GREENER GAMING IN *WORLD SPACE*

CS 411W | Team Crystal | 17 April 2023

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Meet Our Team

Bittu Ahlawat
Mentor

Ashley Borum

Hawar Hawarry

Zach Schumacher

Jeremiah Shelor

Bradley Sherwood

Manuel Tan

Problem Statement

Motivation:

Climate change presents a range of risks to human life and the environment. Avoiding the worst effects of climate change will require urgent action to reduce reliance on energy generated from fossil fuels.

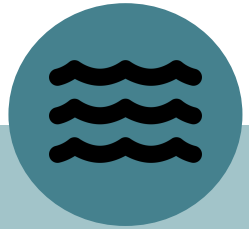
Problem:

The world is already experiencing significant disruptions due to global temperature rise, yet there exists a disconnect between high-performance personal computing trends and the realities of decarbonizing the electric grid.

Problem Background: The Big Picture

Climate Change

We have seen a 1.1° C rise in temperature since 1880 and projected a 3.2° C increase by the end of this century.



Natural Disasters

There has been a 4 inch rise in global sea levels since 1993. We are likely to see higher rates of flooding and wildfires.

Actions

The world is falling short of the emissions reductions needed to avoid the most severe impacts from global warming.

Financial Strain

The World Economic Forum ranked climate change as the biggest risk to the economy in 2020.

Sources: United Nations, NASA, Washington Post

Problem Background: How does this affect us?

Food Shortages

With the continuous increase in temperature and change in weather, there would most likely have a decrease in harvest due to flooding.

Poverty

People are expected to live in poverty due to floods sweeping away homes, and livelihoods. The change in temperature would also affect the way people work.

Health Risks

Over 90% of people breathe unhealthy levels of air pollution, largely resulting from burning fossil fuels driving climate change. Heat strokes.

Animal Population

The world is currently suffering from coral bleaching where fish are losing their habitats and sources of food.

Sources: United Nations

Problem Background: Gaming and the Climate

A typical gaming computer consumes an estimated 1,400 kWh/year and accounts for around 1,700 pounds of CO_2 annually. [1]

3 Refrigerators = 1 Gaming PC

Gaming consumes 34 TWh/year in the U.S., emitting the same CO_2 as 85 million refrigerators, or more than 5 million cars. [2] Gaming PCs account for an outsized share of power consumption among personal devices [1].

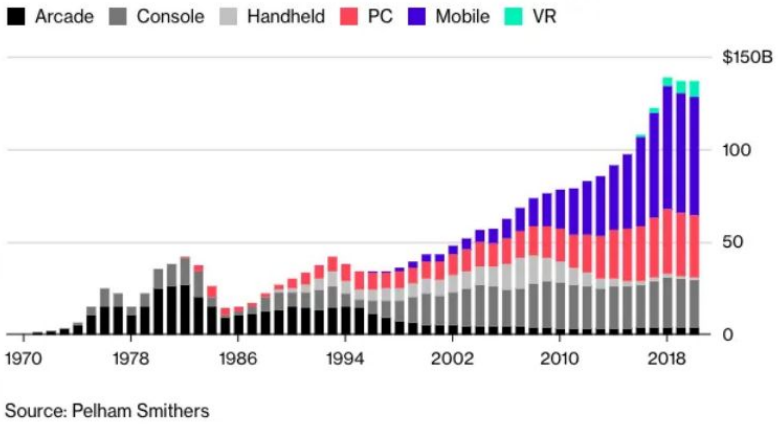
> 5 million

Research suggests energy use could be significantly reduced without negatively affecting user experience. [2]

Sources: Lawrence Berkeley National Laboratory [1], Mills, et al. “Toward Greener Gaming...” [2]

A growing problem…

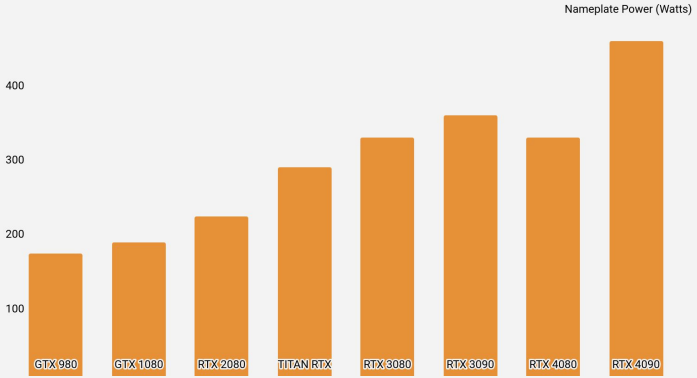
PC gaming's increased market share[1]



Source: Pelham Smithers

GPU power demands keep rising.

High-end NVIDIA GPU power draw, recent generations:[2]



And rising?

AMD recently predicted GPU power consumption of 600-700W by 2025.[3]

[1] *Game Developer*, January, 2019

[2] *TechPowerUp.com*

[3] *TechSpot*, July 13, 2022

Problem Background: PC Stats

- To put into perspective how much power someone with a gaming PC might use while running a resource intensive game or program, here are some wattage statistics while playing a resource-intensive video game:

- CPU: AMD Ryzen 5 5600X
- GPU: NVIDIA GeForce RTX 3070 Ti
- Game: Escape from Tarkov

Main Menu:

	Current	Min	Max	Avg
CPU Package Power	37.282 W	35.136 W	45.800 W	40.294 W
GPU Power	105.166 W	91.369 W	123.825 W	101.413 W

Gameplay:

	Current	Min	Max	Avg
CPU Package Power	63.294 W	35.136 W	72.390 W	46.505 W
GPU Power	217.262 W	50.351 W	288.331 W	159.049 W

This also demonstrates how the power consumption of a PC can vary drastically depending on what software is currently in use and the actions of the user. The gameplay wattage is equivalent to:

- Two 65” LED TVs [2]
- Six fluorescent lamps [2]
- One fridge/freezer combination [2]
- Eight DVD players [2]

[2] *Power Consumption of Typical Household Appliances.*

Our Solution

Eco-feedback software that leverages gamification to teach PC users about the carbon intensity of their computing habits and promote more sustainable behaviors.

Customers and End-Users

End-Users

- PC gamers
- Parents/guardians of PC gamers
- Content-creators (Video, 3D rendering, streaming)
- Any PC power user engaged in demanding workflows

Stakeholders

- Researchers
- Advocacy groups
- Educators
- Regulators
- Gaming companies with public commitments on the environment

Solution Characteristics

The software will:

- Continuously sample PC wattage
- Monitor hourly regional electricity generation by fuel type
- Produce a personalized estimate of a device's carbon-intensity
- Use gamification to challenge users to reduce CO_2 emissions
    - Achievable daily targets
    - Earnable rewards to incentivize progress
- Predict periods of high renewables availability
- Make recommendations on optimal time frames to carry out demanding tasks
- Estimate carbon-intensity of individual computing tasks

Solution Characteristics

The software will (cont.):

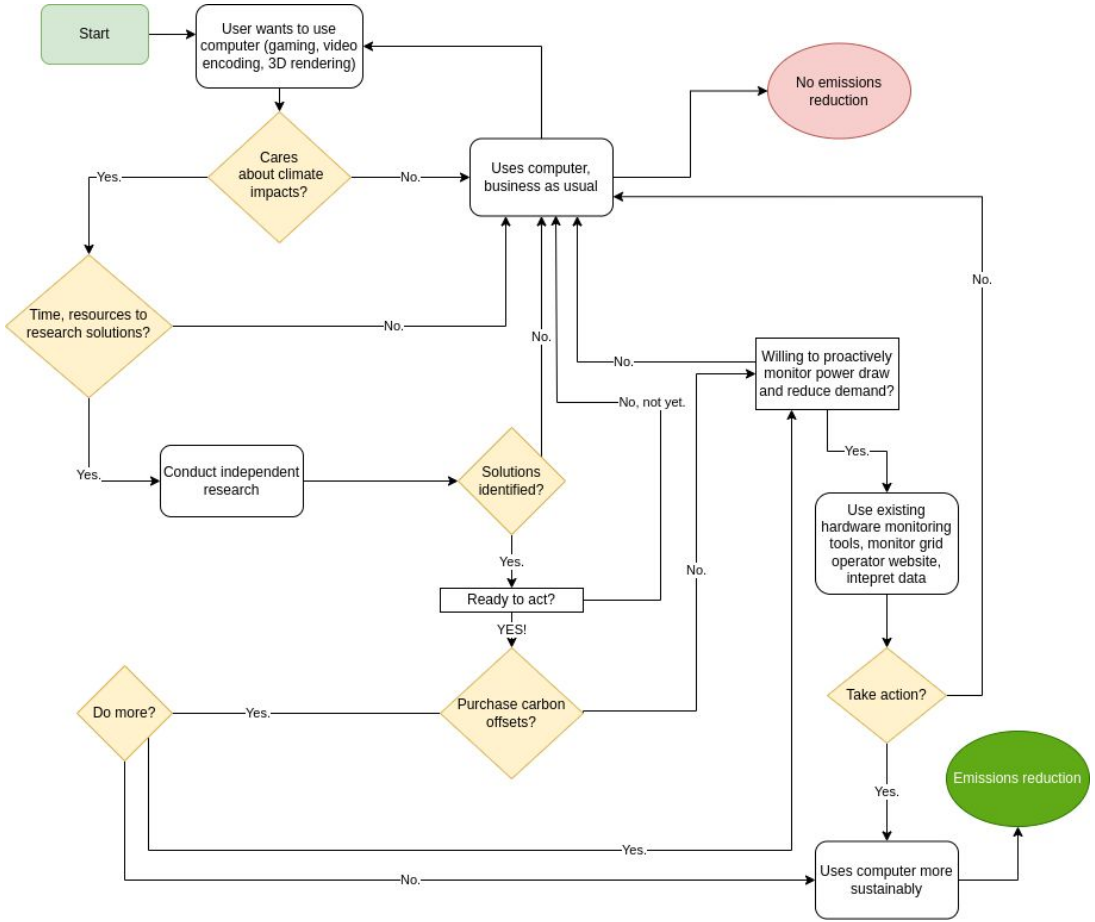
- Provide both climate- and cost-focused parental monitoring features through a companion application
- Collect anonymized data on hardware and usage:
  - Provide access to consumption and hardware statistics through a research API
  - Data used to help drive research and policymaking around climate impacts of personal computing (e.g. California efficiency standards for PCs)
  - Push for greater efficiency in gaming hardware through data transparency

