Mobile Energy Efficiency Services

Co-promoted Project ID: CENTRO-01-0247-FEDER-047256

E1.2 . Project's Technical-scientific Poster

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1 Introduction

This section contains a brief introduction to the **Greenstamp** project, with its motivation and objectives. At the end of the section, one may find the description and objectives of the task being studied in this document. This general introduction aims to give the context of the project to new team members who participate in only one task.

The rest of the document contains the necessary sections for the research and development of the task being addressed.

1.1 Motivation

The importance that mobile devices have in our lives is such that it is difficult to imagine our daily activities without their use. The use of smartphones, tablets and, more recently, wearables such as smartwatches, has changed and simplified not only the way we communicate, but also the way we have fun, individually and collectively, or the way we work and do business. In fact, the number and scope of mobile apps seem limitless, but users still have increasing expectations about them. The distribution of such applications is highly facilitated by digital markets, which democratise the opportunity to market software to mobile devices. In 2017, the number of mobile applications installed was 178 billion, a figure estimated to grow to 258 billion in 2022.

While much of the app market is targeted at mobile devices, whose autonomy depends on the limited battery life, the fact is that today's markets do not provide any indication of the energy efficiency, absolute or relative, of the applications they offer. With this gap in mind, in the **GreenStamp** project we propose to investigate and develop innovative mechanisms for analysing and cataloguing the energy efficiency of mobile applications integrated into app store processes. Pedagogical recommendation systems for developers will also be studied, on how to improve the efficiency of their applications, and for users, of energy-efficient applications aligned with their profile. The objective is to reduce at least 20% of the energy consumed by applications that follow the technical recommendations proposed and, inherently, of the mobile devices where they are installed, thus contributing to a significant savings of resources consumed in the mobile market, particularly and immediately by the large user base of the company promoting this project (250 million unique users active in 2019).

1.2 Objectives

The **GreenStamp** project aims to investigate and develop techniques and technologies capable of analysing, cataloguing, and informing about the energy efficiency of mobile applications and how to optimise it, thus reducing the energy consumption of the mobile market. This goal is realised in direct impacts on the wide range of citizens who are consumers of apps, mobile application companies and app stores.

As for app consumers, the impact will be first and foremost on your satisfaction. This will come from the certainty that you can have energy-efficient applications that optimise your device's resources, rather than having applications that, in some cases you're usually unaware of at first, drain your mobile device's limited energy resources with excessive and unnecessary battery consumption. This certainty will be achieved by providing information on the energy profile of applications at the time of their choice and installation, and through a system of recommendations to be investigated. Such knowledge will allow consumers to opt for energy-efficient solutions, as is currently the case in other markets (home appliances, automobiles, real estate, and others), thereby optimising the energy performance of their device and increasing the autonomy time of the device. Thus, a user who chooses efficient applications, will charge your device less often, will have a lower cost in your energy bill and reduce the risk of developing nomophobia, with the certainty that the energy consumption of your applications is great.[1]

1.3 Main contributions

To achieve the strategic objective and impacts mentioned, this project aims to research and develop highly innovative techniques and technologies, unparalleled in the market. They are translated into the following technical-scientific objectives:

- Investigate and conceptualise new systems for the acquisition, processing and analysis of data related to the energy efficiency of mobile applications;
- Investigate and conceptualise innovative machine learning mechanisms and cataloguing energy consumption patterns of mobile applications based on static and dynamic data;
- Investigate and conceptualise ways to information to users about the energy efficiency of apps, and relevant recommendations related to this factor;
- Investigate and conceptualise models and mechanisms of technical and action-oriented recommendation to mobile application promoters, on how to optimise this parameter in their products, in an integrated way in their practice;
- Investigate and conceptualise a new interface to support decision and system management.

[1] https://www.infopedia.pt/dicionarios/lingua-portuguesa/nomofobia

2 Description of Tasks

T1.1: Research on energy efficiency analysis of mobile applications in centralised and decentralised Cloud architectures

Leader: UBI; **Participation**: UC and CMS; **Output**: E1.1

To support and justify technological and scientific choices as well as to motivate innovation in the proposed solutions, we will lead a thorough and exhaustive analysis to the state of the art over 1) the techniques of evaluation (of efficiency) energy; 2) the computer support platforms for such evaluations; 3) a classification of such mechanisms (automatic, semi-automatic, with or without preparation/prior instrumentation of the mobile code by analysing, on source code, on executable code, etc.).

