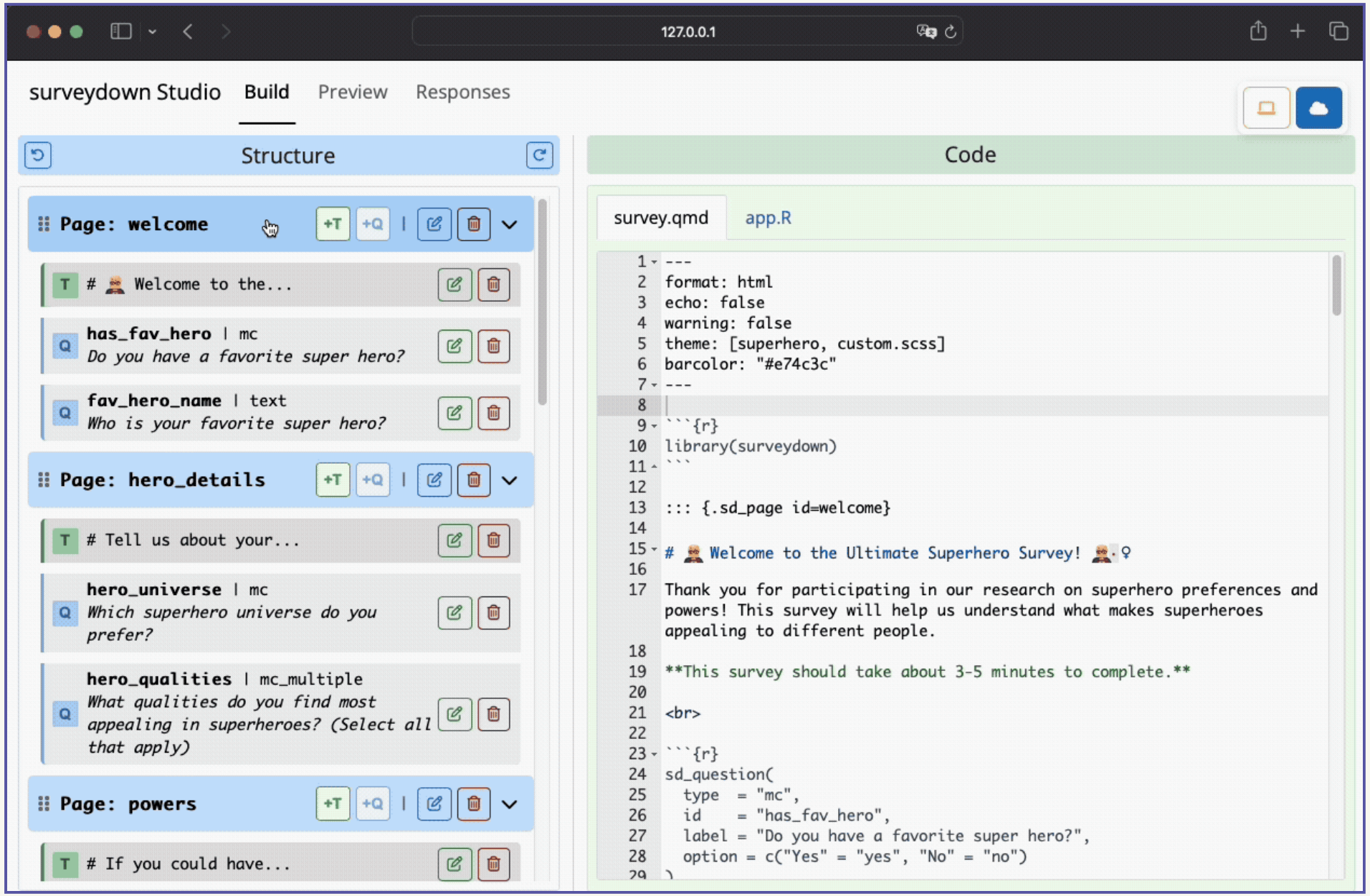
Condition ~ Target

"If {condition}, then show {target}"