Solution Characteristics

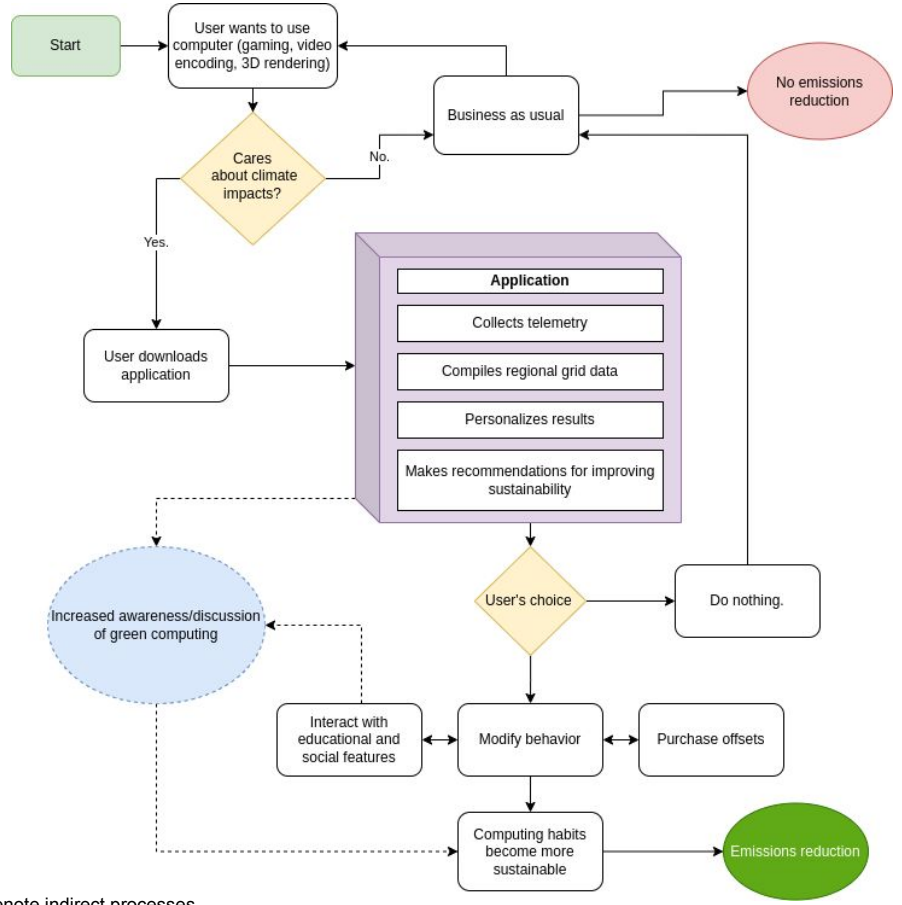
The software will NOT:

- Focus on reducing general household energy costs or make energy efficiency recommendations concerning non-computing devices
- Require a dedicated smart device to monitor electricity usage, such as a smart plug

Current Process Flow

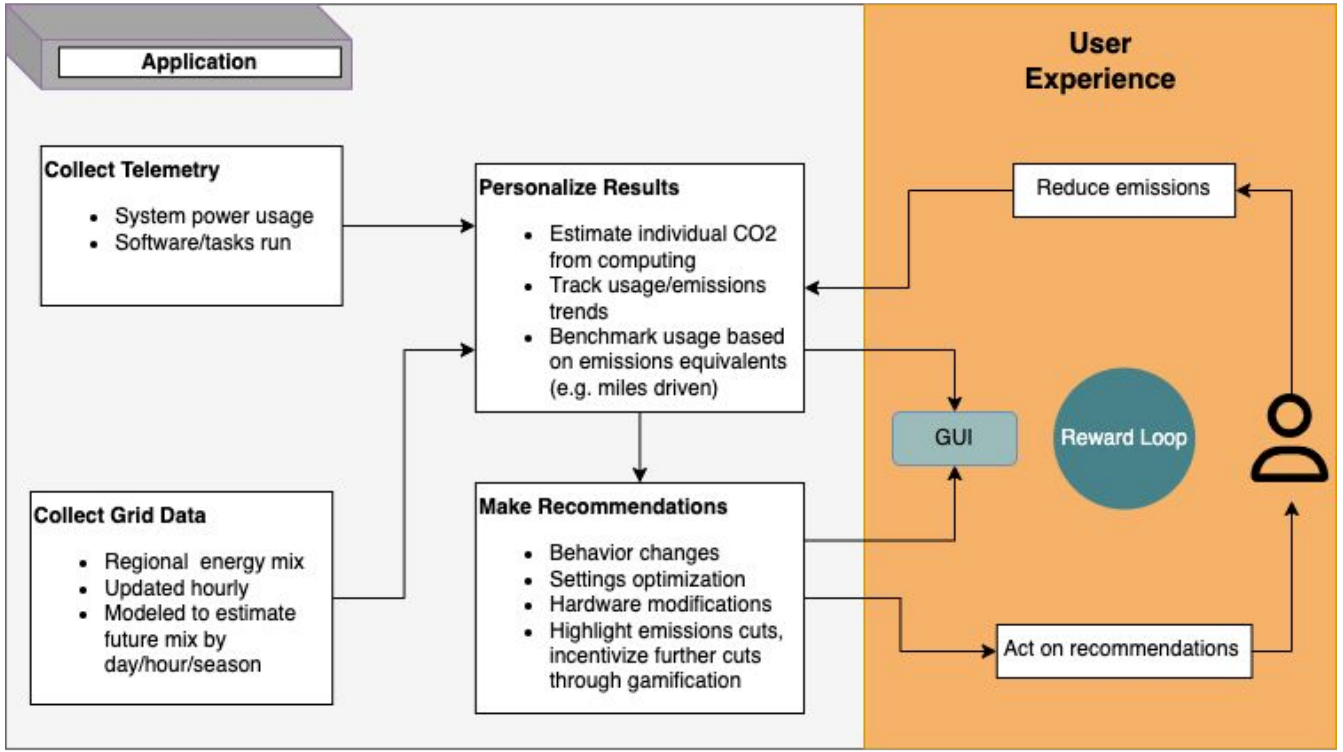


Solution Process Flow



* Dotted lines denote indirect processes.

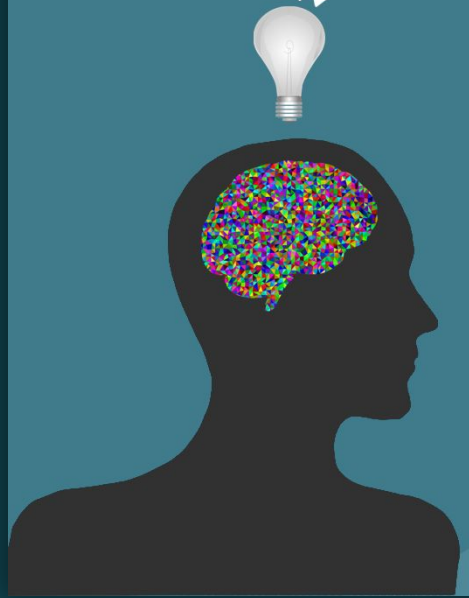
Solution Process Flow: Application Breakout

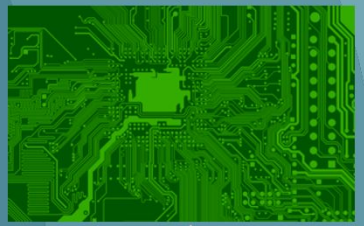


Climate Progress Through Education

Education Through Gamification

Building personal connection to a global problem.





