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ExergyX as an Educational Game

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Abstract

ExergyX is an energy management game, composed by a serious game model, which calculates emissions, efficiency ratio, aggregated efficiency and many others, based on the player's investment in renewable power. The main purpose of this game is to enrich students' experience in the learning of new concepts, such as understand the relation between energy and economic growth, realize what exergetic efficiency depends on and how it is possible to increase it, understand the paths for the carbon neutrality of the economy, and understand the difficulties/limitations of renewable electricity.

In this document, we explain our objectives of integrating the game in an IST course as well as on a MOOC. We provide an explanation of the background of the project, analysing the previous version of the game. Afterwards, we describe in detail the development process of the new version, which includes a renovation on the user interface, improvement of user interaction with the game and additions to the game model.

Next, we describe a user testing process with 24 participants, where each one had to fill a user experience questionnaire (UEQ), a system usability scale (SUS) questionnaire, and three open answers, providing their opinion about the game. We then analyse their answers for each one of the three components, conducting an adequate analysis for each of them, rating the application in two different aspects: user experience and system usability.

Finally, we conclude our work, identifying what is left to be done in future work. We believe that after finalizing these topics, we are able of conducting an experiment in a real life scenario, integrating the game with the IST course, measuring its impact on the learning process.

Keywords: Game-based learning, educational games, educational technology, energy management.

Resumo

ExergyX é um jogo de gestão energética, composto por um modelo de jogo sério, que calcula as emissões, índice de eficiência, eficiência agregada e muitos outros, com base no investimento do jogador em energia renovável. O principal objetivo deste jogo é enriquecer a experiência dos alunos na aprendizagem de novos conceitos, tais como, compreender a relação entre energia e crescimento económico, perceber de que depende a eficiência exergética e como é possível aumentá-la, compreender os caminhos para a neutralidade de carbono da economia e perceber as dificuldades / limitações da eletricidade renovável.

Neste documento, explicamos os nossos objetivos de integrar o jogo num curso do IST, bem como num MOOC. Fornecemos uma explicação dos antecedentes do projeto, analisando a versão anterior do jogo. Em seguida, descrevemos em detalhes o processo de desenvolvimento da nova versão, que inclui uma renovação da interface, melhoria da interação do utilizador com o jogo e adições ao modelo do jogo.

Descrevemos também um processo de teste de utilizador com 24 participantes, onde cada um foi solicitado a preencher um questionário de experiência de utilizador (UEQ), um questionário de usabilidade do sistema (SUS) e três respostas abertas, fornecendo a sua opinião sobre o jogo. Em seguida, analisamos as suas respostas para cada um dos três componentes, realizando uma análise adequada para cada um deles, avaliando a aplicação desenvolvida em dois aspectos distintos: experiência de utilizador e usabilidade do sistema.

Por fim, concluímos o nosso trabalho, identificando alguns tópicos sobre o que ainda há para fazer no futuro. Acreditamos que após a finalização destes tópicos, seremos capazes de realizar uma experiência num cenário real, integrando o jogo com o curso do IST, medindo assim o seu impacto no processo de aprendizagem dos alunos.

Palavras-chave: Game-based learning, educational games, educational technology, energy management.

Acknowledgments

With the completion of this master's thesis, a cycle is closed from which I retained several lessons and learning that I will take with me. Along the way, I encountered immense challenges, sadness, uncertainty and joy that are part of the process. I was able to complete this work because I had several people with me, motivating, guiding and advising that were indispensable to find and follow the best path. These words serve to show them my gratitude.

First, I would like to thank my parents for all the emotional and financial support through my entire academic path. Without them, this would never be possible.

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List of Acronyms

IST	Instituto Superior Técnico
MOOC	Massive Open Online Course
SDG	Simuladores e Modelos de Gestão
GMC	Global Management Challenge
ISTMC	Instituto Superior Técnico Management Challenge
UI	User Interface
DPE	Design, Play, and Experience
GDP	Gross Domestic Product
SPA	Single-Page Application
DOM	Document Object Model
MVC	Model View Controller
GHG	Greenhouse Gas
NPS	Net Promoter Score

1. Introduction

In this chapter, we explain the context and the goals of this project. We also present the followed research methodology and the dissertation structure.

1.1. Context

Through the years, the game industry has been rising a lot due to the technological evolution, which attracted more and more people, substantially those in younger ages. We believe kids have a facilitated access to games nowadays in comparison with ten years ago. They take part in the routine of many people, some as an entertainment activity, others as a way of socialization and connecting with others, and some people even rely on games as their professional way of earning money. This huge development is so real that a new sports segmentation surged in order to fulfil the demand, the so-called E-Sports.

The usage of games as a learning tool has been studied and applied with success, and therefore, *ExergyX* emerged as a means to change the current and traditional learning system. It is an energy management game, where students are challenged to embrace the role of a government advisor, with the responsibility of investing money on the country's energy development. It surged as a thesis project where, during that time, they developed a very real and serious model, composed by complex equations, aiming to reproduce a reliable simulation environment [1].

