

Software Requirements Specification for Software Engineering: subtitle describing software

Team 4, EcoOptimizers

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Revision History

Date	Version	Notes
October 11th, 2024	0	Created initial revision of SRS

1 Purpose of the Project

1.1 User Business

The Information and Communications Technology (ICT) sector, an essential component of the global economy, is responsible for 2-4% of global CO2 emissions today, with projections suggesting this could rise to 14% by 2040 ([Belkhir and Elmeligi, 2018](#)). To meet sustainability goals, including a 72% reduction in CO2 emissions by 2040 ([Freitag and Berners-Lee, 2021](#)), this sector must find ways to improve energy efficiency.

One area of concern is the energy consumption of software systems. However, for software engineers, it is not practical for them to focus on optimizing energy consumption while developing complex programs. Instead, supporting tools and technologies are needed to assist in improving energy efficiency without altering the intended behaviour of the software.

This project aims to tackle Python, a popular but energy inefficient programming language. Python consumes significantly more energy compared to more efficient languages like C and Rust—over 70 times more energy, on average, for similar tasks ([Pereira et al., 2017](#)). The project’s goal is to develop tools to reduce Python’s energy consumption through automated refactoring. While this will not solve the entire problem of the carbon footprint associated with the software, it is a step towards more energy-efficient practices in the software development process.

1.2 Goals of the Project

Purpose: The purpose of this project is to provide software engineers with tools to optimize the energy efficiency of Python programs by automating refactoring suggestions, while still allowing users to review and decide whether to apply the changes.

Advantage: By reducing the energy consumption of Python programs, this project will contribute to the broader effort of decreasing the carbon footprint of software development, supporting the ICT sector’s goal of reducing CO2 emissions by 72% by 2040 ([Freitag and Berners-Lee, 2021](#)).

Measurement: The project’s success can be measured by the reduction in energy usage achieved after applying the refactorings. Benchmarks will compare the energy consumption of original and refactored code, to achieve a measurable percentage reduction in energy consumption. The user’s ability to make informed choices about whether to apply refactorings will also be evaluated through user feedback.

2 Stakeholders

The stakeholders involved in this project include all individuals and groups that have a direct or indirect interest in the development, implementation, and usage of the refactoring library for energy efficiency. These stakeholders influence project decisions and will be impacted by their outcomes. Understanding their roles and expectations is crucial for ensuring that the library meets the needs of its users and aligns with broader organizational goals.

This section introduces the **client**, **customer**, and **other stakeholders** that are involved in the project. Finally, we will look at the users of the product, specifically the **hands-on-users**, what their **personas** may look like, their **priority** levels, and what kind of **participation** we can expect from them throughout the development of this product.

2.1 Client

The client of this project is **Dr. Istvan David** from McMaster's Department of Computing and Software. As the project supervisor, his role is to guide the development team with his technical and domain expertise. As the client, he sets the product's requirements and will be involved throughout its development.

2.2 Customer

The customers of this product are all the **software developers** that use it to improve the energy efficiency of their codebase. As members of corporations or independent workers, they will be the primary users of the product and, therefore, will offer critical feedback on its effectiveness. Suggestions for improvement and/or additional features may come from this stakeholder.

2.3 Other Stakeholders

Project Managers

They oversee project operations and focus on reducing energy costs associated with large-scale or cloud-hosted applications. They might leverage the refactoring library to reduce operational costs and achieve business sustainability goals.

Business Sustainability Teams

This stakeholder is responsible for reducing the company's environmental footprint by analyzing its energy emissions. They will use the energy efficiency metrics provided by the refactoring library to improve environmental sustainability practices within their organization.

End Users

End users refer to the users of software that uses the product in its development. They will indirectly reap benefits from these applications that have been optimized using the refactoring library. Software used, especially mobile or embedded environments where battery life is a key concern, might prove to be more responsive and efficient. They have no involvement in the development of the product.

Regulatory Bodies

This stakeholder is responsible for establishing regulations governing energy consumption and sustainability standards. They can promote the adoption of energy-efficient software practices and potentially certify tools that meet regulatory standards.

2.4 Hands-On Users of the Project

Software Developers

- **User Role:** Integrate library into the codebase, provide tests to check refactoring against original functionality
- **Subject Matter Experience:** Journeyman to Master
- **Technological Experience:** Journeyman to Master
- **Attitude toward technology:** Varies (conservative to positive)
- **Physical location:** Remote (at home), in-person (work office) or hybrid

Business Sustainability Teams

- **User Role:** Access metrics provided by library
- **Subject Matter Experience:** Journeyman
- **Technological Experience:** Novice to Journeyman
- **Attitude toward technology:** Neutral to positive

2.5 Personas

Persona: Raven Reyes

Age: 37

Job Title: Senior Software Developer

Education: Bachelor's in Computer Science

Work Environment: Works at a mid-sized SaaS company with a focus on improving their environmental footprint.

Professional Background: Has over 15 years of experience in software development, specializing in backend systems. Worked with various programming languages (Python, Java, and C++), and is well-versed in optimizing code for performance.

Need: With the company more focused on sustainability, Raven and her team need to go through their codebase and apply energy efficient changes to their code.

Challenges: Knowing what to change in their code to make it more efficient is challenging, not to mention the incredible amount of code they will have to sift through. We are talking hundreds of thousands of lines of code!

Persona: Christopher Robin

Age: 34

Job Title: Data Analyst

Education: Bachelor's in Data Science

Work Environment: Works at a large corporation that has recently started increasing their efforts to become a sustainable company.

Professional Background: Over 8 years of experience in data analysis, just recently looking into sustainability metrics. Christopher regularly collaborates with IT teams to track performance metrics and recently energy consumption metrics to help identify areas for improvement.

Need: Christopher needs accurate data on energy consumption from the company's software systems to generate insights that drive sustainability initiatives and help meet corporate environmental targets.

Challenges: Translating raw technical data into meaningful insights that can guide decisions is difficult, especially when working with complex systems.

Persona: Draco Malfoy

Age: 29

Job Title: Freelance Software Developer

Education: Bachelor's in Software Engineering

Work Environment: Works remotely on multiple freelance projects for small and mid-sized businesses, focusing on web applications and backend systems.

Professional Background: Has 7 years of experience working with various clients to develop and optimize software, primarily in Python and JavaScript. He often works on tight deadlines, where balancing performance and development speed is key.

Need: Draco needs efficient ways to optimize the code he writes for clients, particularly in terms of performance and energy efficiency, as more businesses become environmentally conscious.

Challenges: As a freelancer, time is money. Draco needs tools that help him quickly identify inefficiencies in the code and refactor them, without spending hours analyzing large codebases or learning new systems.

2.6 Priorities Assigned to Users

Key Users: Software Developers, Business Sustainability Teams

Secondary User: Project Managers

2.7 User Participation

For the bulk of the development process, requirements will be gathered from the development team itself with the help of the project supervisor, Dr. Istvan David.

During the testing phase, usability testing will be conducted to further refine the product.

2.8 Maintenance Users and Service Technicians

Due to the nature of this project as a capstone requirement, there are currently no expected maintenance users.

3 Mandated Constraints

3.1 Solution Constraints

MD-SL 1. *The system must refactor Python code without changing its original functionality.*

Rationale: The project is focused on energy-efficient refactoring for Python code, and altering functionality could break existing software behaviour.

Fit Criterion: The system must pass all original test cases after refactoring, ensuring that functionality remains unchanged.

Priority: High

MD-SL 2. *The refactored code must result in measurable energy savings.*

Rationale: The project's primary objective is to improve the code's energy efficiency. Refactorings should lead to a noticeable reduction in energy consumption.

Fit Criterion: The system must show at least a 5% reduction in energy consumption, as measured by tools like PyJoules, for most of the refactored code.

Priority: High

MD-SL 3. *The refactored code must be provided to the user upon completion of the refactoring process.*

Rationale: Developers need access to the refactored code to utilize it in their projects immediately after the refactoring process.

Fit Criterion: The system must deliver the refactored code to the user in a clear format, ensuring it is readily available for implementation.

Priority: High

3.2 Implementation Environment of the Current System

MD-EC 1. *The product shall be able to run on standard laptop environments, including typical developer setups with operating systems such as Windows, macOS, and Linux.*

Rationale: Developers will primarily use the tool on personal workstations, including laptops, and it must integrate smoothly with typical development environments. Supporting standard laptop environments ensures that the tool is accessible to a wide range of users without the need for specialized hardware.

Fit Criterion: The tool must be installable and functional on a standard laptop with commonly used IDEs (such as Visual Studio Code) and tools like GitHub for version control. It should perform well without requiring excessive processing power or memory.

Priority: High

3.3 Partner or Collaborative Applications

The project will focus on developing the tool with flexibility for potential integration with applications like GitHub Actions and Visual Studio Code. While no specific partner applications are required, understanding these possibilities can aid smoother integration. Future collaboration with CI/CD services or Python development tools may be considered, but no formal interface constraints are needed at this stage.

3.4 Off-the-Shelf Software

The project has no strict requirements for off-the-shelf software but will leverage open-source libraries to enhance functionality and maintain flexibility. Tools like PyJoules for energy measurement and Python analysis libraries may be used. While no legal issues are expected, all tools will be assessed for compatibility. Documentation will be maintained, though no specific constraints are set at this stage.

3.5 Anticipated Workplace Environment

The workplace will include standard software development setups with IDEs, version control (e.g., GitHub), and collaboration tools. The tool should integrate smoothly into workflows, offering a non-intrusive interface suited for quiet workspaces and providing quick feedback in collaborative environments. Accessibility to online resources and collaboration tools will be considered, ensuring the tool functions well in diverse settings. A description of the typical workplace, possibly with diagrams, will be provided.

3.6 Schedule Constraints

SCHD 1. *The project shall be completed by April 2025, with interim deadlines for key milestones such as Proof of Concept (November 2024) and the final demonstration (March 2025).*

Rationale: These deadlines are based on the academic timeline and the expectations of the capstone course.

Fit Criterion: All project components must be completed and fully functional by the final demonstration in March 2025.