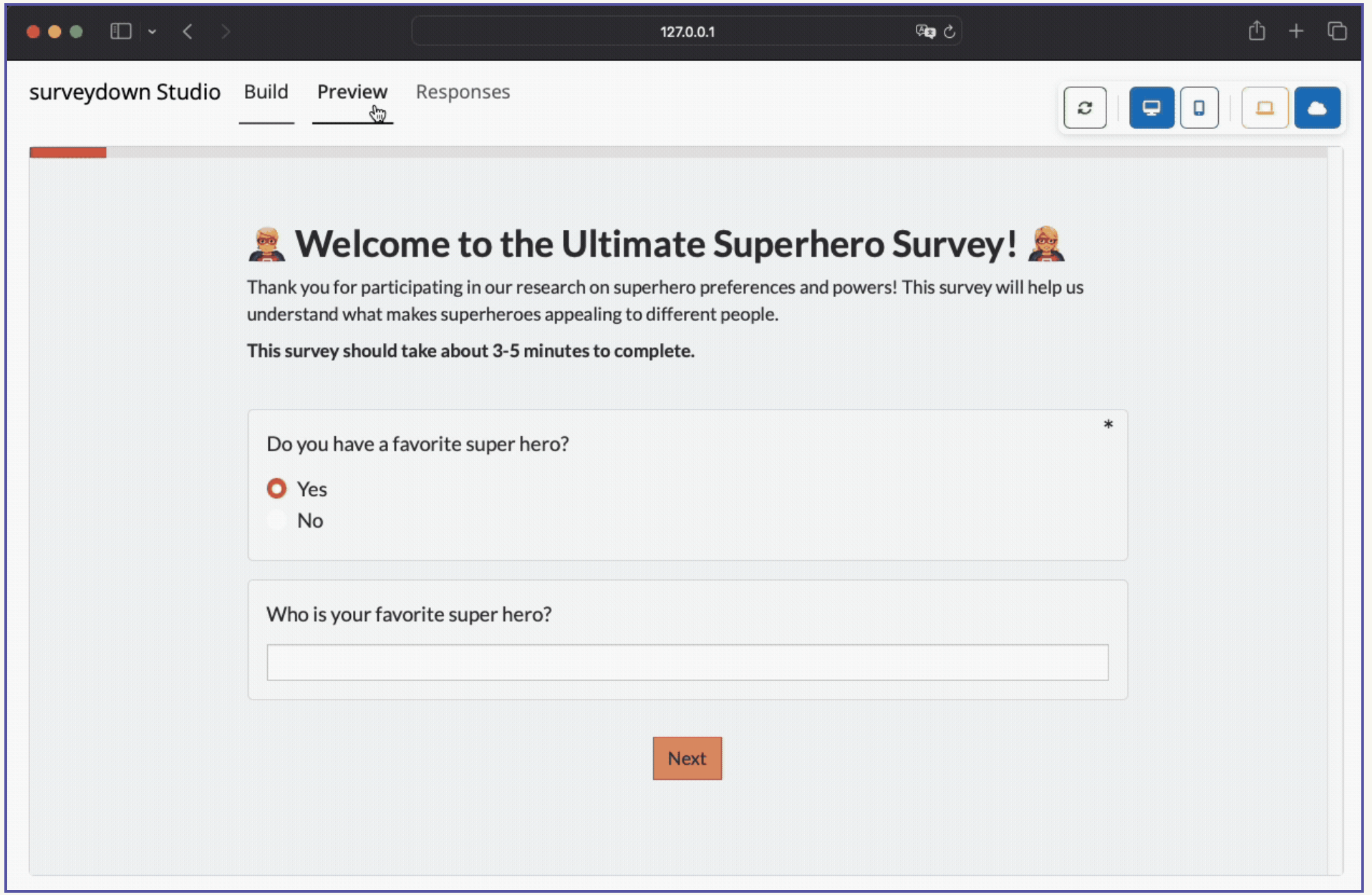
Generate surveys with LLMs!