1.2. Objectives

In this dissertation, as a main goal, we propose a significant improvement to *ExergyX.* As we described before, the game has a very complex, serious and reliable simulation model, however, after analyzing the previous version of the game, it was notorious the need for improvement in the user interface implemented on the game. Therefore, we propose a significant enhancement on the game frontend layer, changing it completely, hopping to provide an engaging user experience. Additionally, aim to improve the game's playability by adding variety and new dynamics to it.

We also propose an improvement on the game model, adjusting or adding components to fit our needs and what we believe is best for a better gameplay experience.

1.3. Research methodology

In order to achieve our goals, we had to plan our time and define a timing for each step.

Our planning was divided in four phases:

1. **Analysis phase:** In this step, we performed an exhaustive analysis on the previous version of *ExergyX*, where we identified the problems needing improvements. In this step, we also took in consideration the feedback received from specialists, where they pointed out some ideas and suggestions for the game.
2. **Discussion phase:** Afterwards, we got together to discuss what we collected from the previously mentioned analysis. Then through some weeks, we talked about our ideas to improve the game, never forgetting the suggestions, but also measuring what could be done in the available time. When we came to a conclusion, we started to define our priorities regarding the implementation of those changes.
3. **Development phase:** This was the longest and laborious step. Since we started the user interface from scratch, we had a lot of work to do and had to readjust throughout the implementation of the new features. During this process, we had some periods to discuss the state of our work and align on new possible features, analysing if there was enough time to deliver them. For this phase, we received support from an artist, who was responsible for the design of an interface, and suggesting a new visual representation of the game, which we integrated in the game.
4. **Testing phase:** Once we completed the development phase, we conducted a testing experience. This step was crucial to support our work, since until that moment the only critical analysis had been done by ourselves. We also considered very important to understand what is needed for future work and what was not so successfully implemented, in order to provide a great version of the product to students, when using the game as a learning tool.
5. **Second Analysis phase:** Finally, we once again conducted an analysis phase, where we went through the feedback resultant from the testing phase. We were able to evaluate our work regarding user experience and system usability. With the obtained feedback, we were able to define what is left opened for future work.

1.4. Document structure

This document is composed by seven chapters and is organized in the following way: Introduction, Related work, Conceptual Solution, Analysis on the alpha version, Implementation of the beta version, Evaluation and Conclusion. Chapter 1, Introduction, introduces the context, the goals of the project along with a brief discussion of the research methodology and document structure. Chapter 2, Related Work, presents and discusses some games relevant to our project wither because the subject or their implementation. Chapter 3, Conceptual Solution, presents a game design framework relevant for our

project, explaining how we incorporated it in our project. Chapter 4, ExergyX: Alpha Version, presents an analysis on the previous version of *ExergyX*, pointing out improvement objectives. Chapter 5, ExergyX: Beta version, we explain the development steps of the new game, as well as new adittions to the game model. In Chapter 6, Evaluation, we explain a testing process, and its results, that we conducted in order to evaluate the developed work. Finally, in Chapter 7, Conclusion, we present a final analysis of the developed work, the contributions for this project and future work.

2. Related work

In this section, we present some work related to the project that we considered in the analysis and development phase. Some of them were introduced in courses at universities and so, they represent an example regarding serious games and reliable game models, and others are inserted in the same subject as *ExergyX*, which is management games. Since one of our goals is to enhance the user interface of the game, it is also important to have this topic in mind when analysing and studying other games, so that we can compare and draw conclusions from that analysis.

2.1. IST Management Challenge

In 1980, SDG – Simuladores e Modelos de Gestão in collaboration with EXPRESSO journal, founded the Global Management Challenge (GMC), a strategy and management competition, involving both the business and university environments [4].

It is currently present in more than 30 countries and has engaged over 650 thousand participants worldwide since its first edition. Later, in collaboration with Instituto Superior Técnico (IST), they founded IST Management Challenge (ISTMC). Which is a strategy and management competition integrated in Management subject which integrates some courses at IST.

Each team, between 3 to 5 elements, assumes the role of a company's board of directors during the next 5 quarters. For that, the group has to analyse the recent past of the company, outline a medium-term strategy, make high responsibility decisions within various areas of the company and analyse the results obtained, taking into account the competition and the economic situation of the market.

This competition aims to increase strategy skills and management, teamwork and detect students with higher potential to be the best managers and future CEOs.

From our analysis, we conclude that this game is an excellent example of a serious game. The model behind is reliable and very accurate, simulating real word scenarios also in the scope of management. However, its UI is very poor, since students only have to fill an excel sheet and submit. We believe students would feel even more engaged if the UI would be somehow improved.

2.2. Cities: Skylines

Unlike the game referred above, *Cities: Skylines* was not created with an educational purpose. It is a strategy game where players engage in urban planning by controlling zoning, road placement, taxation, public services, and public transportation of an area.

Players work to maintain various elements of the city, including its budget, health, employment, and pollution levels.

The developer's goal was to create a game engine capable of simulating the daily routines of nearly a million unique citizens, while presenting this to the player in a simple way, allowing him to easily understand various problems in their city's design. This includes realistic traffic congestion, and the effects of congestion on city services and districts.

This game is being used both in an urban planning and in an educational context, as the game has an education edition since 2018, resulting from a partnership between *Paradox Interactive* and *TeacherGaming*. [5]

One of the main factors responsible for making this an extremely engaging game is the immersive environment capable of captivate the user attention for several hours. We can also notice a very good balance throughout the gameplay, avoiding it to be an extremely impossible game, which would turn it in a very annoying game to play, but also not making it too obvious, implying the user to define a strategy.