Priority: High

3.7 Budget Constraints

BDGT 1. *The project shall not exceed the resources available to the team, which includes free open-source software and free services like GitHub for hosting and CI/CD pipelines.*

Rationale: The team does not have a budget for paid services or proprietary software.

Fit Criterion: The project must be implemented using free tools and libraries

and hosted on GitHub.

Priority: High

3.8 Enterprise Constraints

ENTP 1. *The product shall be built to comply with the standards of McMaster University's capstone project requirements and academic integrity policies.*

Rationale: The project is part of the university's curriculum and must adhere to its standards.

Fit Criterion: The product must meet the requirements specified by the course syllabus and project advisor.

Priority: High

4 Naming Conventions and Terminology

4.1 Glossary of All Terms, Including Acronyms, Used by Stakeholders involved in the Project

supervisor A member of faculty from McMaster University responsible for overseeing a project being worked on by students taking the SFWRENG 4G06 Capstone course.

large-scale applications Applications that manage high volumes of data, users, or transactions, typically requiring scalable architectures.

cloud-hosted applications Software applications deployed and run on remote cloud servers, accessible over the internet.

environmental footprint The total impact an activity or product has on the environment, measured by metrics like carbon emissions and resource consumption.

refactoring The process of restructuring existing code without changing its external behaviour to improve readability, performance, or maintainability.

mobile environment A software environment specifically designed for mobile devices, such as smartphones or tablets, which have limited resources.

embedded environment A software environment where applications run on specialized hardware with constrained resources, often without traditional operating systems.

SaaS Software as a Service (SaaS) refers to cloud-based software applications delivered to users via the internet on a subscription basis.

backend The part of a software system that handles server-side logic, database interactions, and application functionality not directly visible to users.

software developer A professional who designs, writes, and maintains software applications or systems.

data analyst A professional who processes and analyzes large sets of data to help organizations make informed decisions.

tech company A company focused on technology products and services, including software, hardware, and IT services.

freelance Self-employed individuals who offer specialized services, such as software development, without long-term commitments to any employer.

usability testing A method of evaluating how easy and user-friendly a software application or product is by observing real users interacting with it.

Python Code Refers to the original Python code given by the end user to refactor.

Refactored Code Refers to the Python code that had refactorings made to it.

library A collection of pre-written code that developers can reuse in their projects to add specific functionalities.

Git A distributed version control system that allows multiple developers to track changes in source code, collaborate, and manage project history efficiently.

GitHub A web-based platform used for version control and collaboration on code through [Git](#) repositories.

Actions A [GitHub](#) feature that automates tasks such as testing, deployment, and continuous integration via custom workflows.

workflow A sequence of automated steps or actions that define a process, often for continuous integration, deployment, or testing.

Visual Studio Code A free, open-source code editor developed by Microsoft, known for its versatility and wide range of extensions.

VS Code An abbreviation of [Visual Studio Code](#)

Visual Studio Code (VS Code) marketplace An online platform where users can discover, install, and manage extensions that enhance the functionality of [Visual Studio Code](#).

JSON [JavaScript](#) Object Notation, a lightweight data format used to store and exchange information between systems.

XML Extensible Markup Language, a data format used to encode documents in a way that is both human-readable and machine-readable.

package manager A tool that automates the process of installing, updating, and managing software packages or libraries in a project.

PIP A package manager for [Python](#) that simplifies the installation and management of Python libraries.

IDE Integrated Development Environment, a software application providing tools like a code editor, debugger, and compiler to facilitate development.

progress indicators Visual or textual cues, such as loading bars or percentages, that inform users about the status of ongoing processes.

plugin A software component that adds specific features or functionalities to an existing software system.

configuration file A file used to define settings or preferences for a software application, often stored in a human-readable format like [JSON](#) or [XML](#).

dashboard A user interface that provides an overview of key information and metrics, typically presented in graphs, charts, and tables.

sync The process of ensuring that data is consistent across multiple systems or devices by automatically updating changes in real-time.

programming language A formal language used to write software programs by providing instructions that a computer can execute.

Python A [programming language](#) known for its simplicity and versatility, widely used in web development, data science, and automation.

Java A [programming language](#) known for its portability and scalability, commonly used for enterprise-level applications.

C/C++ A [programming language](#) family used for system programming, game development, and applications requiring high performance.

C# A [programming language](#) developed by Microsoft, primarily used for developing applications on the .NET platform.

JavaScript A [programming language](#) used primarily for adding interactivity to web pages and building dynamic web applications.

TypeScript A [programming language](#) that builds on JavaScript by adding static typing, improving code reliability and scalability.

Go A [programming language](#) created by Google, designed for simplicity and efficiency in building scalable applications.

Rust A [programming language](#) focused on safety, performance, and concurrency, often used in system programming.

5 Relevant Facts And Assumptions

5.1 Relevant Facts

Not applicable to this system.

5.2 Business Rules

The following are some business rules established between the team.

1. **Project Timeline Adherence:** All milestones must be completed according to the established project timeline. Any delays or unexpected circumstances must be reported to the team as soon as possible.
2. **Pull Request Review Requirement:** All pull requests must receive at least two independent reviews before they can be merged into the main branch. Reviewers must provide feedback or approval within 48 hours of the request to ensure timely progress.
3. **Team Communication Standard:** All team members are required to communicate in a friendly and respectful manner during discussions, meetings, and in all written communications. Constructive feedback should be provided with the intent to support and enhance team collaboration.

5.3 Assumptions

It is assumed for this system that users will be seeking to refactor Python code and will make use of Visual Studio Code.

6 The Scope of the Work

6.1 The Current Situation

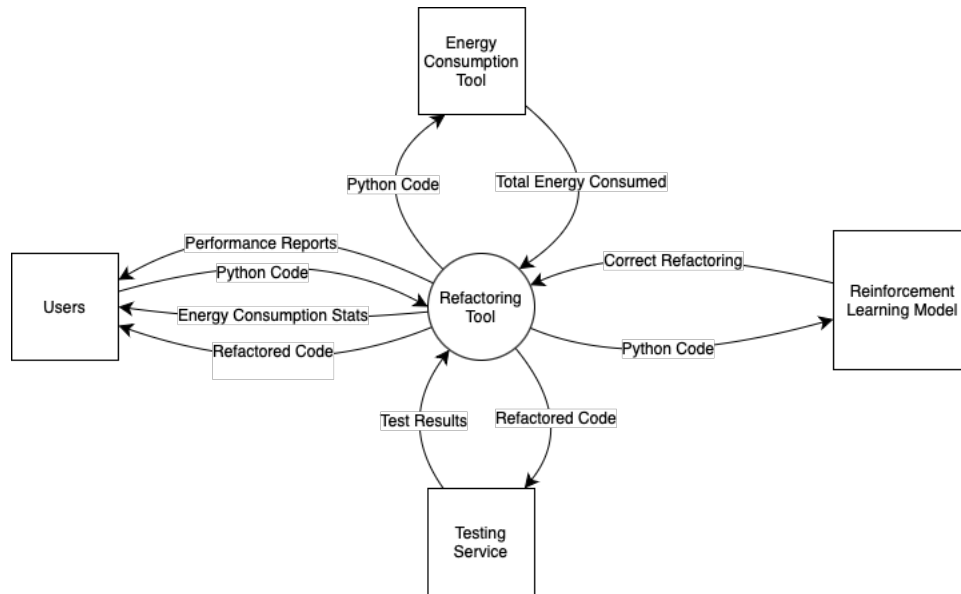
The current software development landscape often prioritizes functionality and performance over energy efficiency. Many existing Python codebases are not optimized for energy consumption, leading to unnecessary power usage and increased carbon footprint. The following aspects characterize the current situation:

1. **Manual Refactoring:** Developers typically perform refactoring manually, which is time-consuming and prone to errors.
2. **Limited Awareness:** Many developers lack awareness of energy-efficient coding practices and their impact on overall energy consumption.
3. **Absence of Automated Tools:** There is a lack of widely adopted automated tools specifically designed to refactor Python code for energy efficiency.
4. **Performance-Centric Optimization:** Most existing optimization tools focus on performance improvements rather than energy efficiency.
5. **Inefficient Code Patterns:** Many codebases contain inefficient code patterns that consume more energy than necessary.

The project aims to address these issues by:

1. **Automated Refactoring Library:** Developing a Python library that automatically detects and refactors code for improved energy efficiency.
2. **IDE Integration:** Creating a Visual Studio Code plugin that integrates the refactoring library, providing real-time suggestions and automated refactoring options.
3. **Energy Consumption Measurement:** Implementing tools to measure and compare energy consumption before and after refactoring.
4. **Developer Education:** Raising awareness about energy-efficient coding practices through the tool's suggestions and documentation.
5. **Continuous Improvement:** Implementing a reinforcement learning model to improve refactoring suggestions over time based on developer feedback and real-world energy savings data.