A particular emphasis will be placed on architectural solutions and their impact on the potentiation of such analyses. If a Cloud architecture is consensual, many alternatives within this technological context are possible: how to break down the computing, a file, a data collection? What will be the impact? Centralised? Decentralised? It will be relevant to establish how these issues impact the state of the art. Aspects such as availability, resilience, confidentiality, impact on the personalization/fairness of the analysis (etc.) will be studied.

The whole study will deal particularly with the survey of knowledge in the technological ecosystem of app stores, according to the solution that was specified, or, due to the dissolving of innovation, in other systems where energy efficiency analysis is performed. An exhaustive knowledge base will be created on app energy efficiency analysis, using dynamic or static analysis, in centralised Cloud architectures (centralised processing), decentralised architectures, users' or developers' devices, and hybrids. This work will make it possible to advance the following tasks in an informed manner regarding the existing technical-scientific knowledge.

The scientific skills of UBI team members and employees, in particular the study of centralised vs. decentralised models, lead to the choice of leadership in this task.

T1.2 - Requirements of the data analysis, acquisition, and processing system

Leader: UC; **Participation**: CMS; **Output**: E1.1.

The objective of this task is to identify functional requirements, technical constraints, quality attributes and business objectives that influence the architecture, development, validation, deployment and maintenance of the system of analysis, acquisition and processing of data. This system is anticipated to consist of a developers-side static analysis component, a user-side dynamic analysis component, and a centralised orchestrator component on the app store side. To achieve this goal, the following actions will be carried out:

- Requirements' elicitation: it will be carried out through interviews, by the development team to all stakeholders of the project and by the analysis of the state of the art and current practices in this field. The promoters should promote workshops, with the participation of stakeholders, dedicated to elicitation, analysis and validation of requirements and quality attributes.

- Requirements' analysis: trade-offs, or conflicts, will be identified between the identified requirements; user stories will be developed to document the identified requirements, as well as quality attribute scenarios; metrics to develop and validate the system will also be identified.
- Documentation: After the previous step, the identified requirements and quality attributes will be recorded and specified in a document that will contain all requirements relevant to the software architecture.
- Validation: The document will be validated by stakeholders.
- Management: Throughout the implementation, this being a research project, it is expected that changes to the requirements will arise and that there will be unidentified restrictions at the outset, both situations may result in requests for changes to the requirements and quality attributes.

The results of this task will be used to formulate in an articulated way the technical-scientific roadmap in T1.5 and will feed the beginning of the research task that will seek to meet the requirements raised here in A2.

UC leads the task based on the scientific skills of its team, and in particular its experience in requirements gathering other systems currently in production in the industrial context.

T1.3 - Requirements of machine learning and profiling mechanisms of application energy consumption patterns, and recommendation systems for stakeholders

Leader: UBI; **Participation**: CMS; **Output**: E1.1.

This task focuses on the mechanisms of machine learning and profiling of patterns of energy consumption of apps, and from recommendation systems to stakeholders. As in the previous task, the objective of this task is also to identify functional requirements, technical constraints, quality attributes and business objectives that have influence on architecture, development, validation, deployment and maintenance of learning, cataloguing and recommendation mechanisms.

The success of this goal will be supported by the elicitation and analysis of requirements, preparation and validation of the documentation, and a dynamic management that reacts to any necessary change in the face of changes in requirements and other restrictions and problems that may occur.

This task will feed the development to be carried out in activity A3, and UBI is the leader of either this task or the said activity.

T1.4 - Requirements for decision support interface and management, and recommendation channels

Leader: CMS; **Participation:** UC; **Output**: E1.1.