Summarizing, we conclude that this game is a good example when it comes to in-game balance and user interface, something we tried to improve in *ExergyX*.

2.2.1. The urban planning context

In Stockholm, Sweden, this video game helped shape a new development. City planners were using the game to let citizens try out their own ideas and contribute to the city's development [6].

Additionally, urban planners in the United States also used *Cities: Skyline* for consultation exercises and planning competitions. [7]

For the purpose of our work, this is a good indicator regarding the simulation model running in the game, since *ExergyX* also has a simulation model whom was reviewed and changed during our project's development phase.

2.2.2. The educational context

Steve Connelly is a senior lecturer who delivers a module titled "Sustainable Development: A Critical Perspective" at the University of Sheffield in the United Kingdom. He used this game as a complement to the referred subject. He found that this game lacks the representation of certain social factors. However, he encouraged the students to use that game to critically reflect on and discuss how the game differed from reality. [7]

In his words, the use of the game was a lever, it was not the be all and end all, it was not the thing that everything hinged on, it was kind of a pivot point for them to reflect on some of the theoretical concepts that students were exploring in the sessions. Connelly reported that despite positive feedback from students, there was no major improvement in the quality of the submitted work.

Having this ambitious goal of incorporate *ExergyX* in at least one course at IST, we certainly took in consideration other previous studies, like this one, in order to analyses what would suit best in a learning environment regarding the design of our game.

2.3. SimCity

SimCity, similarly to Cities: Skylines, it is a city management game.

Vanessa Haddad, Assistant Professor and chair of Liberal Arts, General Studies at the State University of New York (SUNY) Erie in New York, United States, has used this game as a tool to teach an introductory sociology course.

She describes that students were able to make connections between very basic functional perspectives, thus making the game a good and semi-successful tool, considering a variety of technical problems when using the game, for example problems with firewall, licenses for usage and hardware requirements to run the game. [7]

In Germany, Heinrich Söbke of Bauhaus-Universität Weimar, delivers a technical infrastructure management course, and adopted SimCity4 as a tool to help students understand the many interdependencies in a complex system. He divided the students by groups, and then each group's screen was projected on the wall, so the whole class can observe the progress of each group. The Activity was divided in three different supervised sessions. The first one was intended to familiarize students with the game, then, in a second session, students played in a given scenario where the city zones were already laid out. Finally, in the last session, students were encouraged to develop their own scenarios from scratch.

The professor's opinion about the game's impact in students' education is that they come away with an understanding of infrastructure planning and the need to "react immediately to an imbalanced development". [7]

Another study, conducted by two professors in the Department of Geography Education, in South Korea, measured the pedagogical benefits of SimCity in Urban Geography Education. A total of thirty-three students, enrolled in an urban geography course, participated in this study.

The general opinion about the use of SimCity as a learning tool is that students were able to enhance a variety of skills, namely, students' engagement with the course, their theoretical knowledge, critical thinking, and creativity applicable to the subject. [8]

They were challenged to plan and build their own cities, having in consideration different concepts of Urban Geography. In the end of the semester, the analysis of this method was based in three different stages.

The first one was the analysis of the students' constructed cities. In addition, for that the professor created a data set to categorize the students' cities according to the main themes. The expected

outcome of this analysis was to reflect and understand which principles and ideas of the subject taught were incorporated by them.

For the second step of the analysis, the main goal was examining the students' response to this educational approach. For that, the participants were asked to answer a quantitative questionnaire to investigate how they responded to their learning activities. Then, a qualitative analysis was conducted to understand and identify the main themes.

Finally, the third step of the conducted analysis was the creation of a word cloud using the students' performance reports.

This study revealed that using SimCity in the referred course was successful and beneficial for students, based on the conducted analysis, leading to a positive pedagogical effect. The participants critically evaluated whether theories that they learned in the urban geography course worked properly in SimCity.

This is a very similar example to the Cities: Skyline. Although, this has a very detailed study that we analyzed for future work, when we introduce students to the game. Additionally, it is relevant to point out the outcomes of the previously described experience. Students felt more engaged with the course just by simply adding a new learning tool. In addition, we can observe a comparative analysis between the game model and the real world, encouraging the students to develop their critical thinking about it.

2.4. En-ROADS

En-ROADS, a climate change solutions simulator, developed by Climate Interactive1, Ventana Systems2, and MIT Sloan3 is a policy simulation model. Different from previous works already discussed, this one in particular has a very similar purpose to ExergyX.

In En-ROADS, the user has the opportunity to design their own scenarios to limit future global warming. Comparing to ExergyX, the user also has the opportunity to define a strategy with the goal of leading the country to a cleaner and more sustainable future, by investing in renewable power, electrification policies or economy distribution policies, accordingly to a previously stipulated budget [9].

Accordingly to their information, En-ROADS has already been used by a wide range of people, including members of the U.S. Congress, HSBC bank, the Hewlett Foundation, local community groups, the UN Secretary-General's Office, university professors around the world, leading science educator Bill Nye, and many others.