6.2 The Context of the Work



6.3 Work Partitioning

Event #	Event Name	Input	Output(s)
1	Users submit Python code	Python Code	Refactored Code
2	Energy Analysis of code	Python Code	Total Energy Consumed
3	RI Model produces refactoring	Python Code	Correct Refactoring
4	Testing and Validation of refactored code	Refactored Code	Test Results
5	Reporting Performance metrics of new code	Refactored Code	Performance Reports
6	Viewing Energy consumption reports	Refactored Code	Energy Consumption Statistics

6.4 Specifying a Business Use Case (BUC)

BUC 1: Code Submission

Input: Python Code

Output: Refactored Code

Pre-condition: User uses either GitHub Action or a VS Code plugin to submit code to the refactoring tool

Scenario:

1. Refactoring tool receives the Python code
2. PyJoules is used to store energy consumption data for the original Python code submitted
3. Tool analyzes the code for inefficiencies (PySmells)
4. Python code is provided to the Re-enforcement learning model to find a refactoring
5. Energy consumption is measured of refactored code and compared to the original data
6. Refactored code is tested to ensure functionality is maintained from the original code
7. Refactored code is received by the user

Sub Variation:

- *4a:* If no PySmells are identified, then code is returned to the user
- *6a:* If energy consumption increases for refactored code, the reinforcement model is asked to find another refactoring
- *7a:* If code functionality is not preserved for refactored code, the reinforcement model is asked to find another refactoring

BUC 2: Energy Analysis of Code

Input: Python Code

Output: Total Energy Consumed

Pre-condition: Submission of Python code to the Energy Consumption Tool

Scenario:

1. Tool receives Python Code
2. Energy consumed is measured during execution
3. The analysis results are compiled into a report
4. Report of total energy consumed is received by the refactoring tool

BUC 3: Reinforcement Learning Model Produces Refactoring

Input: Python Code

Output: Correct Refactoring

Pre-condition: Request for refactored code from the Reinforcement Learning Model

Scenario:

1. Model receives Python Code
2. Analyze Code for potential refactoring
3. Generate suggestions based on previous learning and data

4. Implement suggested refactorings

Sub Variation:

- *2a*: If there are no refactorings found, Model outputs are given code back to the refactoring tool

BUC 4: Testing and Validation of Refactored Code

Input: Refactored Code

Output: Test Results

Pre-condition: Energy consumed for refactored code is less than the energy consumed for original code

Scenario:

1. Conduct tests on refactored code
2. Conduct tests on original code
3. Validate results of refactored code to the results of the original code to ensure functionality is intact
4. Signal to refactoring tool to send refactored code to the user

Sub Variation:

- *4a*: If functionality is not preserved, signal to the refactoring tool to refactor again

BUC 5: Reporting Performance Metrics of New Code

Input: Refactored Code

Output: Performance Reports

Pre-condition: Testing and validation is completed successfully

Scenario:

1. Generate detailed performance report based on testing outcomes
2. User receives the performance report

BUC 6: Viewing Energy Consumption Reports

Input: Refactored Code

Output: Energy Consumption Statistics

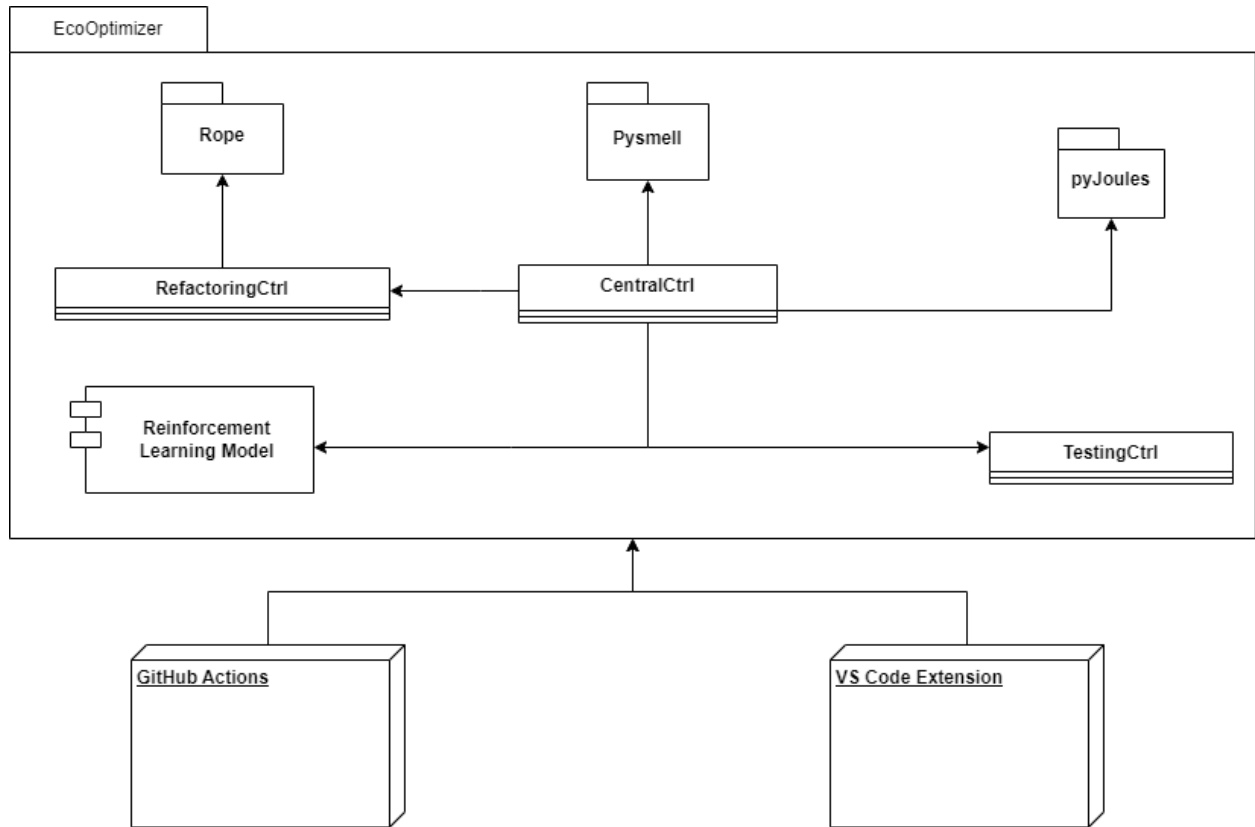
Pre-condition: Testing and validation is completed successfully

Scenario:

1. Comprehensive statistics are compiled from energy analysis data
2. Information is compiled in an accessible format for developers to review

7 Business Data Model and Data Dictionary

7.1 Business Data Model



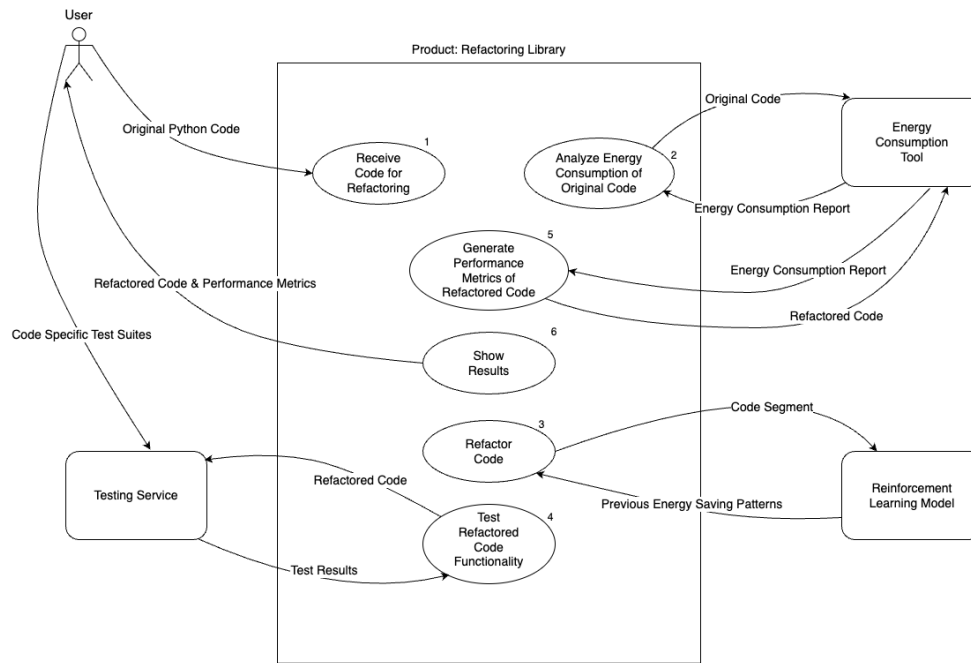
7.2 Data Dictionary

Name	Content	Type
EcoOptimizer	CentralCtrl + RefactoringCtrl + TestingCtrl + Reinforcement Learning Model	package
GitHub Actions	External tool for automated customizable work-flows	External Service Provider
VS Code extension	A plugin containing the EcoOptimizer package delivered through Visual Studio Code Marketplace	External Service Provider
Rope	External refactoring library	package

Pysmell	External python smell detection module	package
pyJoules	External python energy measuring module	package
CentralCtrl	source + excluded + tests + initialEnergy + smells + measureEnergy + getSmells + refactor + check-Functionality	Class
TestingCtrl	testDir + runTests	Class
RefactoringCtrl	selectRefactoring	Class
Reinforcement Learning Model	Data model for improved energy efficient refactoring	Module
source	directory containing the code to be refactored	string
excluded	files and directories that should not be refactored	list[string]
testDir	directory containing tests related to the source code	string
initialEnergy	file containing all initial energy measurements prior to refactoring	string
smells	all code smells detected	list[string]
measureEnergy()	measures the energy consumption of the given source code	method
getSmells()	returns all the smells detected in the source code	method
refactor(smell)	refactors the source code based on the given code smell	method
checkFunctionality()	checks that the original functionality of the code is maintained	method

8 The Scope of the Product

8.1 Product Boundary



8.2 Product Use Case Table

PUC #	PUC Name	Actor/s	Input & Output(s)
1	Receive Code for Refactoring	User	Original Python Code (in)
2	Analyze Energy Consumption of Original Code	Energy Consumption Tool	Original Code (in), Energy Consumption Report (out)
3	Refactor Code	Reinforcement Learning Model	Code Segment (in), Previous Energy Saving Patterns (out)
4	Test Refactored Code Functionality	Testing Service	Refactored Code (in), Test Results (out)
5	Generate Performance Metrics of Refactored Code	Energy Consumption Tool	Refactored Code (in), Energy Consumption Report (out)
6	Show Results	User	Refactored Code, Performance Metrics (out)

8.3 Individual Product Use Cases (PUC's)

PUC 1: Receive Code for Refactoring

Trigger: User submits Python code via GitHub Actions or IDE plugin.

Preconditions:

- User has access to the refactoring tool.
- The refactoring tool is active and ready to receive code.

Actors: User.

Outcome: Python code is received by the refactoring tool.

Input: Original Python Code.

Output: Code is stored for further analysis (internal).

PUC 2: Analyze Energy Consumption of Original Code

Trigger: The refactoring tool submits the original code to the energy consumption tool.