This task will unite the knowledge generated in the T1.1 task to implement participatory design with users similar to end users, to meet the requirements of the decision support interface and management, and the channels of recommendations to users and developers regarding the energy efficiency of apps. to define the interface-specific initial requirements. On the other hand, they will be considered members of the team that develops the application distribution system to better understand the requirements of recommendation channels to mobile users and developers. If it is necessary, end users of the app store, users and developers of apps will also be used. from various geographical points that collaborate with the company informing the needs and characteristics of users of various geographies. This strategy of involvement of the main stakeholders from the initial moments will make them feel co-authors of the innovative technology that comes from, which will promote their acceptance at the end of the project.

In conjunction with tasks T1.2 and T1.3, the requirements to be raised in this task are related to three distinct interfaces. On the one hand, it is intended to adjust and detail the solution proposed in this application in terms of the interface of decision support and management of the system. On the other hand, it is intended to define the requirements in terms of recommendations (and recommendation formats) that application developers value in terms of optimising the energy efficiency of their applications. The third strand concerns recommendations to mobile app consumers, and their requirements in terms of what is valued and useful in terms of app energy efficiency on consumer devices.

The stakeholders consulted here will be again in each phase of evaluation of the solution (activity A6), informing R&D with the real needs of the market where the results will apply throughout the project.

The results of this task will inform and launch the a4 activity research roadmap. Because this is a task that will lead to an app store management platform, and because it has the technical resources that by its experience are appropriate for the development of the table, Caixa Mágica will lead this task.

T1.5 - Specification of the functional architecture and *technical-scientific roadmap* of the project (M4-M5)

Leader: CMS; **Participation:** UC, UBI; **Output**: E1.2.

Task T1.5. aims to consolidate the studies of this activity in an architecture that demonstrates the expected functionality for each component, for each module of each component, and the role of each of these elements in the solution. This architecture will be represented in a technical-scientific poster that will illustrate the *planned functional roadmap*, as well as the vision and objectives of the project. It is expected that this poster will be the first element of public dissemination of the project and that it will be reused in several events to introduce it.

Because this task aims to articulate the knowledge from the previous ones, the three promoters of the project are involved.

3 Technical-scientific Poster & Architecture

This section presents the current state of technology regarding green computing applied to mobile devices. The research available is presented and discussed in three different sections, each focusing on a key aspect of this thesis that will later prove itself useful in the development of the solution in which the thesis is focused on.

The initial definition of the project architecture can be depicted in Figure 1:

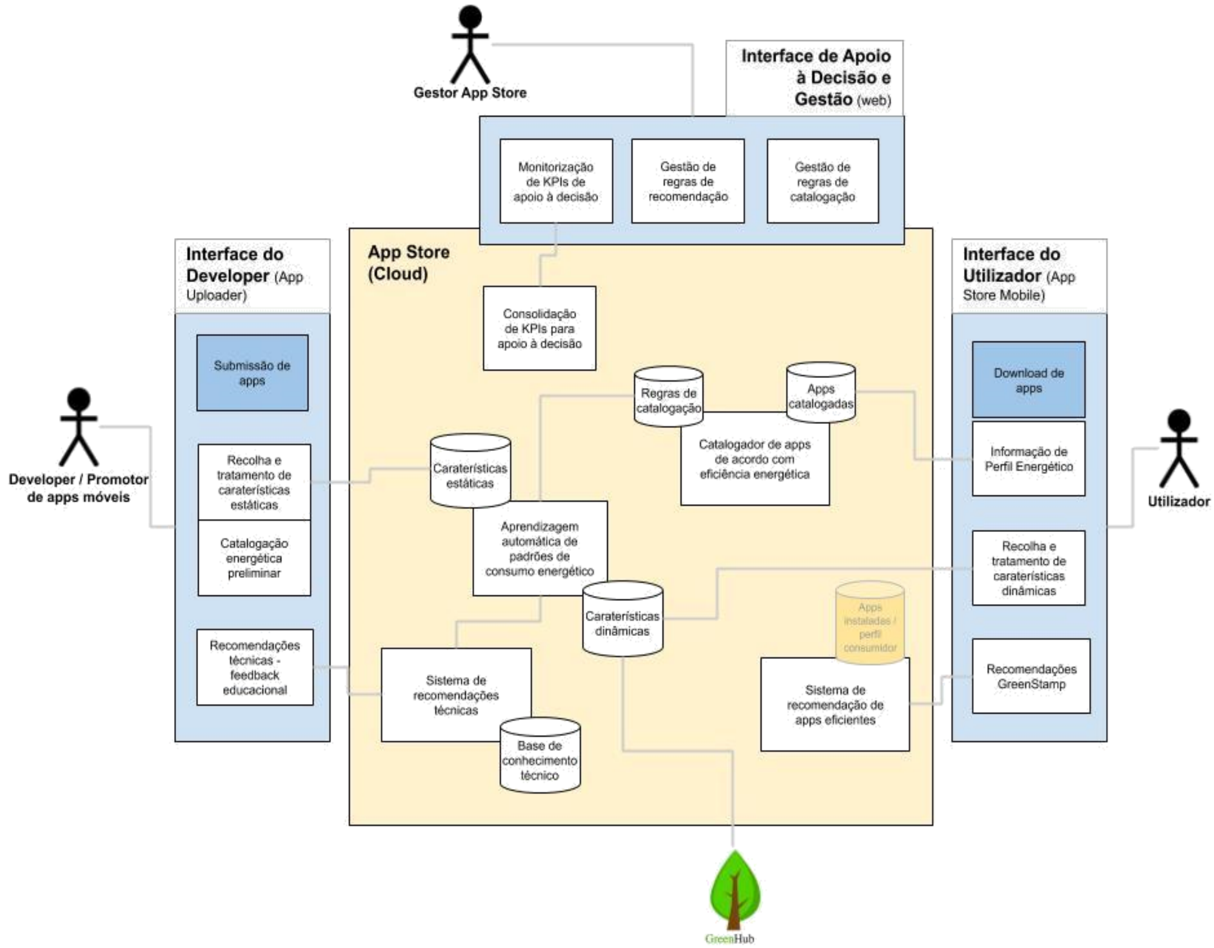

FIGURE 1: GREENSTAMP INITIAL ARCHITECTURE

The central idea is to present framework which has a common core, a cloud-based platform to support the App Store, where the definition of the energy awareness mechanisms and where the best-practices in the area are established, and client modules, split into three different areas, each targeting a specific stakeholder.

3.1 Greenstamp Core Components

Component 1: Mechanisms for acquiring, processing and analysing energy efficiency-related data

Collection, processing and analysis of data related to energy efficiency. This data translates into static and dynamic characteristics of the mobile applications related to their energy behaviour.

Static application analysis refers to the analysis of the source code of the application, and in this case, we will look for software development practices that influence the energy efficiency of the mobile device.

We want the collection of static characteristics of applications to occur in a decentralized way, that is, on the developer's device, when the application is submitted to the app store.

This approach will mitigate challenges inherent in the centralized analysis of many thousands of applications per day, and may even allow to overcome limitations inherent in code obfuscation (a practice of developers for intellectual property protection, which makes it difficult for third parties to centrally analyse applications, but which is sometimes also used to hide malicious practices).

Dynamic analysis refers to the behaviour of the application when it is running, and in this case, we will seek to collect behaviours that affect the energy performance of the application. We will seek to do this using a decentralised approach, in this case, with collection taking place on consumers' devices.

In this context, of collecting dynamic data on energy efficiency in a decentralized way on mobile devices, this project benefits from both the experience and data already collected by the GreenHub (https://greenhubproject.org/) project, carried out by researchers from the University of Coimbra and the University of Beira Interior, co-promoters of this project.

This data, although not directly related to apps but rather to the mobile device as a whole, is particularly relevant, as it can be the starting point for, in conjunction with information about the applications running on millions of devices (to which Caixa Mágica, with its app store, has access to offer updates), infer dynamic behaviour of applications in terms of energy efficiency.

It should be noted that the collection of dynamic data on consumer devices is computationally much less demanding than the centralized approach, as it consists merely of the collection of static data at each moment (such as current battery capacity, running applications, resources to be used, among other data whose relevance will be studied in the project).

The number/periodicity of state snapshots that will characterize the dynamic behaviour of the applications will be studied throughout the project.