[1] Visit corporation website: *https://www.climateinteractive.org/*
[2] Visit corporation website: *https://www.ventanasystems.com/*
[3] Visit corporation website: https://mitsloan.mit.edu/sustainability-initiative/welcome

For our project, we consider very important to have a simulator with all this usage because for future work we certainly need to revise our model and proceed to any possible adjustments, and having a reliable simulation model like En-ROADS, represents a huge possibility for comparing information and obtained results.

2.5. Analysis

After our study on the state of art, when it comes to games being used as educational complements, we can observe that not only they serve their purpose as motivational factor, but also as a way of improving students' critical thinking. Some games inserted in the simulation scope sometimes fail to provide a real and trustworthy representation of the real world, and yet they can be used as a model for comparison, where students can state and notice the different between the game's representation and the one they learn.

It is important to notice that some games presented in this section were not developed with an education purpose, thus making them an interesting choice to deeply analyse which feature make them into good and useful tools for education.

In each of these games, we saw some guidelines for the game that we are developing, *ExergyX,* such as design approaches, which is the case of Cities: skyline and SimCity, with a very appealing user interfaces capable of captivating the students' attention, and serious game model, which is present in ISTMC and En-Roads. For those reasons, we used each one of these games as examples on how to make a good and appealing UI and on how to provide a great model representation to the players.

3. Conceptual Solution

In this section, we will discuss what we planned for our solution. All the following suggestions are based on the results from our analysis to *ExergyX*.

3.1. Game Design Framework

Having in consideration the purpose of *ExergyX,* which consists of becoming an educational game, we previously defined a set of imperative key points, which we would ideally achieve with the final product. Those key points are mostly related with the game's playing experience, and consist on improving the UI, so the game becomes more appealing to the users. Improve the interactivity, which means the number of interactions that the user can perform and, we would like to preserve the game model seriousness, which is crucial since it is an educational game, and finally we decided to impose limits on the user control, adding elements of surprise.

We defined a game design framework to help us guide on the game's development and perform a critical analysis through several steps of the implementation process.

3.1.1. Design, Play and Experience Framework

The DPE framework was created by Brian M. Winn, as an expansion of the MDA framework to address the needs of serious game design for learning. It was built in three distinct components, identified in the name of this framework, Design, Play and Experience. [10]

This framework describes the relation between the player and the designer. While the designer is who designs the game, the player is the one that actually plays it, which results in player's experience. In this approach, the authors established a connection between Experience and Design, to point both the influence of the goals on the original design and the iteration on the design once a prototype of the game is tested against the experience goals.

The extended version of this Framework (Figure 1) tries to identify and describe the subcomponents of serious game designs, including the Learning, Storytelling, Gameplay, and user experience layers. For each layer, the model provides an analysis regarding the three main components of this framework. Then, a representation of technology appears at the bottom since the designer does not implement it but the design itself can be realized in the technology.

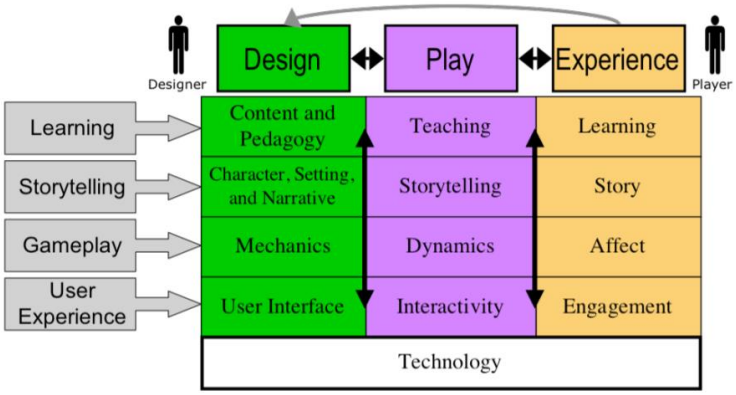

Figure 1 - Extended DPE framework by Winn

Winn replaces Aesthetics with Experience, acknowledging that the Aesthetics of a game are not directly received by the player, but experienced in an individual, subjective, and unique way. Each layer has influence over the other layers. For example, the learning will influence and be influenced by the storytelling, gameplay, and user experience. [11]

Learning Layer. In this layer, the main goal to achieve is teaching while the player plays the game. The designer has to define learning outcomes for the resulting experience and then design the content and pedagogy to achieve these goals. In our case, we developed a set of pedagogic objectives, to identify what we should add to the system in a way that we would fulfil those goals.

Storytelling Layer. The storytelling that occurs during play is a result of the combination between the designer's story and the interactions and decisions made by the player. Some games are truly focused on the storytelling aspect of the game, such as Role Play Games (RPG) or adventure games while others have too little or even none of this layer, such as simulation games.

The learning outcomes often complicate the storytelling in serious game design. When developing a game as a tool for education, it is not expected to a strong story layer, in most cases, the addition of a storytelling could deviate from the facts and the actual events being simulated. *ExergyX* does not have a strong storytelling. However, we incorporated some, by challenging the player to embrace the roll of a government advisor, with great responsibilities and decision power. Throughout the gameplay, the user is also presented with some storytelling about natural events that occur from time to time.

Gameplay Layer. This layer is responsible for defining what the player does in the game. This is, the choices and decisions that a player must make, and the impact of those choices on the following events of the game.