Meaning

Ownership

Social Influence

Achievability

Challenge

Credibility

Source: Ouariachi et al, “Gamification Approaches for Education…”

Gamification: Proof of Concept

Goal: Foster emotional investment in real-world outcomes through simulation and personalization

A personalized 'virtual ecosystem'

Behavioral change rewards virtual currency used to:

- Unlock new plants, animals, insects by purchasing in a virtual storefront
- 'Terraform' the ecosystem, creating new habitat for unlocked species
- Invest in maintaining, cleaning ecosystem
- Invest in recovery, remediation
- Users can share or visit one another's ecosystems

Personal ecosystem has its own greenhouse gas parts-per-million (GHG PPM) stat linked to user behavior:

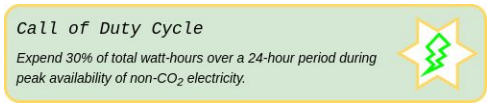
- Periods of high-CO_2 emissions intensity raise GHG PPM
- High GHG PPM destabilizes ecosystem, potential for unlocked species to 'die out' via permadeath system comparable to virtual pet games
- Nudges to reduce CO_2 intensity coupled with specific warnings for personal ecosystem

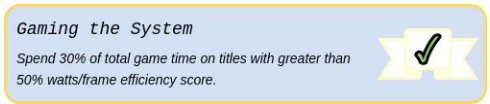
Gamification: Proof of Concept

Goal: Promote behavioral change through time-bound progression system

Achievement/bounty system:

- Tracked by rarity (“only X% of players have this achievement”)
- Reward XP, virtual currency, badges
- Reward completion streaks for daily goals
  - 3-day, 5-day, 7-day, 14-day, 30-day
- Possible daily achievements:





XP gains unlock new items via non-linear progression tree:

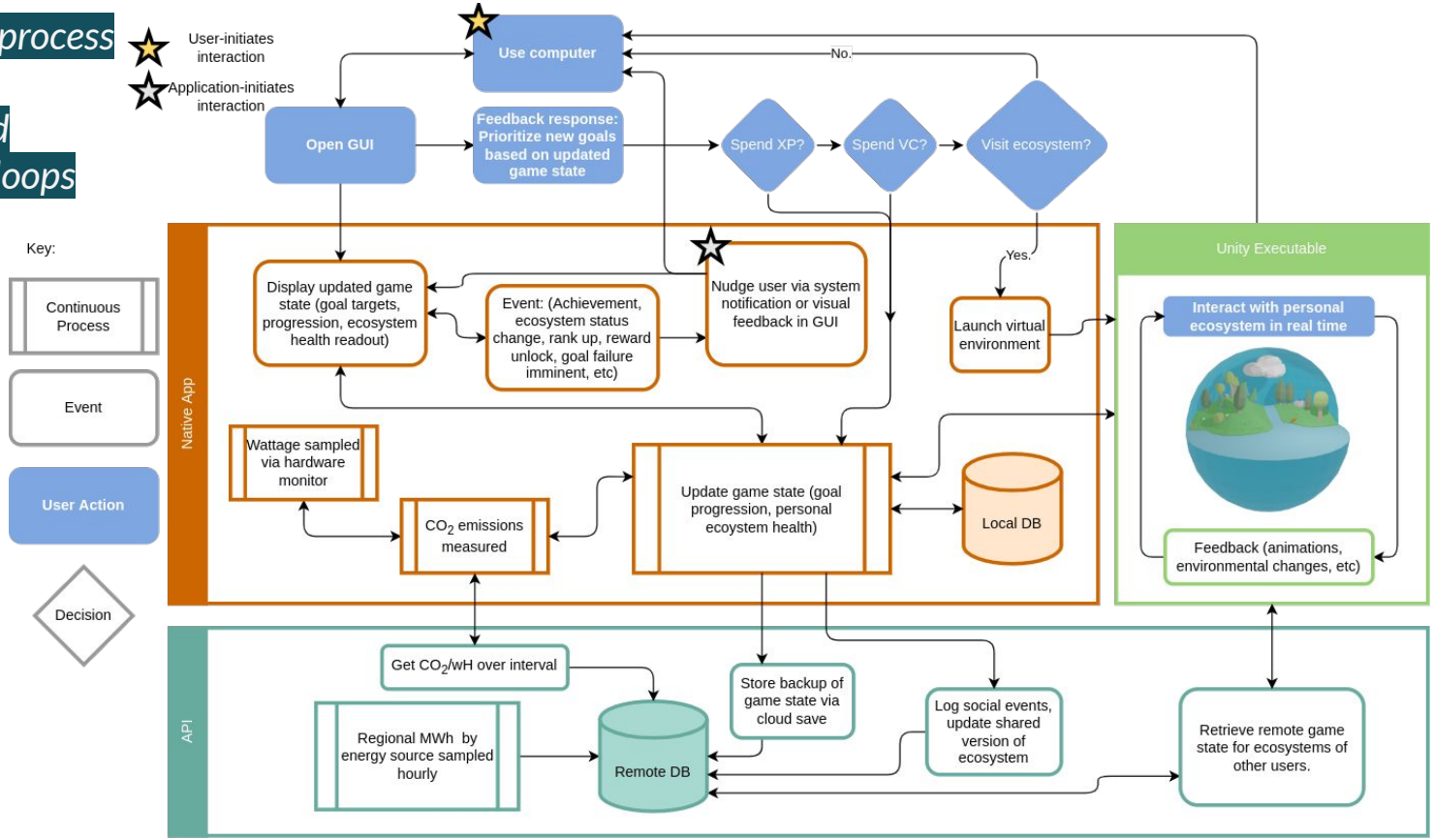
Potential for seasonal refresh, a la the battle pass model used by many live-service games.

Lifetime reputation/rank:

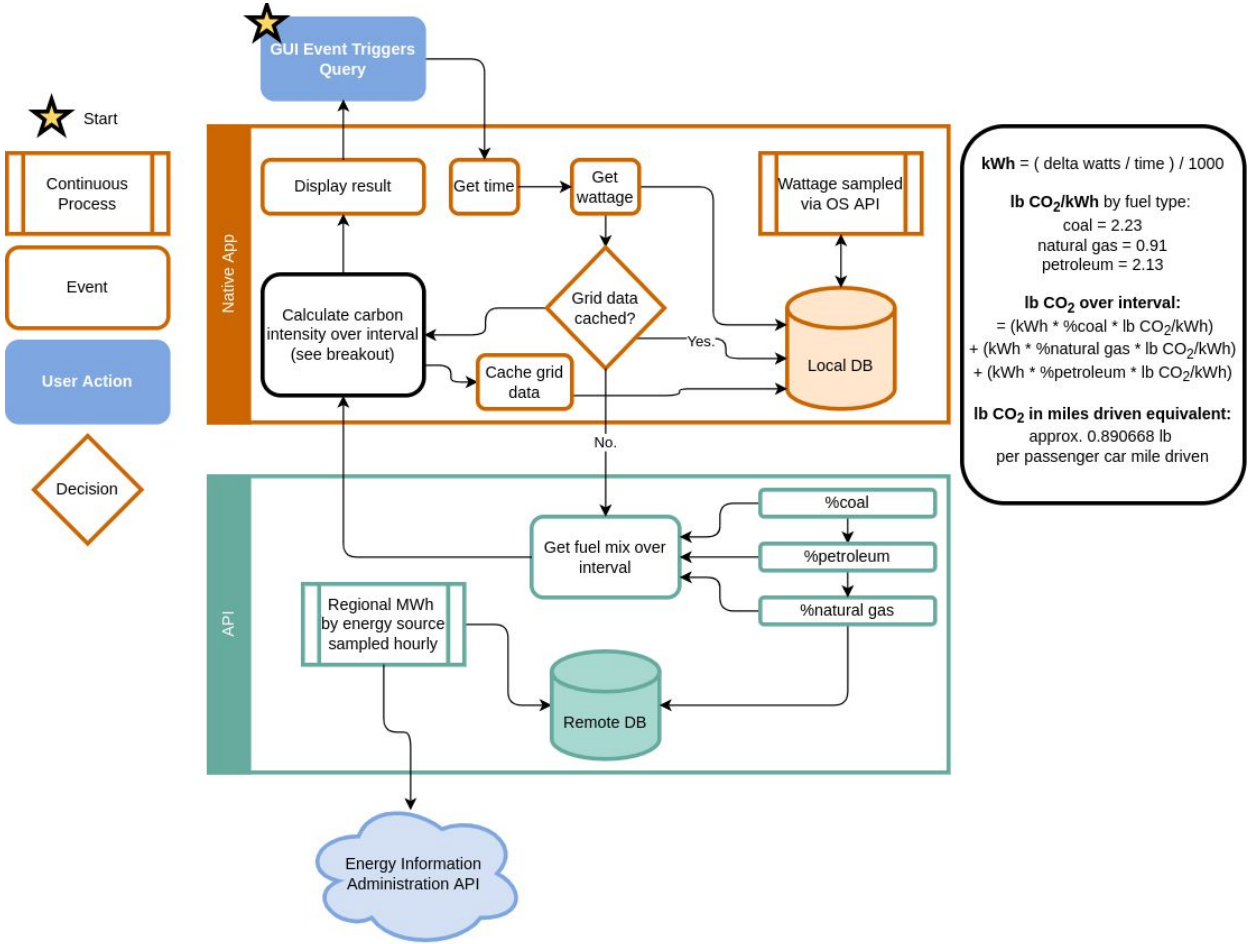
- Comparable to Xbox Gamerscore
- Measure of long-term engagement
- Tracked via leaderboards to foster healthy competition
- Users that achieve exclusive tiers of engagement rewarded with “ambassador” status
- Ambassador profiles (including personal ecosystem) given visibility on application homepage