Preconditions:

- The refactoring tool has received the original code.
- Energy Consumption Tool is active and connected to the refactoring tool.

Actors: Energy Consumption Tool.

Outcome: Energy consumption data is collected and returned to the refactoring tool.

Input: Original Python Code.

Output: Energy Consumption Report.

PUC 3: Refactor Code

Trigger: Refactoring tool identifies inefficiencies in the original code.

Preconditions:

- Energy consumption report has been generated.

Actors: Reinforcement Learning Model.

Outcome: Code is refactored. Previous energy-saving patterns are utilized, if present.

Input: Code Segment.

Output: Refactored Python Code.

PUC 4: Test Refactored Code Functionality

Trigger: Refactored code is ready for validation.

Preconditions:

- Refactoring process has completed.
- Testing Service is available.

Actors: Testing Service.

Outcome: Refactored code is validated for functional correctness.

Input: Refactored Code.

Output: Test Results.

PUC 5: Generate Performance Metrics of Refactored Code

Trigger: Refactored code passes functionality tests.

Preconditions:

- Refactored code has been validated.

Actors: Energy Consumption Tool.

Outcome: Performance report is generated and sent to the user.

Input: Refactored Code.

Output: Energy Consumption Report.

PUC 6: Show Results

Trigger: Refactored code and performance metrics are generated.

Preconditions:

- Preceding use cases have successfully been completed.
- Results are ready to be shared with the user.

Actors: User.

Outcome: Refactored code and performance metrics are presented to the user.

Output: Refactored Code, Performance Metrics.

9 Functional Requirements

9.1 Functional Requirements

FR 1. *The system must accept Python source code files.*

Rationale: The system needs to process Python code as its primary input to refactor and improve energy efficiency.

Fit Criterion: The system successfully processes valid Python files without errors and provides feedback for invalid files.

Priority: High

FR 2. *The system must identify specific code smells that can be targeted for energy saving.*

Rationale: Energy inefficiencies are often related to well-known code smells, so identifying them is the first step in improving efficiency.

Fit Criterion: The tool should detect and report at least 80% of the following code smells: Large Class (LC), Long Parameter List (LPL), Long Method (LM), Long Message Chain (LMC), Long Scope Chaining (LSC), Long Base Class List (LBCL),

Useless Exception Handling (UEH), Long Lambda Function (LLF), Complex List Comprehension (CLC), Long Element Chain (LEC), Long Ternary Conditional Expression (LTCE).

Priority: High

- FR 3. *The system shall maintain the original functionality of the Python code after refactoring.*

Rationale: Ensuring that the refactored code preserves the original behaviour is critical to avoid regressions or unexpected issues in the software.

Fit Criterion: The system runs the original test suite against the refactored code and passes 100% of the tests.

Priority: High

- FR 4. *The system must allow users to input their original test suite as a required argument.*

Rationale: Verifying that the refactored code preserves functionality requires the use of the original test suite.

Fit Criterion: Users can specify a path to their test suite that the tool recognizes and utilizes for testing the refactored code.

Priority: High

- FR 5. *The system must suggest at least one appropriate refactoring for each detected code smell to decrease energy consumption or indicate that none can be found.*

Rationale: For developers to optimize their code, the tool must provide appropriate refactoring suggestions based on detected code smells.

Fit Criterion: The suggested refactored code demonstrates a measurable improvement in energy consumption as measured in joules.

Priority: High

- FR 6. *The system must produce valid refactored Python code as output or indicate that no possible refactorings were found.*

Rationale: Refactored code must remain functional and error-free to ensure maintainability and usability.

Fit Criterion: The output code is syntactically correct and adheres to Python standards, validated by an automatic linter.

Priority: High

- FR 7. *The tool must implement an algorithm to choose the most optimal refactoring based on measured energy consumption.*

Rationale: There may be multiple ways to refactor code, but the most energy-efficient one should be chosen.

Fit Criterion: The algorithm evaluates multiple refactoring options and selects the one that results in the lowest energy consumption for the given code smell.

Priority: Medium

- FR 8. *The tool must be compatible with various Python versions and common libraries.*

Rationale: The tool should be flexible enough to be used across different Python environments.

Fit Criterion: The tool operates correctly with the latest two major versions of Python (e.g., Python 3.8 and 3.9) and commonly used libraries.

Priority: Medium

- FR 9. *The tool must generate comprehensive reports on detected smells, refactorings applied, energy consumption measurements, and testing results.*

Rationale: Developers need clear reports to understand the impact of the refactorings and to track changes effectively.

Fit Criterion: Reports are clear, well-structured, and provide actionable insights, allowing users to easily understand the results.

Priority: Medium

- FR 10. *The tool must provide comprehensive documentation and help resources.*

Rationale: Detailed documentation is necessary to help users install, understand, and use the tool effectively.

Fit Criterion: Documentation covers installation, usage, and troubleshooting, receiving positive feedback for clarity and completeness from users.

Priority: Medium

- FR 11. *The system shall provide developers with refactoring suggestions within an IDE before committing code, allowing them to review and approve energy-efficient changes.*

Rationale: Giving developers control over which refactorings are applied ensures that they can maintain the balance between energy efficiency and their coding style or project requirements.

Fit Criterion: The IDE plugin must display at least two refactoring options for inefficient code patterns, allowing developers to either apply or reject them before committing the changes.

Priority: Medium

- FR 12. *The system shall integrate with GitHub and provide an automated refactoring process that is triggered when code is pushed to a repository.*

Rationale: Automated refactoring integrated into CI/CD pipelines ensures that energy-efficient code is maintained across all stages of development, reducing the burden on developers.

Fit Criterion: The refactoring process must be triggered automatically on GitHub commits, with at least 95% of refactorings improving energy efficiency without introducing any functional errors.

Priority: Medium

- FR 13. *The system shall allow developers to undo any refactorings applied, restoring the code to its previous state.*

Rationale: Developers may want to revert changes if they do not align with specific

project goals or introduce performance bottlenecks unrelated to energy consumption.
Fit Criterion: The system must provide an option to revert any refactoring applied within the last 5 commits, restoring both code and energy consumption metrics to their original state.

Priority: Medium

10 Look and Feel Requirements

10.1 Appearance Requirements

LFR-AP 1. *The IDE plugin refactoring interface shall present the original and refactored code side by side, allowing developers to compare and choose between them easily.*

Rationale: Providing a side-by-side view of the original and refactored code helps developers make informed decisions about applying changes.

Fit Criterion: The interface must display the original code on one side and the refactored code on the other, with clear options for developers to accept or reject the refactorings without confusion.

Priority: High

LFR-AP 2. *The IDE plugin shall adapt to the user's VS Code theme, supporting both light and dark modes.*

Rationale: Ensuring that the plugin matches the user's theme preference enhances user experience and visual comfort.

Fit Criterion: The IDE plugin's interface must automatically adjust to match the user's current VS Code theme settings (light or dark), requiring no manual changes.

Priority: Medium

LFR-AP 3. *The tool shall highlight refactoring suggestions using visual indicators based on the impact of energy savings.*

Rationale: Visual indicators make it easier for developers to quickly identify and prioritize refactoring opportunities based on their energy-saving potential.

Fit Criterion: The tool must use colour-coded indicators (e.g., yellow for minor energy savings, red for major savings), allowing developers to identify refactoring opportunities quickly.

Priority: Medium

LFR-AP 4. *The tool shall have a minimalist design, focusing only on essential elements to reduce clutter.*

Rationale: A clean and simple interface allows developers to focus on the code and refactoring suggestions without distractions, improving usability.

Fit Criterion: The tool should prominently display only the code, refactoring suggestions, and energy metrics, omitting unnecessary visual elements or dis-

tractions.

Priority: Low

- LFR-AP 5. *The GitHub Action shall highlight significant energy savings with visual alerts in pull requests (PRs).*

Rationale: Visual alerts in PRs inform developers of the energy savings achieved, encouraging the adoption of energy-efficient practices.

Fit Criterion: The GitHub Action must display a success icon or green label in the PR summary if energy savings exceed a predefined threshold (e.g., 10%).

Priority: Low

10.2 Style Requirements

- LFR-ST 1. *The tool shall convey a professional and authoritative appearance to instill confidence in developers.*

Rationale: A professional appearance helps build trust and encourages developers to use the tool confidently for energy-efficient refactoring.

Fit Criterion: After their first encounter with the tool, at least 60% of representative developers should feel that it is a trustworthy and reliable solution for energy-efficient refactoring.

Priority: High

- LFR-ST 2. *The IDE plugin interface shall promote a calm and focused atmosphere, enhancing the developer's ability to concentrate on code improvements.*

Rationale: A calm environment reduces distractions and improves productivity, allowing developers to focus on their work effectively.

Fit Criterion: Developers should report feeling less distracted and more productive while using the tool, with 70% indicating a positive change in their coding environment.

Priority: Medium

- LFR-ST 3. *The tool design shall be visually appealing and modern, aligning with contemporary software development tools.*

Rationale: A modern design improves user experience and satisfaction, making the tool more enjoyable to use.

Fit Criterion: At least 75% of users should express satisfaction with the tool's visual design and layout after their initial interaction.

Priority: Medium

11 Usability and Humanity Requirements

11.1 Ease of Use Requirements

UHR-EOU 1. *The tool shall have an intuitive user interface that simplifies navigation and functionality.*

Rationale: A simple, intuitive interface allows users to access the tool's key features quickly, improving usability and reducing the learning curve.

Fit Criterion: Users should be able to complete key tasks (e.g., parsing code, configuring settings) within three clicks or less.

Priority: High

UHR-EOU 2. *The tool shall provide clear and concise prompts for user input.*

Rationale: Clear instructions help users understand what inputs are required, minimizing confusion and errors during the process.

Fit Criterion: At least 90% of test users should report that prompts are straightforward and guide them effectively through the process.

Priority: High

11.2 Personalization and Internationalization Requirements

UHR-PSI 1. *The tool shall allow users to customize settings to match their preferences (e.g., refactoring styles, detection sensitivity).*

Rationale: Allowing customization improves the user experience by letting developers tailor the tool to their specific needs and workflows.