In addition to static and dynamic analysis to acquire data on mobile applications, other methods may also be considered, such as the use of the app store's flag system to allow users to flag applications that they consider to have an abusive energy consumption and, based only on these signals, trigger dynamic analysis.

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As for data processing, it is expected that some manipulation / preparation of the captured information will be necessary in order to optimize the way it is transmitted to the centralized Cloud infrastructure.

It should be noted that the techniques and technologies to be developed for the acquisition, processing and analysis of data, both on the devices of developers and consumers, will respect all the principles of data protection law, particularly those of privacy by default and privacy by design.

Component 2: Machine learning engines and cataloguing energy consumption patterns in apps

Development of a self-evolving system capable of automatically learning new patterns of energy consumption in mobile applications, positive or negative.

This component concerns such intelligent mechanisms. These mechanisms will result in an update of the rules for cataloguing mobile applications, based on the discovery of new factors that influence their energy efficiency.

The discovery of new energy consumption patterns (positive or negative) should give rise to a process, ideally automated or semi-automated with human supervision, of creating technical recommendations to be provided to developers, for optimization of negative consumption patterns (possibly based on functionally equivalent positive consumption patterns found).

Component 3: Models of information and recommendation for app users

Provide consumers with information about the energy efficiency of the app when they are looking for an app to install on their device similarly of how it's done in other areas (see Figure 2):

- Providing clear information on the energy efficiency of applications
- Recommendations for energy-efficient applications

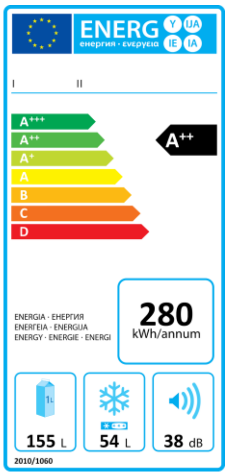

FIGURE 2: ENERGY CONSUMPTION LABEL

Component 4: Technical/pedagogical and action-oriented recommendation mechanisms for mobile app developers

Provide developers, at the time they submit an app for distribution on the app store, with systematic and detailed reports with information regarding:

- Energy efficiency of the app, both relative (compared to other similar apps) and absolute.
- Concrete, specific, action-oriented technical suggestions to improve the app's energy efficiency.

Develop techniques and technologies, integrated into the app submission platform, therefore, in the developer's daily practice, capable of evaluating the application at the time of submission and providing a pedagogical and clear recommendation on how to act.

This processing is intended to happen on the developer's side.

This interface should be regularly updated with the rules for classification/cataloguing of applications, allowing an analysis and cataloguing of the application without it leaving the developer's device.

The knowledge base for these technical recommendations may come from human knowledge, manually loaded into the decision support and management interface (for well-known rules), and from machine learning mechanisms (perhaps supervised by a human agent) that will infer good and bad practices in the development of energy-efficient mobile software, and, through the recommendation system, seek to suggest good practices functionally equivalent to bad ones that have been found in the application

Component 5: Decision support and management interface

Interface for monitoring, decision support and management of the GreenStamp ecosystem

This interface aims to:

- Enable the monitoring of the system's decision support KPIs, e.g., the number of applications of each energy category in the repository.
- The evolution, expected improvement, of the energy efficiency of this set over time.

Monitor KPIs to understand whether users are selecting energy-efficient applications over non-energy-efficient applications.

An analysis of the effectiveness of technical recommendations to developers should be allowed, e.g., through dashboards that allow understanding the energy evolution between different versions of the same application, or between different applications of the same developer.

It can also be ascertained which efficiency problems (static or dynamic characteristics that negatively influence energy consumption) have been detected by the system that do not yet have a technical solution to be suggested to developers, and what is the incidence of these problems (in how many applications have they been detected).

Management of recommendation rules and the management of cataloguing rules:

In the management of recommendation rules, the human operator will be able to assess the factors related to the recommendation systems to users and developers. Examples of user recommendation system benchmarking can be the definition of the energy threshold from which an app can be suggested as energy efficient, or whether other factors should be considered, such as e.g., the popularity of an app (e.g. only suggesting energy efficient apps with a rating above 4, or with more than 5,000 downloads). With regard to the assessment of the technical/pedagogical recommendation system to developers, the human operator may be responsible for introducing technical solutions to energy problems encountered. You may also be responsible for accepting suggestions from the machine learning system, or helping the machine learning system, e.g. by indicating that a particular energy-efficient development practice is functionally equivalent to an energy-inefficient one.