Gamification: Proof of Concept

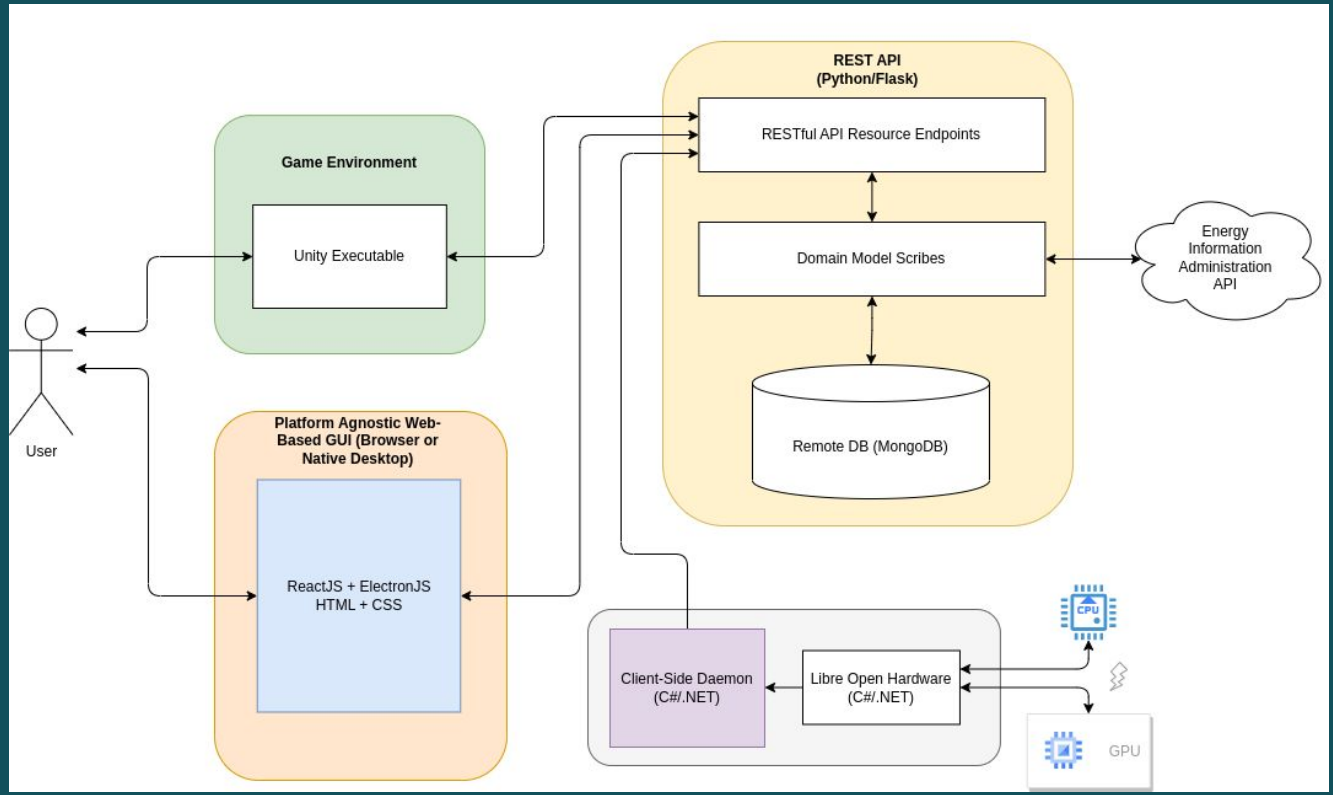
Sample process flow for gamified reward loops



Algorithm Flow:
Carbon Intensity Calculation



Prototype MFCD



Development Tools

Software:

- Version Control: Git
- Repository: GitHub
- IDE: Visual Studio, VS Code
- Build/configuration management: .NET, pipenv
- Unit Testing:
  - xUnit (C#/.NET)
  - pytest for Python
- Documentation: XML, Pydoc, Markdown
  - Maintained/collected in GitHub Pages
- REST API Testing: Postman
- Containerization: Docker, Docker Compose
- Issue Tracking: GitHub

Hardware:

- Windows machines for testing power monitoring functionality

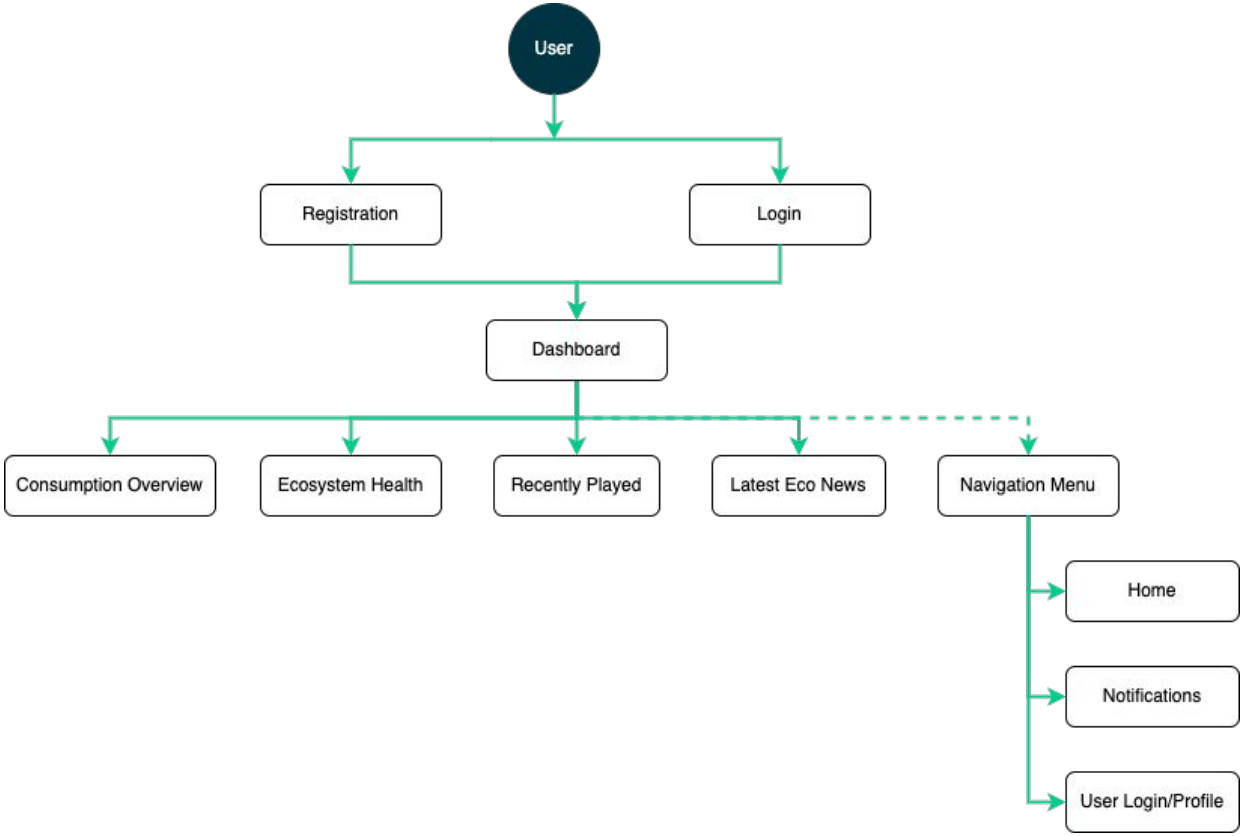
RWP vs. Prototype

Feature	RWP	Prototype	Prototype Actual
GUI layer	X	X	X
Hardware monitoring (GPU + CPU wattage)	X	X	X
Anonymized telemetry collection	X	partial	partial
Push Notifications	X	X	
Regional electric grid monitoring	X	X	X
Remote storage of anonymized telemetry	X		
Research API	X	partial	partial
Electricity cost estimates	X	X	
Environmental/gaming news feeds	X	X	X
User profile	X	partial	partial
User login	X		partial

RWP vs. Prototype (cont.)

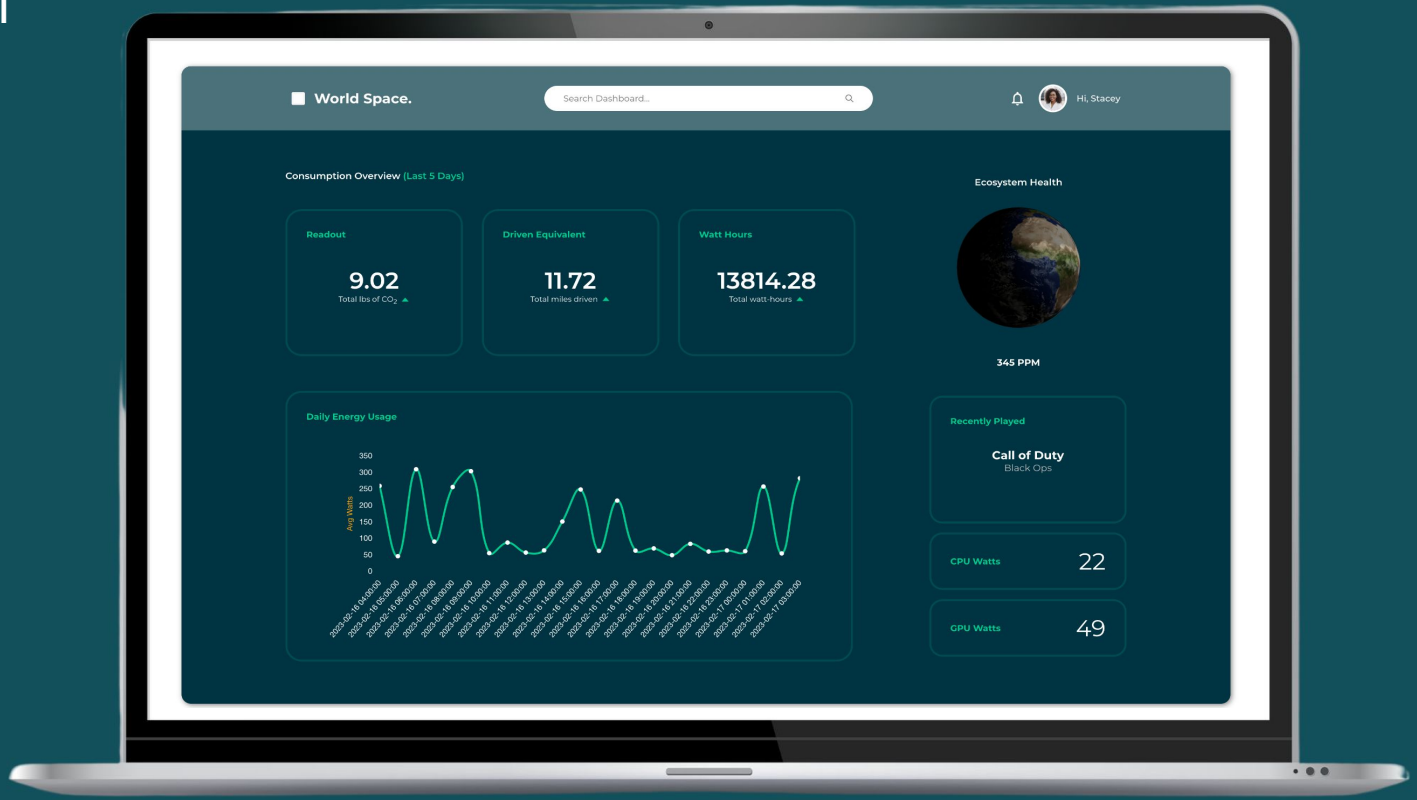
Feature	RWP	Prototype	Prototype Actual
Gamification	X	partial	partial
Seasonal progression/”battle pass” - style unlocks	X	partial	
Fully interactive personal ecosystems	X	partial	partial
Achievement/bounty system	X	X	
Virtual currency system	X		
In-app “storefront” for item unlocks/personalization	X	partial	
Social features	X		
Add friends	X		
Achievement leaderboard	X		
Visit other users’ ecosystems	X		
Share achievements	X		