Fit Criterion: Users should be able to save and load custom configurations easily.

Priority: Medium

UHR-PSI 2. *The user guide shall be available in French and English.*

Rationale: Providing multilingual support ensures that non-English-speaking users can effectively use the tool.

Fit Criterion: French and English installation and use instructions must be available.

Priority: Low

11.3 Learning Requirements

UHR-LRN 1. *The tool shall provide context-sensitive help that offers assistance based on the current user actions.*

Rationale: Context-sensitive help ensures that users can receive timely and relevant assistance, reducing confusion and improving usability.

Fit Criterion: Help resources should be accessible within 1-3 clicks.

Priority: High

UHR-LRN 2. *The tool shall have an available YouTube video demonstrating installation.*

Rationale: Video tutorials provide visual learning resources that can make the installation process more accessible to users.

Fit Criterion: A YouTube video demonstrating installation should be present and easily accessible.

Priority: Low

11.4 Understandability and Politeness Requirements

UHR-UPL 1. *The tool shall communicate errors and issues politely and constructively.*

Rationale: Polite and constructive error messages reduce frustration and enhance the user experience, making the tool more approachable.

Fit Criterion: User feedback should reflect that at least 80% of users perceive error messages as helpful and courteous, rather than frustrating or vague.

Priority: Medium

11.5 Accessibility Requirements

UHR-ACS 1. *The tool shall provide high-contrast colour themes to improve visibility for users with visual impairments.*

Rationale: High-contrast themes ensure that visually impaired users can easily navigate and use the tool, enhancing accessibility.

Fit Criterion: Users should have access to at least 1 high contrast theme.

Priority: Low

UHR-ACS 2. *The tool shall offer audio cues for important actions and alerts to assist users with use and navigation.*

Rationale: Audio cues help users with visual impairments or cognitive difficulties to stay informed about important events or actions.

Fit Criterion: At least 70% of users should report that the audio cues enhance their understanding of important notifications or actions.

Priority: Low

12 Performance Requirements

12.1 Speed and Latency Requirements

PR-SL 1. *The tool shall analyze and detect code smells in the input code within a reasonable time frame.*

Rationale: Fast analysis ensures that developers do not experience significant delays while reviewing code.

Fit Criterion: The tool should complete the analysis for files up to 1,000 lines

of code in under 5 seconds, and for files up to 10,000 lines in under 30 seconds.

Priority: High

PR-SL 2. *The refactoring process shall be executed efficiently without noticeable delays.*

Rationale: Fast refactoring ensures a smooth workflow for developers, preventing frustration during development.

Fit Criterion: The tool should refactor the code and generate output in under 10 seconds for small to medium-sized files (up to 5,000 lines).

Priority: Medium

12.2 Safety-Critical Requirements

PR-SCR 1. *The tool shall ensure that no runtime errors are introduced in the refactored code that could result in data loss or system failures.*

Rationale: Preventing runtime errors ensures system stability and reliability after refactoring.

Fit Criterion: The tool should pass all tests from the user-provided test suite after refactoring, confirming that the original functionality remains intact. The output code is syntactically correct and adheres to Python standards, validated by an automatic linter.

Priority: High

12.3 Precision or Accuracy Requirements

PR-PAR 1. *The tool shall maintain the functionality of the original provided code in all its recommended refactorings.*

Rationale: Ensuring functionality preservation is critical for refactorings to be reliable.

Fit Criterion: The tool should pass all tests from the user-provided test suite after refactoring, confirming that the original functionality remains intact.

Priority: High

PR-PAR 2. *The tool shall reliably identify code smells with minimal false positives and negatives.*

Rationale: High detection accuracy ensures that developers are not misled by incorrect or missed suggestions.

Fit Criterion: Detection accuracy should exceed 90% when validated against a set of known cases.

Priority: Medium

PR-PAR 3. *The tool shall produce valid refactored Python code as output or indicate that no possible refactorings were found.*

Rationale: Ensuring that the tool produces valid output is essential for maintaining code quality.

Fit Criterion: The output code is syntactically correct and adheres to Python standards, validated by an automatic linter.

Priority: Medium

12.4 Robustness or Fault-Tolerance Requirements

PR-RFT 1. *The tool shall gracefully handle unexpected inputs, such as invalid code or non-Python files.*

Rationale: Ensuring stability with error handling prevents tool crashes and improves user experience.

Fit Criterion: The tool should provide clear error messages and recover from input errors without crashing, ensuring stability.

Priority: High

PR-RFT 2. *The tool shall have fallback options if a specific refactoring attempt fails.*

Rationale: Providing fallback options ensures the tool remains functional even when a refactoring fails, reducing disruptions in development.

Fit Criterion: In the event of a failed refactoring, the tool should log the error and propose alternative refactorings without stopping the process.

Priority: Medium

12.5 Capacity Requirements

PR-CR 1. *The tool shall efficiently manage large codebases.*

Rationale: Efficient handling of large projects ensures that the tool remains usable for teams working with extensive codebases.

Fit Criterion: The tool must process projects with up to 100,000 lines of code within 2 minutes, maintaining performance standards.

Priority: High

12.6 Scalability or Extensibility Requirements

PR-SER 1. *The tool shall be designed to allow easy addition of new code smells and refactoring methods in future updates.*

Rationale: Extensibility ensures that the tool remains relevant and adaptable to future developments in coding standards and practices.

Fit Criterion: New code smells or refactorings can be incorporated with minimal changes to existing code, ensuring that current functionality remains intact.

Priority: Medium

12.7 Longevity Requirements

PR-LR 1. *The tool shall be maintainable and adaptable to future versions of Python and changing coding standards.*

Rationale: Ensuring the tool can be updated easily guarantees that it will remain useful and relevant over time.

Fit Criterion: The codebase should be well-documented and modular, facilitating updates with minimal effort.

Priority: Medium

13 Operational and Environmental Requirements

The Operational and Environmental Requirements define the conditions under which the system must function effectively. These requirements ensure that the system performs reliably within specified operational boundaries, such as compatibility, deployment, and environmental constraints. Additionally, this section addresses the external environmental factors that could influence the system. Meeting these requirements is critical to ensure the tool's proper operation and sustainability in various working environments.

13.1 Expected Physical Environment

OER-EP 1. *The product shall be used in temperatures ranging from 10 °C - 35 °C.*

Rationale: A computer's safe operating range is 10 °C - 35 °C ([Christensson, 2016](#)). If the computer doesn't work then it is not possible to use the refactoring library.

Fit Criterion: The computer turns on, and no temperature warning is issued.

Priority: High

OER-EP 2. *The product shall be used in proximity to a stable power supply.*

Rationale: As a coding library, the product depends on the continuing operation of the computer system it is used on. Should the computer lose power, the refactoring library will see its processes halted.

Fit Criterion: The computer is connected to a power outlet or the computer possesses charge on its battery.

Priority: High

13.2 Wider Environment Requirements

OER-WE 1. *The system must align with widely used emissions standards (e.g., GRI 305, GHG, ISO 14064) ([GHG, 2011](#); [ISO, 2024](#); [GRI, 2016](#)).*

Rationale: Providing metrics tailored to these standards, makes the library reporting tool more attractive to users part of companies looking to reduce their ecological footprint.

Fit Criterion: The emissions tracked by the standards are present in the reported metrics.

Priority: Medium

13.3 Requirements for Interfacing with Adjacent Systems

OER-IAS 1. *The refactoring library must provide integration capabilities with GitHub Actions.*

Rationale: This will allow the automation of the refactoring process within existing workflows to ensure that energy-efficient practices are consistently applied during continuous integration.

Fit Criterion: The library is available to use via GitHub Actions when writing workflows.

Priority: Low

OER-IAS 2. *The library should be compatible with the Visual Studio Code (VSCode) IDE.*

Rationale: Developers will be able to refactor code easily without leaving their working environment, therefore enhancing the accessibility and usability of the library.

Fit Criterion: An extension is available for installation in VSCode marketplace.

Priority: Medium

OER-IAS 3. *The library should support importing existing codebases and exporting refactored code and energy savings reports in standard formats (e.g., JSON, XML)*

Rationale: This ensures that users can easily integrate the library into their existing workflows without significant disruption.

Fit Criterion: Developers are able to refactor existing codebases and view relevant metrics.

Priority: Medium

13.4 Productization Requirements

OER-PR 1. *The library shall be package with PIP and made available to python users through the public package manager.*

Rationale: As a widely used package manager, PIP will be able to distribute the library to any users that wish to use it.

Fit Criterion: Users are able to install the library using `pip install`.

Priority: Medium

13.5 Release Requirements

OER-RL 1. *All core functionalities specified in the requirements must be implemented and tested, including energy consumption measurement, automated refactoring, and reporting features.*

Rationale: This will ensure that the library delivers the promised capabilities to users.

Fit Criterion: Follows the steps outlined in the Verification and Validation

(V&V) plan.
Priority: Medium

OER-RL 2. *The library must be ready for release by March 17th, 2025.*

Rationale: The library must be ready for final demonstration as a requirement of the McMaster University SFRWENG 4G06 Capstone course.

Fit Criterion: The project is ready for the final demonstration of the appointed date.

Priority: Low

14 Maintainability and Support Requirements

The following are defined as maintainability requirements:

14.1 Maintenance Requirements

MS-MNT 1. *The tool must allow new refactoring techniques to be added within one week of identification.*

Rationale: Rapid integration of new techniques ensures the tool remains up-to-date with evolving best practices in energy-efficient coding.

Fit Criteria: Developers can integrate new refactoring methods into the tool, and they are fully operational within seven days.

Priority: Medium

MS-MNT 2. *The tool must be maintainable by developers who are not the original creators.*

Rationale: Ensuring that new developers can easily understand and modify the system reduces dependency on original developers and facilitates long-term maintenance.

Fit Criteria: Comprehensive documentation is available, including setup guides and code comments, allowing new developers to understand and modify the system within two days.