In the management of cataloguing rules, it may be the case that the human operator can define energy levels/profiles according to the studies carried out, which are clear to app consumers. In addition, also according to the research, the human operator will be able to accept or reject cataloguing rules inferred by the machine learning system. This may be especially relevant if, in the course of the investigation, it is seen that there is a need for some relativisation factor, e.g. according to the types of applications. This may be because, if the system sees all applications as equal in terms of energy efficiency, it may be the case that very simple applications (e.g. a calculator) are always very efficient and more complex applications (e.g. a game that uses multiple sensors and network) are always very inefficient.

3.2 Greenstamp User Interfaces

The architecture foresees its specialisation into three different stakeholders interfaces, one targeted to the developers, which encompass IDE integration and tools that assess the energy efficiency of the developed apps, another targeted to the App Store Managers, which allows them to show on their app store the classification of their stored apps, as well as performing multiple static and dynamic tests on their sandboxes, and to distinguish the various apps in terms of their energy efficiency. Finally, an end user interface allows final users to assess downloaded APKs to determine their energy efficiency and get best practices in terms of how to use their mobile device in the best possible way.

The current definition of the architecture was presented at events FISTA 2022 (at ISCTE-IUL). Then the architecture definition was specialised considering the architecture of the Caixa Mágica/Aptoide environment and a final specification was defined in

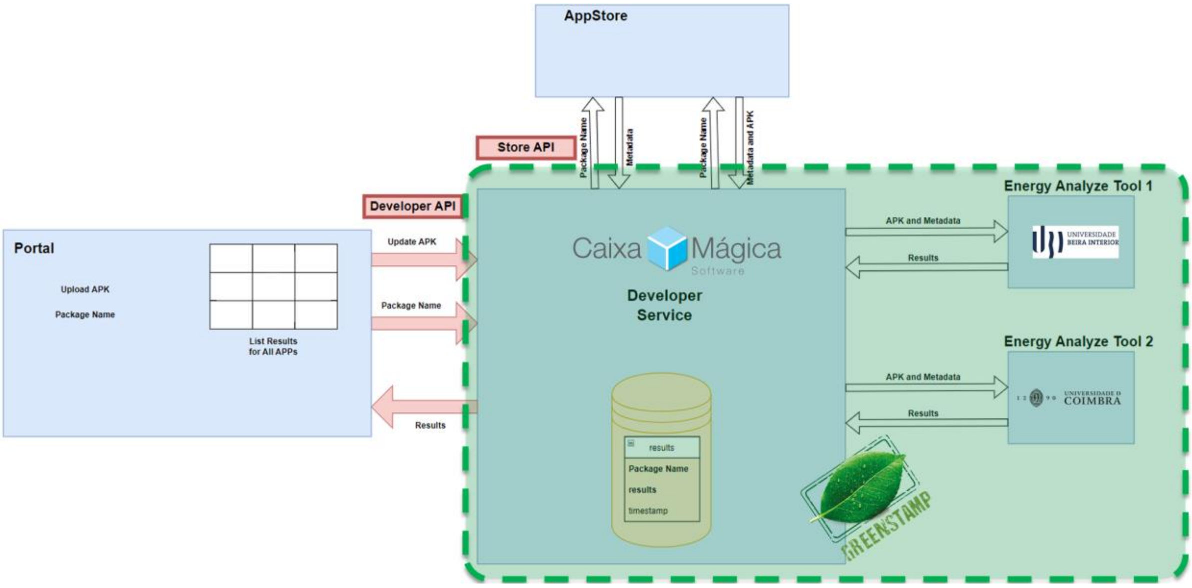

FIGURE 3: UPDATED ARCHITECTURE DEFINITION

The new architectural definition shows a specific service to be provided to the App Stores, and a common Portal which is accessible by developers and end users.