GUI Sitemap


User
Registration
Login
Dashboard
Consumption Overview
Ecosystem Health
Recently Played
Latest Eco News
Navigation Menu
Home
Notifications
User Login/Profile

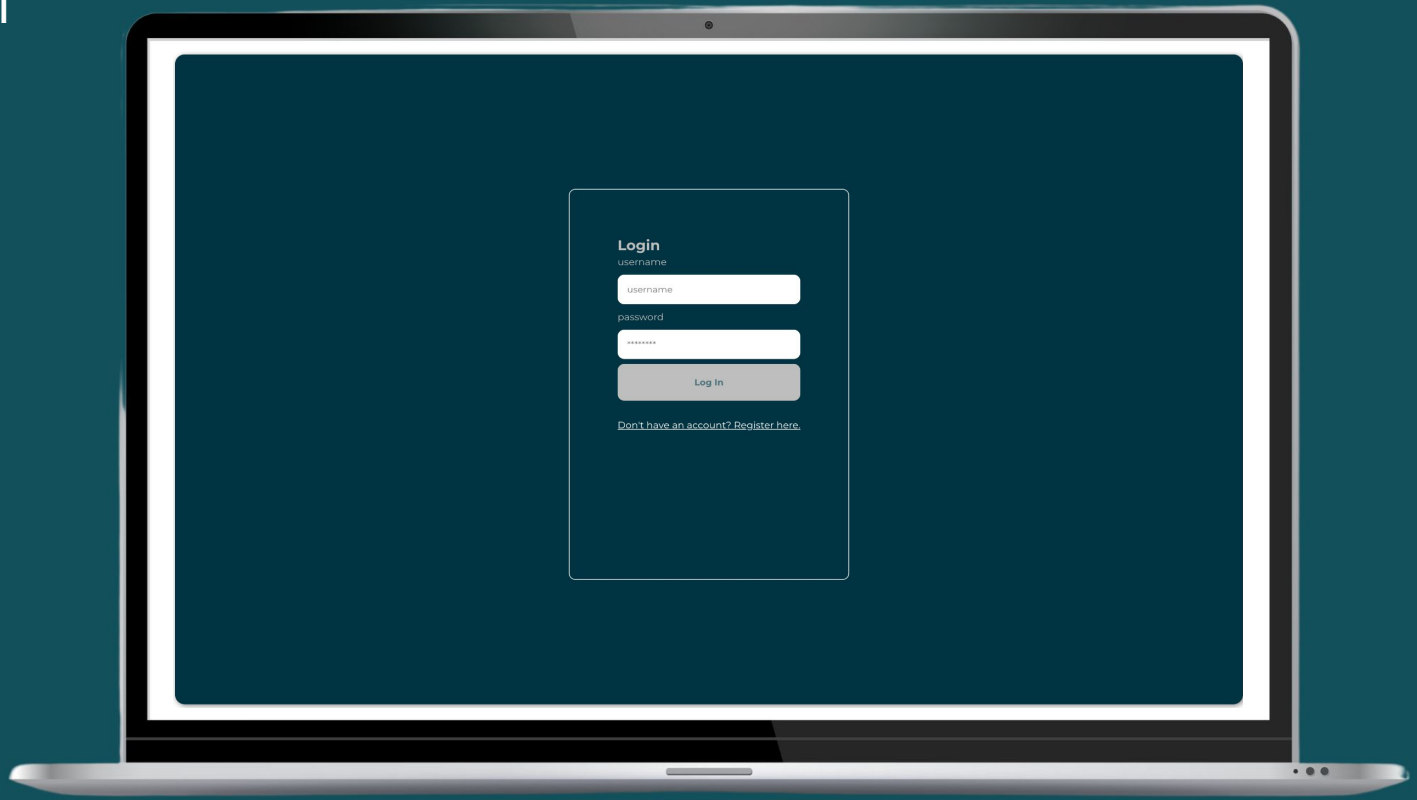
World Space GUI

Dashboard



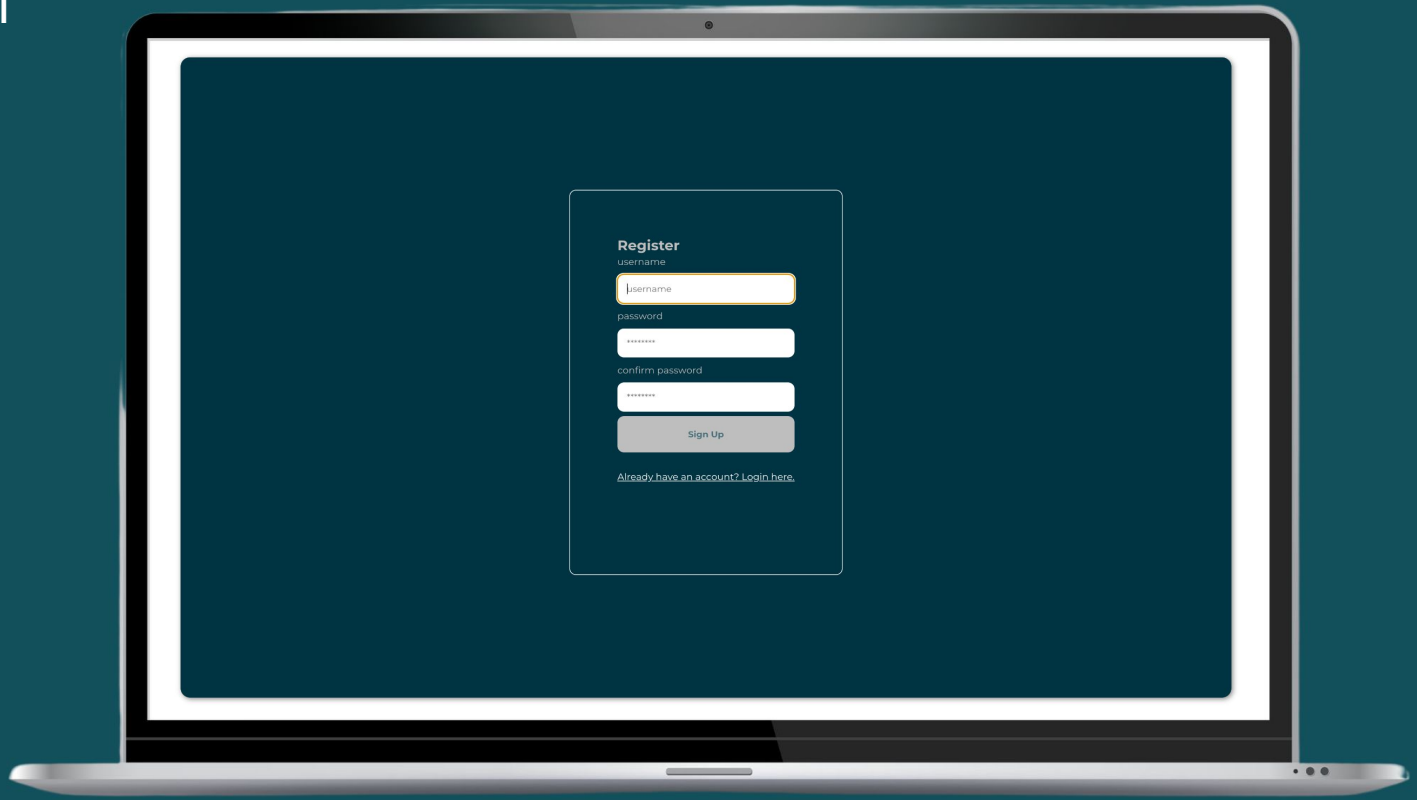
World Space GUI

Login Page



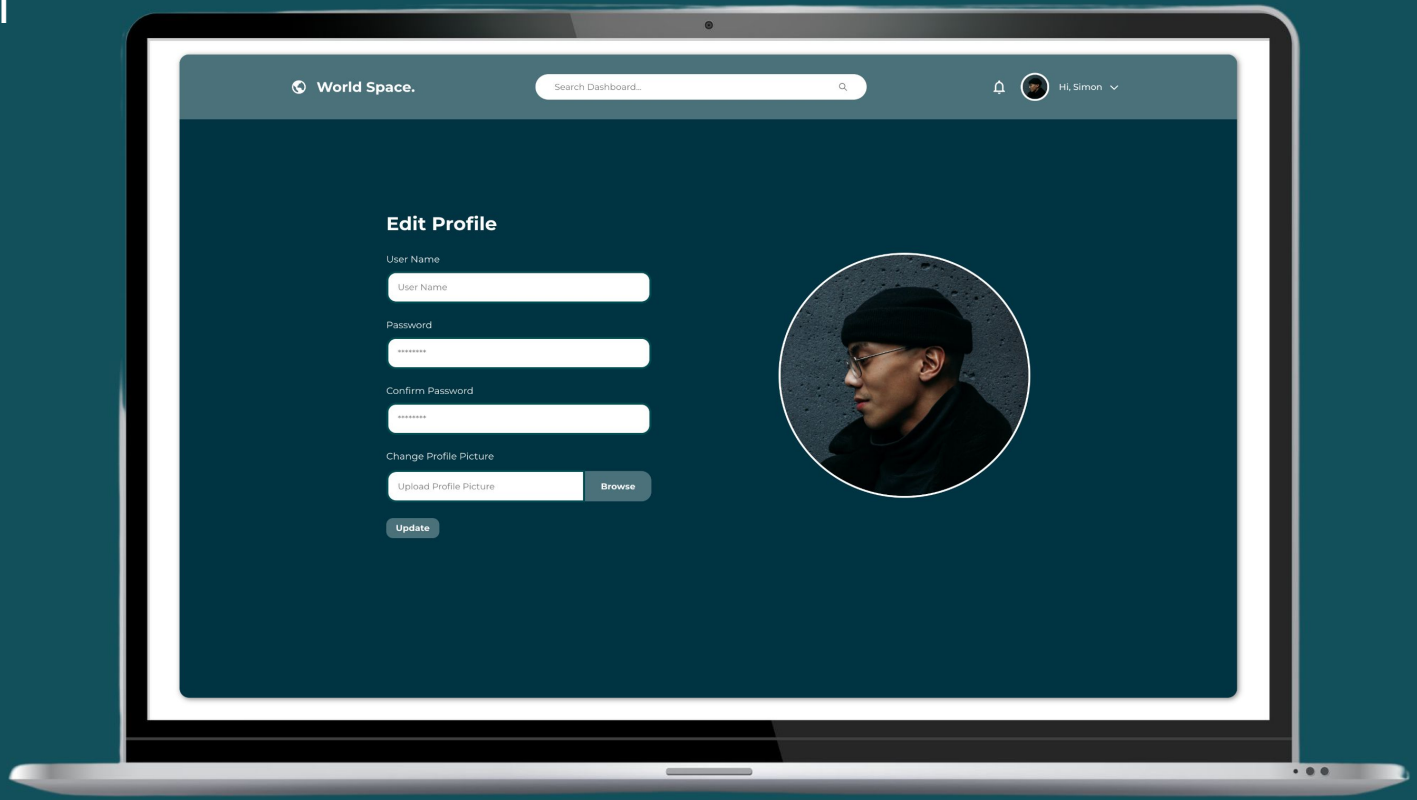
World Space GUI

Registration Page



World Space GUI

Profile Page



World Space GUI

News Page

Game World GUI

Conclusion

- Enthusiast personal computing an area ripe for emissions cuts
- Individual behaviors make an impact, but too many barriers to action
- Software can help engage and educate users, providing personalized, meaningful calls to action

Prototype Demonstration

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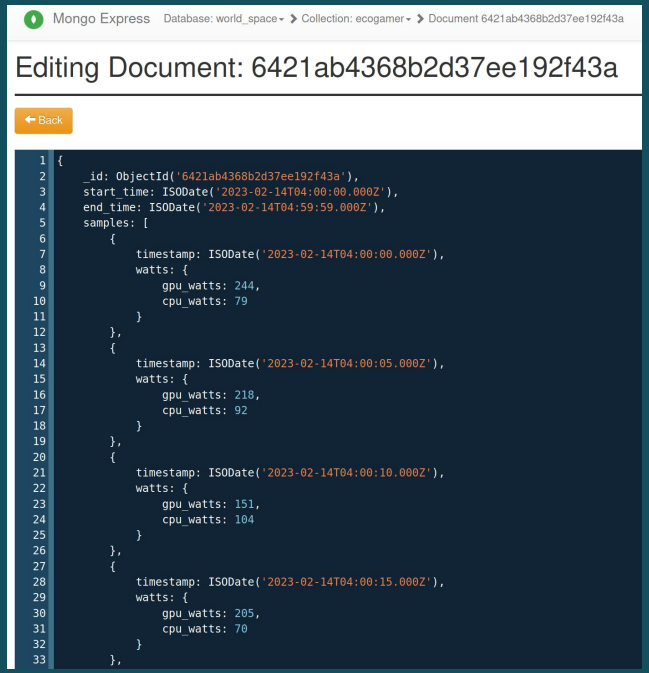
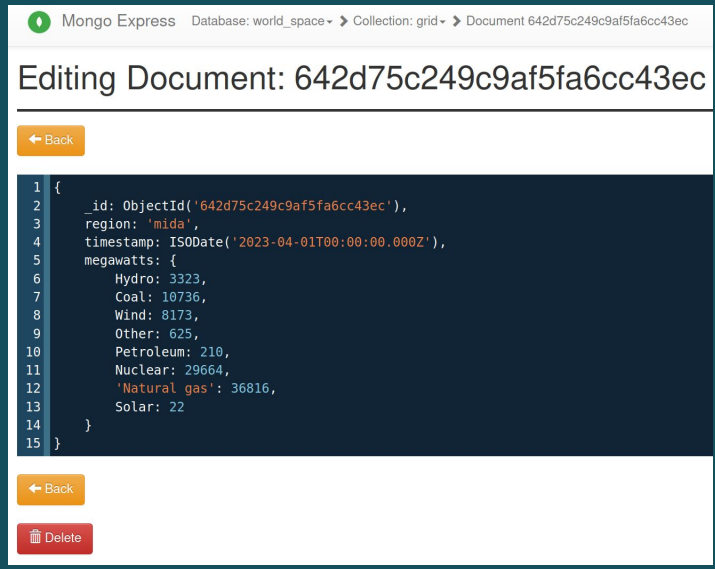
Prototype Data Management: IOT-Style Sample Collection Using Bucket Pattern in MongoDB