Priority: High

MS-MNT 3. *The tool must allow for easy rollback of updates in case of errors.*

Rationale: Quick rollback capabilities minimize downtime and user disruption in case an update introduces issues.

Fit Criteria: Any update can be reverted with minimal effort, ensuring the system returns to a stable state within one hour.

Priority: Medium

MS-MNT 4. *The tool must provide automated testing for all refactoring functions.*

Rationale: Automated testing ensures that changes do not introduce new bugs, maintaining the reliability and stability of the tool.

Fit Criteria: All refactoring methods have associated unit tests that run

automatically with each code change, ensuring 80% code coverage.

Priority: High

MS-MNT 5. *Each version of the library must maintain compatibility with the current releases of external libraries during its development phase.*

Rationale: Keeping external libraries up-to-date ensures compatibility and leverages improvements or security patches provided by library maintainers.

Fit Criteria: The system successfully integrates updates from external libraries without breaking existing functionality.

Priority: Medium

The following are defined as maintainability requirements:

14.2 Supportability Requirements

MS-SP 1. *The tool must offer bilingual support for help documentation.*

Rationale: Bilingual support ensures that users from different regions can understand and use the tool effectively, increasing its accessibility.

Fit Criteria: Help documentation is available in both major languages, English and French.

Priority: Low

14.3 Adaptability Requirements

Not applicable in this project currently

15 Security Requirements

15.1 Access Requirements

SR-AR 1. *Users must authenticate before accessing any feature of the refactoring tool, especially the refactored code or reports.*

Rationale: User's code and refactoring results are private data that must only be accessed by legitimate, authenticated users.

Fit Criterion: The user can submit code and view refactoring results once authenticated using their company's credentials.

Priority: High

SR-AR 2. *Only the refactoring tool can communicate with the energy consumption tool and the reinforcement learning model.*

Rationale: Reinforcement learning model and energy consumption tools are internal, abstracted services that are not directly needed by the user.

Fit Criterion: The refactoring tool does not include any exposed API endpoints to the energy consumption tool and reinforcement learning model.

Priority: High

15.2 Integrity Requirements

SR-IR 1. *The tool must prevent unauthorized, external changes to the refactored code and energy reports.*

Rationale: The system must maintain code consistency and correctness vis-à-vis the original input and energy improvement data. Any corruption of the code and/or performance reports could undermine trust in the tool.

Fit Criterion: The system should be fully secure against any external attempts to modify the data in each implemented layer.

Priority: High

15.3 Privacy Requirements

SR-PR 1. *The user must be notified of data collection, usage, storage and processing practices related to their code.*

Rationale: The tool must safeguard user privacy rights.

Fit Criterion: The system notifies and obtains explicit consent from users in compliance with PIPEDA before collecting their code.

Priority: High

SR-PR 2. *Any data related to user submissions, energy reports and refactored results must be treated as confidential and handled according to Personal Information Protection and Electronic Documents Act (PIPEDA).*

Rationale: The tool must ensure compliance with PIPEDA to avoid any legal action and gain user trust.

Fit Criterion: All submitted code, energy reports and refactored code are encrypted when being transmitted or stored. The system includes an option to allow users to request modification of their personal data as per PIPEDA specifications.

Priority: High

15.4 Audit Requirements

SR-AUR 1. *The tool should record which users submitted the code and/or accessed the refactored code and energy reports.*

Rationale: The system must ensure accountability and traceability of the refactoring process to resolve any future conflicts.

Fit Criterion: The system maintains tamper-proof logs of the following events: login, code submission and access to refactoring results.

Priority: Medium

SR-AUR 2. *The system should maintain an audit log of all refactoring processes including pattern analysis, energy analysis and report generation.*

Rationale: The tool must include a trail of refactoring events for any future security disputes.

Fit Criterion: The system maintains tamper-proof logs of refactoring changes made to the original code.

Priority: Medium

15.5 Immunity Requirements

SR-AUR 1. *The tool must be protected from any malware, viruses and unauthorized programs that could alter the refactoring process.*

Rationale: Users need a secure and reliable system that is resistant to external attacks.

Fit Criterion: The system includes a regularly updated security component that is tested against new threats.

Priority: High

16 Cultural Requirements

The cultural requirements of this project include the following:

16.1 Cultural Requirements

CULT 1. *The tool must avoid using colours or symbols that could be culturally sensitive or offensive.*

Rationale: Ensuring cultural sensitivity in design helps avoid alienating or offending users from diverse backgrounds, which is critical for global acceptance and usability.

Fit Criteria: Conduct a cultural review to ensure that all icons and colours used in the tool are neutral and universally acceptable. **Priority:** Low

CULT 2. *The tool must support both metric and imperial measurement units.*

Rationale: Users have different preferences and standards for measurement units. Supporting both metric and imperial units ensures accessibility and ease of use for a global audience.

Fit Criteria: Users can toggle between metric and imperial units for any measurements related to energy consumption. **Priority:** Medium

CULT 3. *The tool must not include content that could be considered culturally insensitive.*

Rationale: Avoiding culturally insensitive content ensures that the tool is respectful and inclusive, fostering a positive user experience across different cultures.

Fit Criteria: A cultural sensitivity review is conducted to ensure all content is appropriate for a global audience. **Priority:** Medium

17 Compliance Requirements

17.1 Legal Requirements

CR-LR 1. *The system must comply with Personal Information Protection and Electronic Documents Act (PIPEDA) (of the Privacy Commissioner of Canada, 2024) and Canada's Anti-Spam Legislation (CASL) (Radio-television and , CRTC)*

Rationale: The product should not violate any Canadian laws, which could result in financial penalties, delays in bringing the product to market or loss of user trust.

Fit Criterion: The system has obtained successful compliance reports for CASL, PIPEDA and third party IP rights.

Priority: High

17.2 Standards Compliance Requirements

CR-SCR 1. *The system must adhere to applicable industry standards for team work and software development.*

Rationale: Compliance with standards builds trust with stakeholders and improves the likelihood of the product's acceptance in the market.

Fit Criterion: The system has obtained ISO 9001 certification (for Standardization , ISO) for quality management as well as Compliance with SSADM (Structured Systems Analysis and Design Method) (UK, 2024) for software development processes.

Priority: High

18 Open Issues

This section outlines unresolved questions and challenges that may impact the development, functionality, or integration of the system. These issues require further research, discussion, or testing to ensure successful project completion.

- Further research is needed to determine the optimal balance between energy efficiency and code readability. While refactoring may improve energy consumption metrics, it could inadvertently make the codebase less maintainable and more difficult to expand in the long term.
- The same can be said when it comes to performance. More energy efficient code might actually end up being less efficient when it comes to time and space complexity.

19 Off-the-Shelf Solutions

19.1 Ready-Made Products

- **Pylint:** A widely used static code analysis tool that detects various code smells in Python. It can be integrated into the refactoring tool to help identify inefficiencies in the code.
- **Flake8:** Linter that combines checks for style guide enforcement and code quality. Flake8 can assist in maintaining code standards while the tool focuses on energy efficiency.
- **PyJoule:** A tool for measuring the energy consumption of Python code. This product can provide essential data to evaluate the impact of refactorings on energy usage.

19.2 Reusable Components

- **Rope:** A library for Python that provides automated refactoring capabilities, helping streamline the process of improving code quality.

19.3 Products That Can Be Copied

- **SonarQube:** An open-source platform designed for continuous inspection of code quality. It helps developers manage code quality and security by analyzing source code to identify potential issues. Its architecture and methods for detecting code smells could be adapted to focus specifically on energy efficiency.

20 New Problems

20.1 Effects on the Current Environment

The introduction of the energy efficiency refactoring tool may lead to several changes in the current development environment. These effects include:

1. The tool temporarily increases CPU and memory usage while running. The tool aims to optimize energy efficiency in code however it takes energy to run - in large code-bases this could be significant energy and impact the performance of other applications running concurrently.
2. The tool may have its own dependencies that now need to be included in the app or installed into the current system. Think Pysmells, Pyjoule etc.

20.2 Effects on the Installed Systems

1. Existing systems may need to be evaluated for compatibility with the new tool. Older versions of Python or other needed dependencies may not support the tool.

2. The refactoring process could lead to variations in the performance of existing applications
3. As the tool updates existing code, thorough testing will be needed to ensure everything still works correctly. This may require more effort from QA teams and additional time and resources to check the updated code.

20.3 Potential User Problems

1. Users may face difficulties in understanding how to effectively utilize the tool, particularly if they are not familiar with concepts like code smells and refactoring techniques. This learning curve may lead to initial frustration or reduced productivity.
2. Some users may be resistant to adopting new tools or processes, particularly if they perceive the existing workflows as sufficient. This resistance could hinder the tool's successful implementation and limit its overall effectiveness.
3. Users may misinterpret the output reports generated by the tool, such as energy savings or performance metrics. If users do not fully understand how to interpret these results, it could lead to incorrect conclusions about the tool's impact on their code.
4. There is a risk that users might become overly reliant on the tool for refactoring without fully understanding the underlying principles. This could result in poor coding practices if users do not engage in thoughtful analysis of the suggested changes.

20.4 Limitations in the Anticipated Implementation Environment That May Inhibit the New Product

1. **Limited Computational Resources:** Environments with restricted computational power may face challenges when running the tool, especially for large codebases. Limited resources could result in longer processing times or failures during analysis and refactoring.
2. **Lack of Test Coverage:** If existing codebases lack comprehensive test suites, validating the functionality of refactored code may become challenging. Without adequate tests, it will be difficult to ensure that the tool's changes do not introduce new issues.

20.5 Follow-Up Problems

1. **Ongoing Maintenance:** The tool will need regular updates to stay compatible with new programming languages or standards, adding to the workload.
2. **Performance Trade-offs:** Users may find that while some refactorings improve energy efficiency, they could negatively impact other performance metrics, such as execution speed.