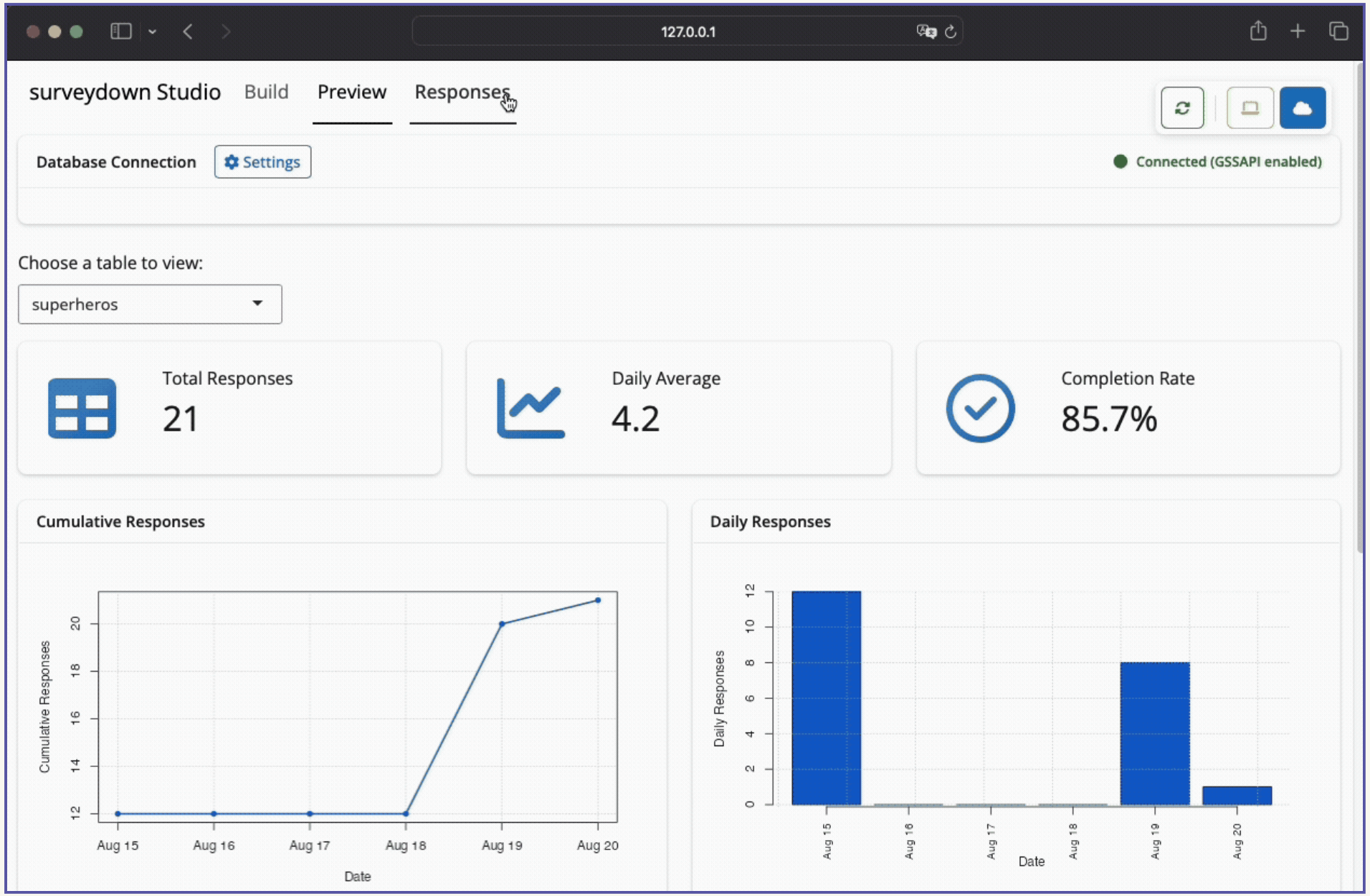
The companion `sdstudio` package



The companion `sdstudio` package



The companion `sdstudio` package



Reference List

Huang, Bing, Aart Gerard Meijssen, Jan Anne Annema, and Zofia Lukszo. 2021. "Are Electric Vehicle Drivers Willing to Participate in Vehicle-to-Grid Contracts? A Context-Dependent Stated Choice Experiment." *Energy Policy* 156 (September): 112410. https://doi.org/10.1016/j.enpol.2021.112410.

Philip, Thara, and Jake Whitehead. 2024. "Consumer Preferences Towards Electric Vehicle Smart Charging Program Attributes: A Stated Preference Study." Rochester, NY. https://doi.org/10.2139/ssrn.4812923.

Wong, Stephen D., Susan A. Shaheen, Elliot Martin, and Robert Uyeki. 2023. "Do Incentives Make a Difference? Understanding Smart Charging Program Adoption for Electric Vehicles." *Transportation Research Part C: Emerging Technologies* 151 (June): 104123. https://doi.org/10.1016/j.trc.2023.104123.