This framework brakes down this layer into mechanics, dynamics, and affects. The mechanics are the rules that define the operation of the game world, what interactions the player can make, the challenges proposed to the player, and the player's goals. The dynamics are the resulting behaviour when the rules are instantiated over time with the influence of the player's interactions. All the emotions that are generated by every event of the game, are the resulting experiences called affects.

The designer must ensure that goals are being reached, and to conduct this analysis he must resort to playtesting. After this process it is expected that the designer has an idea of what should be improved. This approach is known as balancing the game.

One way to implement game balancing is introducing the balancing of the level difficulty (Figure 2). The theory of flow, developed by Mihaly Csikszentmihalyi [12], states that a level difficulty should match the players skill and abilities, obtained from the experience of the playing the previous levels.

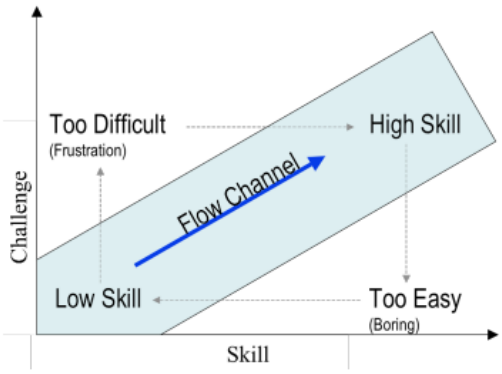

Figure 2 - Balancing the level of difficulty

Another useful method to achieve the balancing of the game, relates to the frequency of rewards given to the player, (Figure 3). In the beginning, it is important to reward the player to captivate his attention to the game. Then, as the challenges start to grow and the slope of the learning curve is more pronounced, the rewards should be given more often than before. This way the player is encourage and motivated to keep playing even if the objectives of the game are getting harder to achieve.

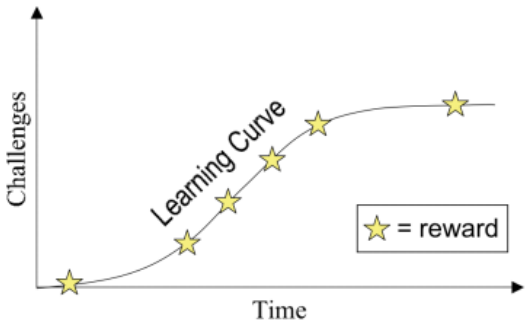

Figure 3 - Balancing the frequency of rewards

In an early stage of the game, the player is still learning and deepen his knowledge about it, so the designer may want to facilitate that process reducing the amount of choices the player can make. Like this, the player spends more time learning the game avoiding getting lost in making decisions. Therefore, through the player's progress in the game, new choices are available. The typical pattern for introducing new choices is that the designer will present the player with a new goal in the game.

In *ExergyX,* the interaction between the user and the game are quite simple. He is able to choose between a set of politics, each one with its own impact, and can install renewable power. However, it is challenging to decide which politics should be implement and in what stage of the game. Since the player has a budget and a variety of possibilities, he has to choose wisely and accordingly to the assigned budget. When investing, the player sees the impact mainly based on population happiness. This creates a feeling of contentment when the overall happiness is rising but, when it decreases, generates fear or preoccupation in the player, leading him to analyse his previous choices and deciding where he could improve.

In the current version of the game, with did not implement achievements yet. We already have it planned but, in the meantime, we were not able to concretize it. Our opinion about this topic is that when implemented, it will possibly represent a great improvement on player's engagement and motivation with the game.

User Experience Layer. This is the most visible layer in the framework from the user perspective. The user interface is the actual representation of the game, it encompasses everything the user sees, hears, and interacts with and how that interaction happens.

The ultimate goal to the designer, regarding this layer, is to create an immersive environment, where the player feels engaged with and part of, an environment that appeals to the senses creating in the user the will to keep playing it.

Through our development phase, we agreed on focusing the majority of our time in the user interface. From our analysis on the previous version of the game, we could affirm that the UI, as it was, was demotivating and falls short of expectations.

3.1.2. Decision Analysis

Based on a previous study on game design frameworks, we decided that the one that best fits our project needs is the Design, Play and Experience (DPE) Framework. We think this is the appropriated one because it incorporates three main aspects that we consider relevant for *ExergyX.* The Design level defines the components of the game, at the level of data representation and algorithms. Having this aspect in mind is also important because, based on the information that we retrieved from the feedback analysis, the lack of elements of surprise, capable of captivate the user's attention to the game, and avoiding a boring and repetitive experience. The second part, Play, which includes the gameplay, was pointed as needing improvements. The biggest problem noticed was the lack of useful feedback to the user on what was happening during the simulation process, which can lead to a poor experience for him. Lastly, we have the Experience level, which defines the user interaction with the game, and all the emotions flowing from the game to the player. This aspect was much criticized on one of our earliest analysis phase, because the UI integrating *ExergyX*'s first version was very poor and limited regarding user interactions with the game, leading to a very repetitive experience.

4. ExergyX: Alpha Version Analysis

In this section, we focus on analysing the previous UI, and some problems associated with it.