21 Tasks

21.1 Project Planning

- **Development Approach** The team will use an agile development approach with the following high-level process:
 1. Initial requirements gathering and product backlog creation
 2. Sprint planning and execution
 3. Regular testing and quality assurance
 4. Stakeholder reviews and feedback
 5. Iterative refinement
 6. Release planning and deployment
- **Key Tasks**
 - Form cross-functional development team (already completed)
 - Create initial product backlog and prioritize features
 - Set up development environments and tools
 - Establish CI/CD pipeline using GitHub Actions
 - Develop core functionality:
 - * Determine code smells to address for energy-saving
 - * Implement code smell detection
 - * Develop appropriate refactorings for detected smells
 - * Measure energy consumption before and after refactoring
 - * Ensure original code functionality is preserved
 - Build out additional features iteratively
 - Conduct regular testing (unit, integration, user acceptance)
 - Refine based on stakeholder feedback
 - Present final solution to stakeholders
- **Timeline Estimate**
 - Requirements Document (Revision 0): October 9th, 2024
 - Hazard Analysis (Revision 0): October 23rd, 2024
 - Verification & Validation Plan (Revision 0): November 1st, 2024
 - Proof of Concept: November 11th-22nd, 2024
 - Design Document (Revision 0): January 15th, 2025
 - Project Demo (Revision 0): February 3rd-14th, 2025
 - Final Demonstration: March 17th-30th, 2025

- Final Documentation: April 2nd, 2025
- Capstone EXPO: TBD
- **Resource Estimates** The team consists of 5 members who will all function as developers, sharing responsibilities for creating issues, coding, testing, and documentation.
- **Key Consideration**
 - Data migration may be necessary for existing systems
 - A phased development approach will help minimize major setbacks
 - Regular stakeholder involvement will ensure alignment with business needs
- **Documentation Process**
 - Pull changes from `docs` (epic documentation branch)
 - Create a working branch with format [main contributor name]/[descriptive topic]
 - Commit changes with descriptive names
 - Create unit tests for changes
 - Create a pull request to merge changes into an epic branch
 - Wait for all tests run with GitHub Actions to pass
 - Wait for at least two approvals from teammates
 - Merge changes into the target branch

By following this agile approach and development process, the team aims to deliver a high-quality product iteratively while maintaining flexibility to adapt to changing requirements

21.2 Planning of the Development Phases

The planning of the development phases is based on the deliverables submissions as follows:

1. Requirements Phase

- Deliverable: Requirements Document (Revision 0)
- Due Date: October 9th, 2024

2. Risk Assessment Phase

- Deliverable: Hazard Analysis (Revision 0)
- Due Date: October 23rd, 2024

3. Verification and Validation Planning

- Deliverable: Verification & Validation Plan (Revision 0)
- Due Date: November 1st, 2024

4. Proof of Concept Implementation

- Period: November 11th-22nd, 2024

5. Design Phase

- Deliverable: Design Document (Revision 0)
- Due Date: January 15th, 2025

6. Initial Implementation and Demo

- Deliverable: Project Demo (Revision 0)
- Period: February 3rd-14th, 2025

7. Final Implementation and Testing

- Deliverable: Final Demonstration
- Period: March 17th-30th, 2025

8. Project Closure

- Deliverable: Final Documentation
- Due Date: April 2nd, 2025

9. Project Presentation

- Event: Capstone EXPO
- Date: TBD

22 Migration to the New Product

22.1 Requirements for Migration to the New Product

The migration to the new tool will involve minimal disruption to existing workflows, as the product is designed to integrate seamlessly with GitHub Actions and Visual Studio Code. Developers will be able to continue using their current workflows, with the addition of the refactoring tool as a library that can be installed directly via Python's package manager (pip), an IDE plugin for an enhanced development experience, and a GitHub Action for automated refactoring in their CI/CD pipelines. The minimal installation and integration requirements ensure ease of adoption for developers without needing to overhaul existing infrastructure or processes.

- **Installation Phase:** Developers can install the refactoring library directly using pip: `pip install ecooptimizer`. The IDE plugin can be installed by users through the Visual Studio Code marketplace. The GitHub Action can be integrated by adding the appropriate YAML configuration to the repository's workflow files.

- **Parallel Running:** There is no need for a phased implementation or parallel running of old and new systems. The tool can be directly integrated without affecting existing code or infrastructure.
- **Manual Backups:** Since the tool does not alter data but rather provides refactoring suggestions, no manual backups are required before installation.
- **Phased Rollout:** If required, developers can start using the refactoring library first, followed by the IDE plugin, and then integrate the GitHub Action to automate refactoring in their CI/CD workflows.

22.2 Data That Has to be Modified or Translated for the New System

Not Applicable

23 Costs

The total cost of developing this project is primarily based on the effort involved by the development team, given that the tools and platforms used (GitHub, open-source libraries) are free. The project must be completed within the academic year (MVP ready by February 2025), which warrants smart planning and efficient resource allocation.

23.1 Metrics for Estimation

To estimate the total cost in terms of time and effort, the following key metrics have been considered:

- Number of input/output flows for the system.
- Number of business events.
- Number of product use cases.
- Number of functional and non-functional requirements.
- Number of constraint requirements.

23.2 Estimation Approach

Each deliverable has been assessed to estimate the time it will take to implement based on the development environment. Early cost estimates are based on general knowledge of the system and refined as the team gradually gets a better understanding of the scope.

23.3 Cost Breakdown

- **Development Effort:** Based on the team size and project timeline, following time allocation is estimated:
 - Initial Research & Setup: 50 hours per team member.
 - Core development (e.g., refactoring tool, plugin): 300 hours per team member.
 - Testing and debugging: 80 hours per team member.
 - Documentation & finalization: 100 hours per team member.
 - **Total estimated effort:** 530 hours per team member.
- **Tools and Software:**
 - GitHub (for CI/CD): Free account, with no cost expected.
 - Open-source libraries (PySmells, PyJoules): No associated costs.
- **Testing Environment:**
 - The testing of the refactoring tool and energy consumption measurements is planned to be carried out using free tools on open source projects, with no additional cost expected.

23.4 Estimated Cost

The above discussion indicates that the total effort will be approximately 2650 team hours spread across the project phases. These estimates could be refined using more detailed information as the project progresses.

24 User Documentation and Training

24.1 User Documentation Requirements

1. User Manual

- **Purpose:** Provide comprehensive guidance on how to use the refactoring library
- **Target Audience:** Software developers integrating the library into their projects
- **Content:** Installation instructions, API reference, usage examples, and best practices

2. Technical Specification

- **Purpose:** Detail the library's architecture, algorithms, and integration points
- **Target Audience:** Technical leads and architects evaluating the library
- **Content:** System design, performance characteristics, and technical limitations

3. Quick Start Guide

- **Purpose:** Enable rapid adoption and basic usage of the library
- **Target Audience:** New users looking to quickly implement the library
- **Content:** Concise setup instructions and simple usage examples

24.2 Training Requirements

Not Applicable.

25 Waiting Room

This section lists potential features and enhancements that are not critical for the initial release of the system but may be considered for future updates. These ideas represent additional functionalities that could improve the tool’s performance, user experience, or integration with other systems.

- WTRM 1. *The IDE plugin must provide interactive tips and progress indicators to guide users during the refactoring process.*

Rationale: This helps prevent user confusion during the refactoring process and enhances the user experience by providing clear, real-time feedback.

Fit Criterion: Tips and progress indicators display automatically when users initiate a refactoring action in the VSCode interface.

Priority: Medium

- WTRM 2. *The tool must provide automated error reporting with user consent.*

Rationale: Automated error reporting helps developers quickly identify and address issues, improving the tool’s reliability and reducing downtime with an option to include additional comments for context.

Fit Criterion: Users are prompted to send error reports when an issue occurs,

Priority: Medium

- WTRM 3. *The tool must allow users to define custom refactoring rules or preferences within the plugin.*

Rationale: This would allow developers more flexibility and control, enabling them to apply refactorings that best suit their projects while maintaining energy efficiency.

Fit Criterion: Users can create a configuration file that describes their refactoring preferences.

Priority: High

- WTRM 4. *The tool should provide a dashboard that offers deeper insights into refactoring decisions, showing side-by-side comparisons of energy consumption before and after refactoring, along with performance metrics.*

Rationale: This would help users better understand the impact of refactoring on both energy consumption and performance.

Fit Criterion: Users are able to access energy metrics for all their projects on a centralized platform.

Priority: High

WTRM 5. *The tool should provide a plugin that integrates with multiple popular IDEs and syncs information across them through a centralized database.*

Rationale: Supporting multiple IDEs allows developers to use the tool within their preferred coding environments, enhancing user experience and adoption.

Fit Criterion: Integration guides are provided for each supported IDE, with successful installation and functionality confirmed through user testing.

Priority: Low

WTRM 6. *The refactoring library must be able to provide energy efficient refactorings for a wide variety of program languages (e.g., Java, C/C++, C#, JavaScript, TypeScript, Go, Rust, etc.)*

Rationale: Users around the world code projects in multitudes of languages depending on the context of their work. Being able to refactor in most popular languages would allow for the widespread usage of the tool.

Fit Criterion: The tool accepts and tailors code from the detected/specified language.

Priority: Low

WTRM 7. *The reinforcement learning model for the tool should accept human feedback in the reinforcement learning process.*

Rationale: This will allow users to guide the system's refactoring decisions based on developer expertise and preferences. Moreover, it will balance automated refactoring with human oversight to ensure that complex refactoring decisions align with the project's goals and constraints.

Fit Criterion: The language model accepts human feedback and incorporates it into its future decisions.

Priority: Medium

26 Ideas for Solution

In this section, we capture various ideas for implementing the project requirements. These ideas provide technical approaches and methods for achieving the energy-efficient refactoring of Python code through the refactoring tool, IDE integration, and CI/CD automation. By capturing these ideas now, we ensure that potential technical approaches are not lost and can be referred to during the design and development phase.

- **Refactoring Library Implementation via AST Parsing:** Use Python's built-in `ast` (Abstract Syntax Tree) module to analyze code structure. The refactoring library

can traverse the AST to detect inefficiencies and apply refactorings without modifying code functionality.