User samples stored in hourly ‘buckets’



Grid data grouped to align with user samples



Appendix

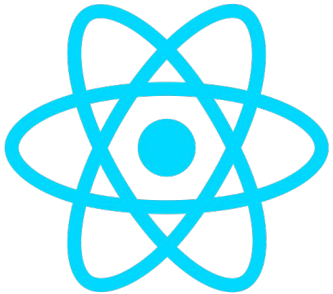
Competition

	COMPETITIVE ANALYSIS MATRIX					
	Does not require external hardware (e.g. smartplugs)	Collect full PC wattage estimates	Collects whole PC wattage estimates that adjust in real time	Gives guidance on when clean energy is being utilized	Focus on PC rigs	Use gamification to entice users to continue good habits
HWMonitor	✔				✔	
HWinfo64	✔				✔	
Outervision.com	✔	✔			✔	
Ohmplug		✔	✔	✔		
Us	✔	✔	✔	✔	✔	✔

Tech Stack: Native Desktop + Companion Mobile Applications

Languages/Frameworks:

- C# (backend)
- React.js
- Unity game engine



Database (Local):

- MongoDB (NoSQL)

Tech Stack: REST API/Remote Database

Languages:

- Java
- Python (web scraping, data manipulation)

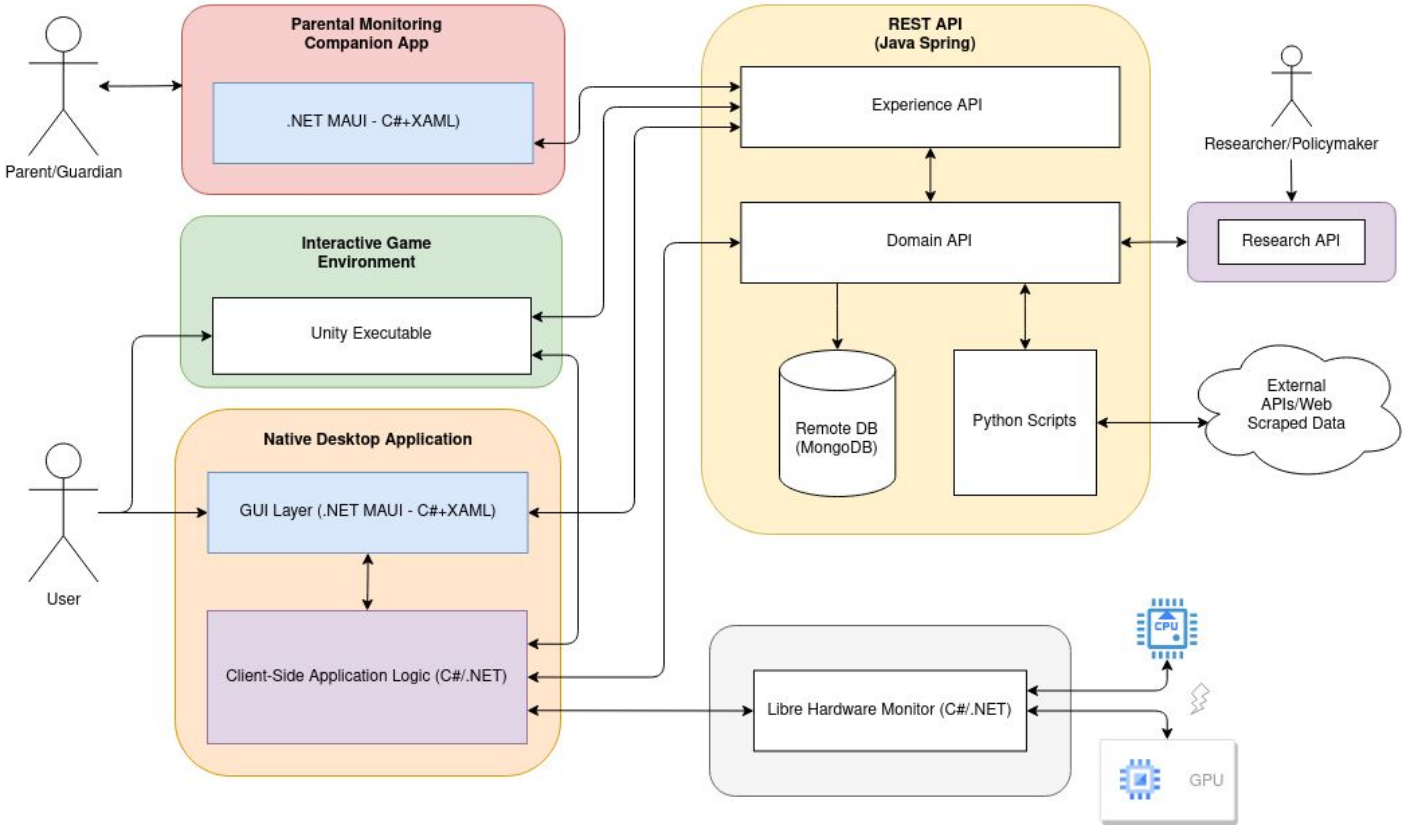
Framework:

- Spring

Database:

- MongoDB (NoSQL)

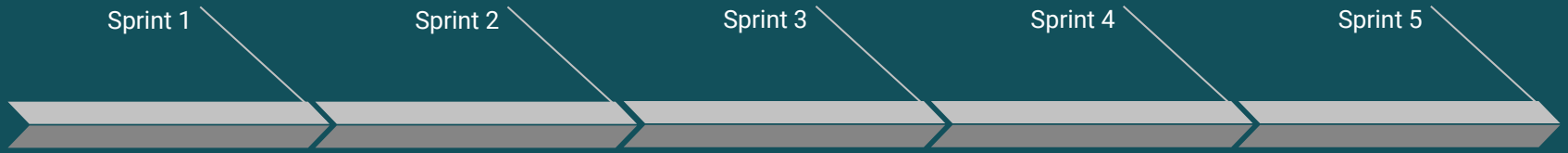
Major Functional Component Diagram



Indirect Competition

- CodeCarbon
  - For software developers
  - Open-source
- Green Algorithms
  - Shows estimated carbon footprint based on runtime of an algorithm and hardware info such as:
    - Type of core (CPU or GPU)
    - Number of cores
    - Model
    - Available memory
    - Platform (PC, cloud computing, or local server)
    - Geographic location

Prototype Agile Development Roadmap



1/9 - 1/20

- Setup environment / initial build configurations / documentation
- Setup database
- Begin implementing front-end functionality (navbar, essential components, etc.)

1/23 - 2/3

- Implement logic for retrieving grid data from third-party API
- Set up hardware monitoring logic
- Data mocking for GUI
- Iterate on GUI (site map, button hookups, display of some data)

2/6 - 2/17

- Implement logic for automating data storage
- Begin implementing domain API layer
- Begin implementing experience API layer
- Begin data visualization in GUI

2/20 - 3/3

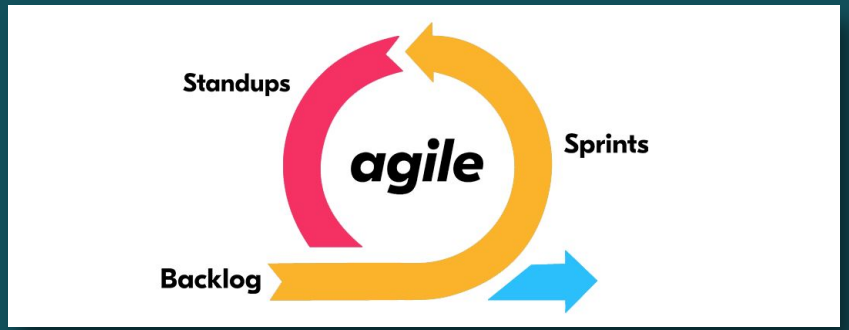
- Begin adding gamification logic to experience and domain API layers (XP progression, unlocks)
- Add basic GUI components to display game state logic
- Iterate on GUI (tiling, feeds, graphs)

3/13 - 3/24

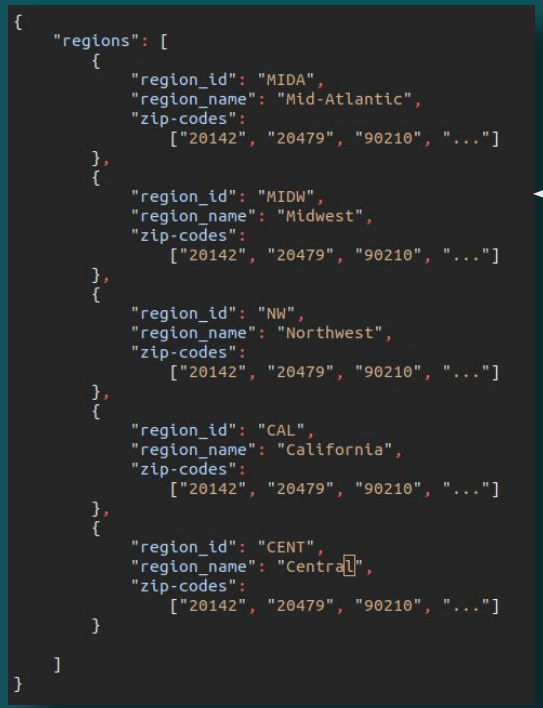
- Implement basic achievement system
- Add user profile/login system
- Interoperability between game progression and separate ‘game world’ executable
- Refinements across GUI and API
- RSS feeds

Development Model

- Divide work into manageable tasks
- Emphasize iteration on core functionality
- Quickly adapt to shifting project requirements



Database Design: Grid Monitoring



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        },
        {
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                ["20142", "20479", "90210", "..."]
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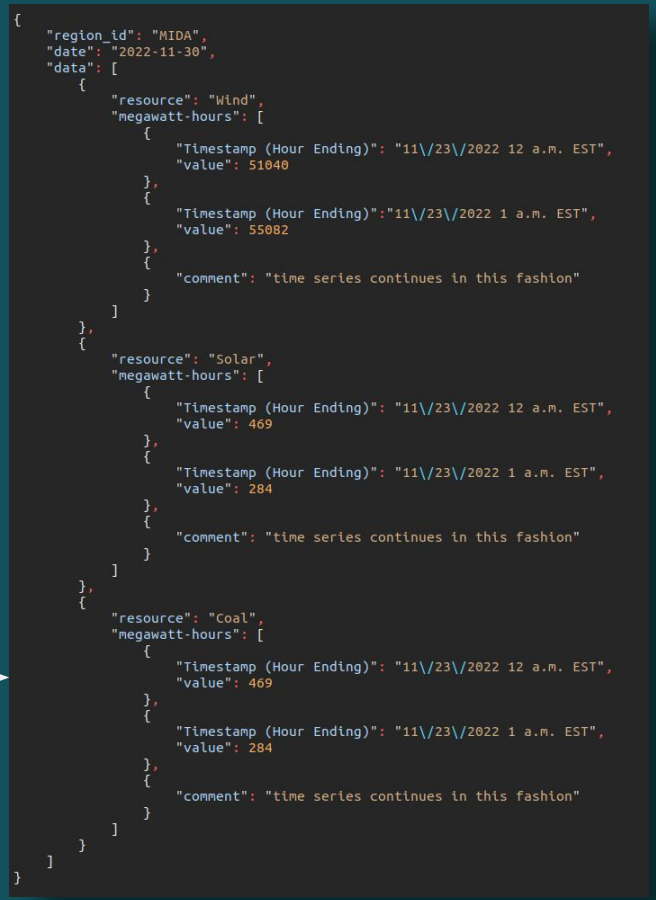
        }

    ]
}
```

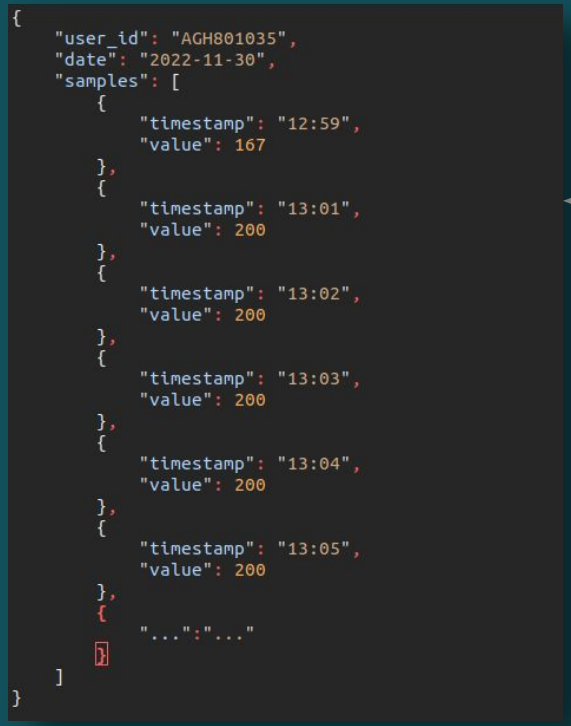
Evergreen region information for assessing user's location.

Generation by resource type banked by day for each region.