We conducted a two steps analysis, first focusing on the user interface where we discuss mainly the aesthetics of the game. Then, we analyse the gameplay, aiming to identify some problems or enhancement opportunities that will provide a better experience for the player. Lastly, we present a description on the game model.

The first version of the game went live although it was not used in any course yet. It was only submitted to some user tests by specialists in the game's subject, and to a small group of students. It is currently available at ***http://exergyx.tecnico.ulisboa.pt/oldversion*** (last accessed on 31/10/2021).

4.1. UI Analysis

Probably one of the first things that we notice when interacting with a game or an application, is the UI. The result from that experience can influence our opinion on it.

The first version of ExergyX had a poor interface, faulty and not so much user friendly. Some of their elements could cause confusion to the user or even lead them to misunderstanding the meaning of those elements because of the lack of guidelines through the playing experience.

First, we noticed the welcome screen (Figure 4), containing too much information, was not appealing to the user, and even leading them to skip it, probably without carefully reading it all. However, the information contained in there is really important and beneficial for the player, since it gives some hints on how to play the game. So we had to define a strategy where we could still provide this valuable information, but not in such a boring or distracting way. We discussed some options like and onboarding approach, where the information is divided through different steps, allowing the user to absorb useful tips and guides slowly. This way, the user can clearly understand it is a tutorial which he is able to skip at any time. We also considered implementing this component in a way that for each step of the tutorial, a certain element of the game is highlighted, helping the user to clearly relate explanation text with its element.

Figure 4 - Introduction screen from the old version

Another issue that we could find it is related with the main screen (Figure 5), which is where the user interacts and is provided with feedback on the changes after each submission. There we can observe the main content is not properly aligned and does not use the full screen width.

Ideally, the user should clearly understand which elements have additional information such as tooltips. On this first version, it is not clear where you should hover to see the tooltips and when it appears, it shows the hint text for a group of elements, making it hard to read the help text for a certain element. A better approach would be adding an info icon, which the user can easily associate with hint text, and, when hovered, shows information for its associated label. Additionally, the tooltip container should not have the same colors as the background elements, standing out from the other components.

When a submission occurs, the user sees a confirmation popup with the decisions' summary and then sees the main screen again. However, in this screen it is not clear which elements changed, he has no feedback on the decisions previously submitted. We discussed this topic and agreed on adding additional information to each label, representing the difference from the current and previous iterations. Simple adding this makes a huge difference when analyzing the information, helping to define strategies for the following decisions. Also, since the model is quite complex, we believe the game should give more information about what is happening. This problem was also identified by some specialists and exposed on their analysis, for example:

"It can improve a lot in pedagogical terms, for example with brief explanations of what is happening..."

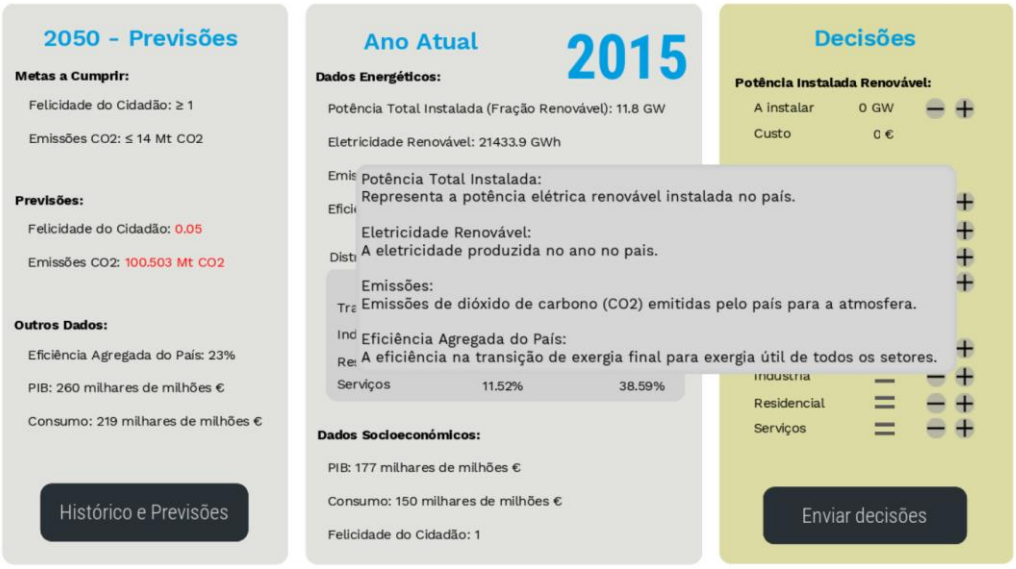

Figure 5 - Main screen from the old version

We also concluded the game lacks on the clarification of some icons and their meaning in the game context (Figure 6). In our opinion, the symbols could be improved or a brief explanation on its implication could be added. This is a crucial point because the game should be easily understandable for the students, and therefore it can lead to a misunderstanding on the game functionality.