- **IDE Plugin for Refactoring – Leveraging VS Code API:** Build an extension for Visual Studio Code that hooks into the editor’s event system to provide real-time refactoring suggestions.
- **Integration with Existing Tools via Pre-Commit Hooks:** Integrate the refactoring tool with popular tools like PyLint or Black by setting up pre-commit hooks to run the refactoring library before committing.
- **Energy Usage Dashboard Using JavaScript and Flask:** Build a simple dashboard that displays energy consumption metrics for code refactorings over time.

Appendix — Reflection

1. *What knowledge and skills will the team collectively need to acquire to successfully complete this capstone project?*

- Learn how reinforcement learning works as well as how to incorporate it into our project.
- Understanding of Python’s performance characteristics and common code smells
- Experience in using libraries like rope for automated refactoring and familiarity with integrating linters such as Pylint or Flake8 into the development workflow.
- Ability to develop algorithms that analyze and compare different refactoring strategies, using tools like PyJoule for energy profiling.
- Proficiency in JavaScript or TypeScript, as most VS Code extensions are developed using these languages.

2. *(team) For each of the knowledge areas and skills identified in the previous question, what are at least two approaches to acquiring the knowledge or mastering the skill?*

- *Learn how reinforcement learning works as well as how to incorporate it into our project.*
 - Watch online courses on reinforcement learning.
 - Read articles/books teaching reinforcement learning.
 - Look through open source python projects that use reinforcement learning tools such as PyTorch or TensorFlow.
 - Read through the documentation for reinforcement learning tools.
- *Understanding of Python’s performance characteristics and common code smells.*
 - Enrol in courses like Effective Python or Python Performance Optimization on platforms like Coursera, edX, or Udemy.
 - Work on real-world projects or contribute to open-source Python projects. Regular code reviews with a focus on performance will help identify common code smells and inefficiencies.
- *Experience in using libraries like rope for automated refactoring and familiarity with integrating linters such as Pylint or Flake8 into the development workflow.*
 - Set up a personal or team-based project that uses rope for refactoring and integrates linters (Pylint or Flake8). Experimenting with these tools in a real project will provide direct experience with their workflows and limitations
 - Read through documentation for the tools.
 - Follow comprehensive tutorials or attend workshops focused on Python tooling.
- *Ability to develop algorithms that analyze and compare different refactoring strategies, using tools like PyJoule for energy profiling.*

- Conduct research on energy-efficient algorithms and their application in Python refactoring. Experiment with PyJoule to analyze the energy impact of different code structures.
- Work under the guidance of a mentor or collaborate with experts in energy-efficient computing.
- *Proficiency in JavaScript or TypeScript, as most VS Code extensions are developed using these languages.*
 - Practise by building simple VS Code extensions using JavaScript or TypeScript using tutorials on YouTube.
 - Take online courses specifically tailored to JavaScript or TypeScript for extension development

2. (**Individual**) *Of the identified approaches, which will each team member pursue, and why did they make this choice?*

Ayushi Amin Reflection

Learn how reinforcement learning works as well as how to incorporate it into our project.

I would choose looking through open-source Python projects that use reinforcement learning tools like PyTorch or TensorFlow. It lets me see real-world applications, understand how others are using reinforcement learning, and gives me concrete examples to work with, which helps me learn more effectively through hands-on experience.

Understanding of Python's performance characteristics and common code smells.

I would go with practical experience, contributing to open-source projects, where I can directly apply performance optimizations and get feedback through code reviews. Real-world application will help cement these concepts better.

Experience in using libraries like rope for automated refactoring and familiarity with integrating linters such as Pylint or Flake8 into the development workflow.

I would go for hands-on implementation in my projects. I learn best by doing, so I would set up a project where I can integrate rope for refactoring and Pylint or Flake8 for linting. This would give me a chance to really see how these tools fit into the development process, and I could refine my setup as I work.

Ability to develop algorithms that analyze and compare different refactoring strategies, using tools like PyJoule for energy profiling.

I would prefer diving into the research around energy-efficient algorithms and then trying things out with PyJoule. I enjoy exploring new tools and methods, so experimenting with how different code changes affect energy use would be a good challenge for me.

Proficiency in JavaScript or TypeScript, as most VS Code extensions are developed using these languages.

I like learning by creating, so I would build an extension right away. This way, I would get immediate experience with JavaScript and TypeScript while learning the VS Code extension framework.

Mya Hussain Reflection

To advance my skills for the capstone project, I plan on deepening my understanding of Python's performance characteristics and common code smells while leveraging my existing knowledge of Python. I plan to read up on different potential code smells, detection methods and possible refactoring remedies and immediately apply these insights to help develop a proof of concept (POC) for our project. For mastering refactoring tools like Rope and integrating linters such as Pylint and Flake8, I will set up a local project environment to experiment with these tools specifically for our POC. Additionally, I'll explore energy-efficient algorithms and use PyJoule to analyze how different refactoring strategies impact performance in our specific context. To enhance my proficiency in JavaScript or TypeScript for developing VS Code extensions, I plan on watching online tutorials and perhaps take an online Javascript/Typescript course as it has been a while since I have been familiar with the syntax. I will also watch tutorials on how to set up a VSCode extension as this project will be my first time doing it. I'm very excited to start coding up a POC and move on from the documentation stage. With every requirement we write the team feels more and more pressure to make sure our idea will work. It's hard to write so much about a product that doesn't yet exist without having the proof that it can exist. Or at least my mind is having a hard time writing so much about what currently is an empty repository.

Tanveer Brar Reflection

Learn how reinforcement learning works as well as how to incorporate it into our project.

I plan to watch online courses on reinforcement learning. I prefer learning visually whenever possible. Since this is a fairly new concept for me, I think online courses would be the best, providing a mix of lectures and self-assignments. A lot of courses also provide access to an online learning community which is perfect for a beginner like me.

Understanding of Python's performance characteristics and common code smells.

For this, I will contribute to open source Python projects. Live projects are a good way to expose to practical coding challenges related to performance and code smells. It will also allow me to learn from more experience contributors and spot common code smells so that I can write scalable and efficient Python code.

Experience in using libraries like rope for automated refactoring and familiarity with integrating linters such as Pylint or Flake8 into the development workflow.

I will follow comprehensive tutorials to get experience in using Rope for automatic refactoring. Comprehension tutorials provide guided experience with Python tooling, helping to explore features of tools like Rope, Pylint, and Flake8 in-depth. The tutorials are structured, therefore helping to quickly gain familiarity with functionality and usage in real-world scenarios.

Ability to develop algorithms that analyze and compare different refactoring strategies, using tools like PyJoule for energy profiling.

For this I will conduct research on energy-efficient algorithms and their application in Python refactoring. This will give me the option to follow a hands-on approach which allows for comparing different strategies and assess their energy consumption in multiple scenarios.

Proficiency in JavaScript or TypeScript, as most VS Code extensions are developed using these languages.

For this I will practise building simple VS Code extensions using JavaScript or TypeScript through YouTube tutorials. It can help me gain hands-on experience with the languages in a real-world context. These practical exercises can be used to not only solidify my understanding of JavaScript/TypeScript but also familiarize me with how these languages are used to create functional VS Code extensions, enhancing both my coding skills and extension development proficiency.

Sevhena Walker Reflection

Learn how reinforcement learning works as well as how to incorporate it into our project.

For this topic, I plan on watching online courses and tutorials since it's a subject I have basically no experience in. Watching videos is the better option for me in this case since having someone explain the knowledge and providing examples will allow me to grasp the material faster.

Understanding of Python's performance characteristics and common code smells.

I believe reading articles and going through documentation will be best for me for this topic. I already have a good base in programming and Python specifically so written documents will allow me to digest the new information at my own pace.

Experience in using libraries like rope for automated refactoring and familiarity with integrating linters such as Pylint or Flake8 into the development workflow.

When it comes to libraries and modules, I tend to fare well by just reading the documentation and looking over code examples using those tools.

Ability to develop algorithms that analyze and compare different refactoring strategies, using tools like PyJoule for energy profiling.

For this topic, experimentation will be my best option as it is not really a matter of learning something completely new but applying a new tool in a known environment.

Proficiency in JavaScript or TypeScript, as most VS Code extensions are developed using these languages.

I already have some experience working with those languages, so I will only need to refer to the documentation for the occasional refresher on syntax and such.

Nivetha Reflection

Learn how reinforcement learning works as well as how to incorporate it into our project.

I prefer to look through open source Python projects that use reinforcement learning tools to get used to it. While documentation and tutorials are readily available online whenever I need to reference them, I'm interested in seeing how tools such as PyTorch are applied in a live project so that I can get a clear understanding of their use. If possible, I will also contribute to these open source projects to implement these tools in a side project before doing for the capstone. This way I can be ready to implement in our project.

Understanding of Python's performance characteristics and common code smells.

I will enrol in online courses since they include structured learning for these tools to optimize Python code. These courses also include hands on exercises that I can practice solidifying my skills for identifying performance bottlenecks and avoiding code smells.

Experience in using libraries like rope for automated refactoring and familiarity with integrating linters such as Pylint or Flake8 into the development workflow.

I plan to follow comprehensive tutorials as these can break down complex topics into manageable subtopics, therefore helping in gradually building experience in these libraries. I can follow them at my own pace, so I have time to both experiment and troubleshoot. This way I can fully grasp the process of integrating these into Python projects.

Ability to develop algorithms that analyze and compare different refactoring strategies, using tools like PyJoule for energy profiling.

I plan to conduct research on analyzing the energy impact on various code structures using PyJoules. This way I can gather data to make informed refactoring decisions. This also opens up the opportunity to develop more efficient algorithms that can optimize performance and energy usage in Python applications.

Proficiency in JavaScript or TypeScript, as most VS Code extensions are developed using these languages.

Taking online courses tailored to JavaScript or TypeScript for extension development would give me a deeper understanding of how these languages are used in developing VS Code extensions. These focused courses include key concepts and best practices, helping me quickly become comfortable in the exact skills needed for extension development.

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