```
{
    "region_id": "MIDA",
    "date": "2022-11-30",
    "data": [
        {
            "resource": "Wind",
            "megawatt-hours": [
                {
                    "Timestamp (Hour Ending)": "11\/23\/2022 12 a.m. EST",
                    "value": 51040
                },
                {
                    "Timestamp (Hour Ending)":"11\/23\/2022 1 a.m. EST",
                    "value": 55082
                },
                {
                    "comment": "time series continues in this fashion"
                }
            ]
        },
        {
            "resource": "Solar",
            "megawatt-hours": [
                {
                    "Timestamp (Hour Ending)": "11\/23\/2022 12 a.m. EST",
                    "value": 469
                },
                {
                    "Timestamp (Hour Ending)": "11\/23\/2022 1 a.m. EST",
                    "value": 284
                },
                {
                    "comment": "time series continues in this fashion"
                }
            ]
        },
        {
            "resource": "Coal",
            "megawatt-hours": [
                {
                    "Timestamp (Hour Ending)": "11\/23\/2022 12 a.m. EST",
                    "value": 469
                },
                {
                    "Timestamp (Hour Ending)": "11\/23\/2022 1 a.m. EST",
                    "value": 284
                },
                {
                    "comment": "time series continues in this fashion"
                }
            ]
        }
    ]
}
```

Database Design: User Data



Wattage readings sampled at regular intervals, grouped by date.

User progression, customization, and game state information.

Customer Risks

C1: Difficult to engage users on environmental focus

Mitigation:

- Appeal to users with game-like experiences and reward loops
- Make free to use, leverage curiosity gap

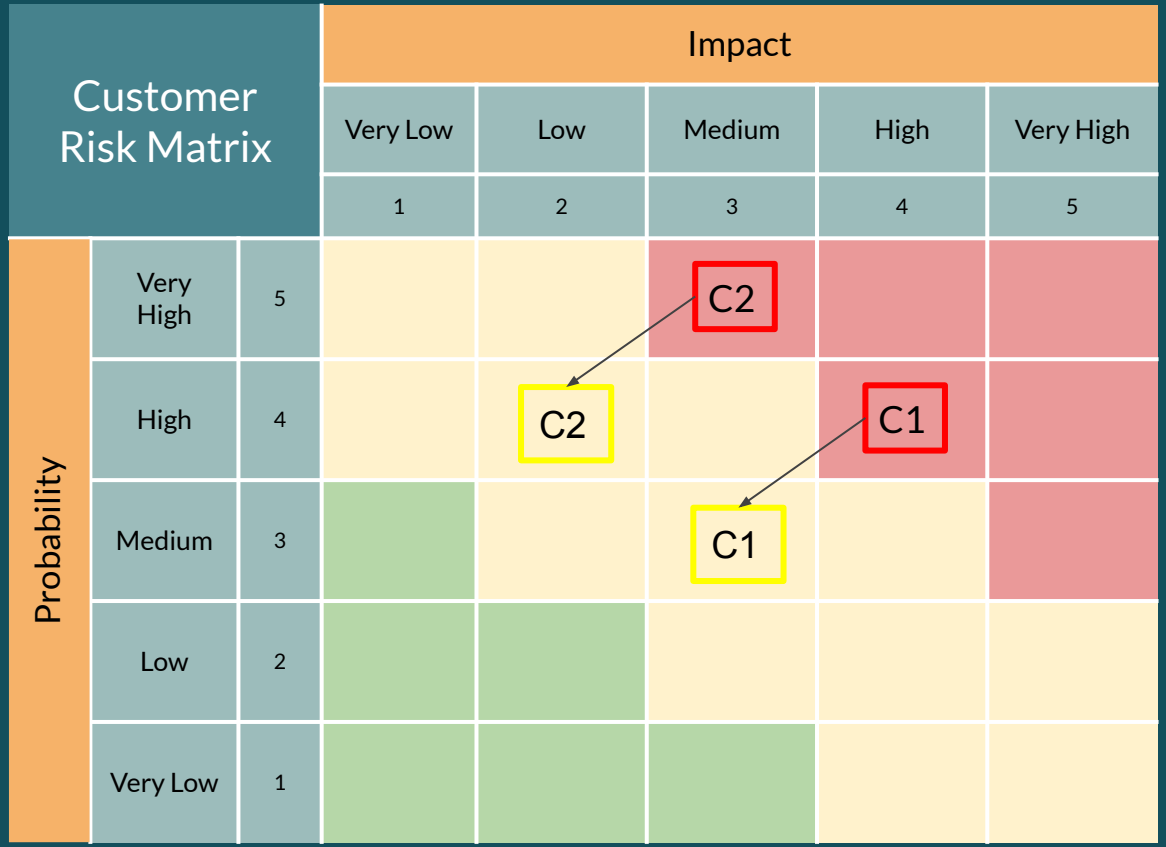
INITIAL: HIGH -> MITIGATED: MEDIUM

C2: Difficult to keep users engaged – core functionality may not promote continued use

Mitigation:

- Offer unlockable rewards for progression over time
- Structure rewards around repeatable achievement streaks
- Incorporate social features (leaderboards, achievement sharing, etc)

INITIAL: HIGH -> MITIGATED: MEDIUM



Technical Risks

T1: Security threats to user data

Mitigation:

- Follow industry best practices for encryption in transit and at rest
- Anonymize hardware configuration data stored remotely

INITIAL: HIGH -> MITIGATED: LOW

T2: Reliance on third-party APIs for data

Mitigation:

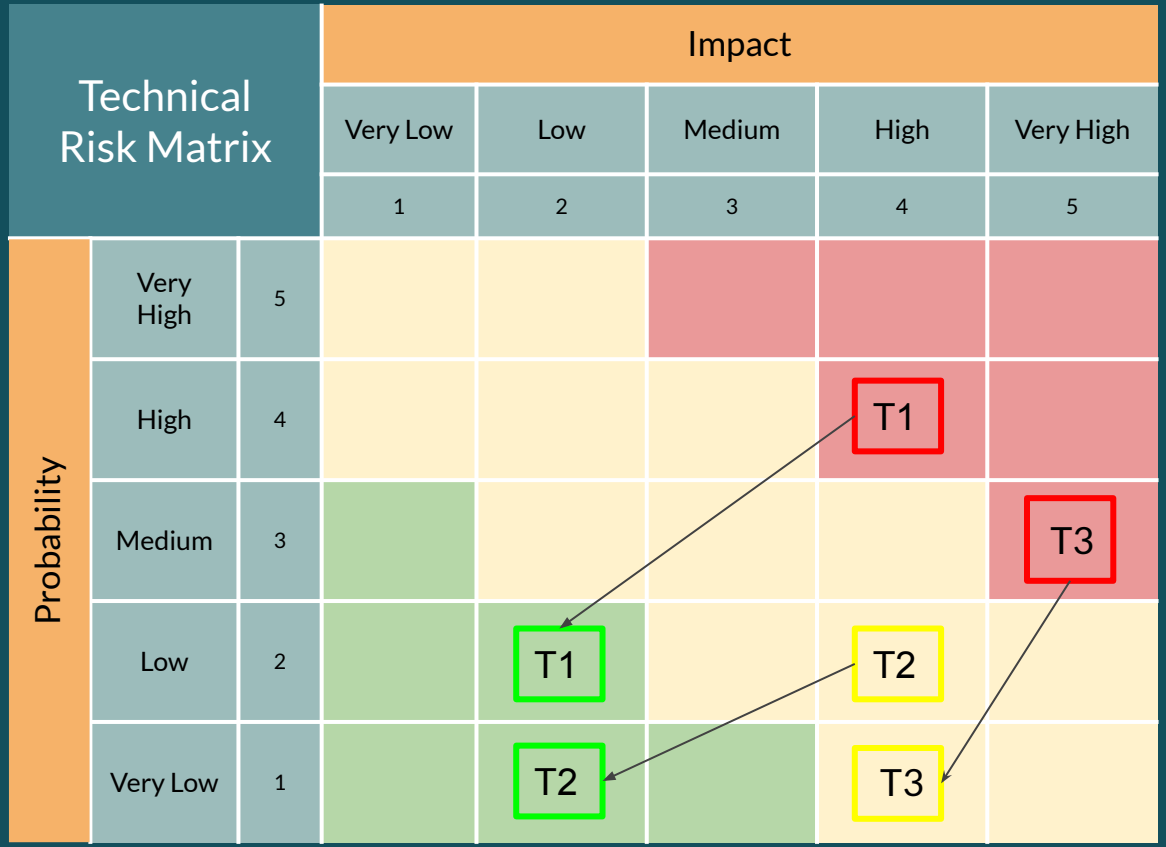
- Use government sources
- Make methodology resilient to temporary service interruptions (e.g. bank historical data to feed projections)

INITIAL: MEDIUM -> MITIGATED: LOW

T3: Accuracy of data/estimates

- Engage third-party subject matter experts (e.g. academics) to vet methodologies

INITIAL: HIGH -> MITIGATED: LOW



Legal Risks

L1: Challenges from hardware and software makers to application data/recommendations

Mitigation:

- Base all recommendations on established methodologies for measuring carbon intensity
- Only use information from reliable, well-established third parties such as NASA, IPCC, EPA
- Publish methodologies to address any perceived bias

INITIAL: HIGH -> MITIGATED: MEDIUM

L2: Compromise of user data/privacy

Mitigation:

- Limit collection/storage of potentially sensitive information from users
- Follow industry best practices for handling personal data
- Authenticate through third-party platforms for social features

INITIAL: HIGH -> MITIGATED: LOW