Figure 6 - Example of an unclear UI

4.2. Gameplay Analysis

The user is responsible for making decisions that will have impact in some socioeconomic and energetic areas, in the following year. The player's decisions must be done every year, starting from 2015 until 2050 and are related to the amount of renewable energy, in GW, to install, the investment to be done in different economic sectors, and the variation of the electrification by sector. In this versions the player has to decide and simulate 35 times, which corresponds to the years between 2015 and

2050. Since there are no twists or unexpected events throughout the gameplay, makes it boring and a somehow unenjoyable for the players. The specialists provided opinions about this issue such as:

"But it* [the game] *should start in 2020 and be every 5 years (at this stage the game is very boring, it doesn't work in classes!!!) and should have a help to explain the value of arrows (at least I didn't find it!!)"

Since it is a simulation game, it is a challenge to find a context story for it, and therefore, depending on the game genre, the player experience lack on primary involvement. In the first stage of the development, the game introduces the player as a member of the government with detailed tasks and the respective objectives that he must fulfil.

Regarding the game scope, it is not clear that the user is focusing on energy system emissions only, leading to a possible misunderstanding, since there are other scopes responsible for a great percentage of CO2 emissions. To be useful, the game must be as accurate as possible for the player, when explaining the context and the scope where it belongs.

A general critic, made by different specialists, was that due to some lack of feedback about what is happening during each simulation, the games turns itself in trial and error, which is not very engaging.

"*The description of the energy system is too incomplete to allow for decision making. (…) Without this information the player is limited to "trial and error" until getting the result right, which is not very encouraging."*

Since it is somewhat trivial to find a working combination, if the player repeats the same input every year of the simulation, it is certain that he will win. To avoid that and improve the game challenge, some variants could be added to the game, such as natural events or economic crises that would add a sort of restrictions and twists to the gameplay, forcing the player to change his current approach and to adapt his strategy to these variants.

Another important topic, approached by one of the specialists involved in the testing process, indicates it is expected that with more renewable energies there will be a closing of fossil fuel plants, which is invisible to the player. Although this information is present in the model, the difficulty is to understand how it can be shown to the player, without overloading him with information.

"It is to be expected that with more renewables there will be a closure of fossil fuel plants, which is invisible to the player"

4.3. Model explanation

An educational game, in this case focused on simulating a scenario, needs to be accurate as possible when comparing with real world cases. The game must be a tool for training students and an environment where players can apply the previously acquired knowledge and simulate it as faithful as possible to reality.

We think that a range of 35 years (2015-2050), since the start of the simulation until the evaluation of the previously defined goals, is a long period. If we have in consideration several aspects like the mandate's duration or how the performance of the current government influences the next election period, we understand that it is not realistic to only have goals after the referred time span. Additionally, regarding the player's decisions, they are somehow unrealizable in a one-year period, because, theoretically, they take a couple of years to conclude.

Another topic is related to the economic concept in the game. In the first version, the user can see some information, indicating the total cost of the electrification process that he is simulating, and it is also possible to follow the decisions' impact on the gross domestic product (GDP), over the years. However, this parameter is almost irrelevant to take in account when making decisions because it is never evaluated and it is impossible to run out of money during the simulation, regardless the taken approach. Energy management and Economic management are two themes that should be related and connected, because investing in new sources of energy requires financial investment and this should be relevant too. Therefore, we believe it is necessary the implementation of a budget concept, where a portion of the GDP is made available for the user, who is responsible for managing it and invest accordingly to his strategy.

One thing that we received a lot of feedback was about the game model. It is complex and almost impossible to transmit all its information in the game itself. Therefore, to facilitate any adaptation on the game model, we decided to break it down into a diagram (Figure 7), so we can easily analyse possible changes and enhancements, and this way we are able to analyse all its relations and how user inputs affect the model and its calculations.

In this diagram, it is possible to identify model configurations, which represent every variable that can be manually changed by us or anyone else with access to the source code. We also highlighted the objectives of the game, the variable directly influenced by user inputs and the most relevant concepts represented in the game, available to the player.

To facilitate the analysis of this diagram, we subdivided it in groups, which we will explain in detail. First, we have the **GDP (Gross Domestic Product) group**, where labour, capital and TFP (total factor productivity) produce the final GDP value. The labour is obtained based on the population, the number of working hours per year and a percentage of the active population. Capital updated from year to year with the investment in capital. Finally, the TFP increase with the previous year aggregated exergy efficiency. There is a directly relation between GDP and the annual useful exergy: the higher the GDP,

the higher the useful exergy needed. The useful exergy in combination with the aggregated efficiency is used to estimate the final exergy (represented outside this group).

Next, in the **renewable power group,** we can observe that it is possible to calculate the total renewable power and the renewable investment based on the amount of power installed in that period (dictated by the user), the installation cost per gigawatt and the total power of the previous year.

Moving on to the **electrification group**, the new shares distribution is obtained by processing the user input regarding the changes on shares distribution (of final exergy) among economic sectors and the previous shares distribution. Similarly, we obtain the new electrification value for each sector based on the user input regarding the electrification effort and the previous year electrification of each sector. Finally, by computing the new shares distribution and the new electrification by sector and using the final annual exergy (see paragraph on the GDP group), we obtain both final exergy by sector and final exergy by sector and by carrier.

In the **efficiency group**, we obtain the useful exergy by sector and by carrier, after combining the final exergy by sector and by carrier with the efficiency of each carrier. With this result, we can calculate the useful exergy by sector, which combined with the final exergy by sector, produces the efficiency by sector as well as the aggregated efficiency. The CO2 emissions by carrier is calculated by the emissions factor by carrier and the final exergy by sector.

Next, on the **electricity production group**, the renewable electricity is obtained based on each renewable source power, its production factor and the number of hours producing. Afterwards, combining the renewable electricity obtained before with the final electricity needed we obtain the non-renewable electricity production, which lead us to the final group.

In the **emissions group**, combining the non-renewable electricity production obtained before with the installed gas power and installed coal power, we obtain the non-renewable emissions, which together with CO2 emission by other carrier produces the total CO2 emissions. Finally, the population happiness is calculated with the total emissions and the consumption – it increases with consumption and it decreases with emission (a proxy for environmental quality). Consumption is equal to GDP minus total next year investment calculation.

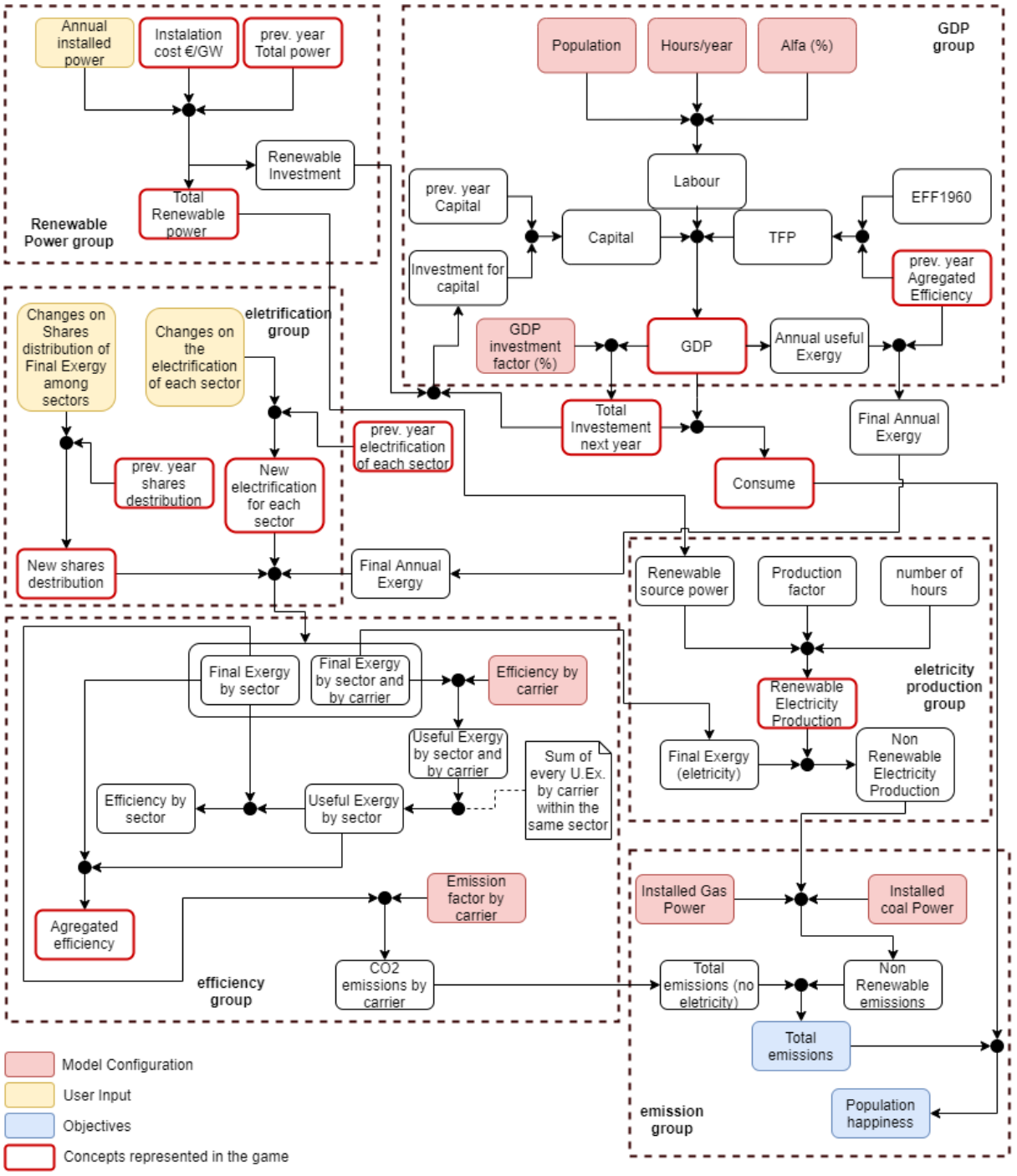

Figure 7 - Game model diagram

4.4. Summary

In short, we identified some problems, explained in more detail above. Those topics represent what we consider important and relevant to improve/add on/to the system. We strongly believe that implementing them, would result in a better version of the game, providing a more enjoyable and engaging playing experience, contributing to attain our goal of inserting *ExergyX* as an education game.

We defined as a goal to find a solution for the following topics:

- **Remake the user interface**, adding a new visual to the game, as well as fixing some problems identified before, such as, the tutorial, the model representation in the game, general layout problems, icons' meaning, and others.
- **Improve the interaction** between the player and the game, by adding new dynamics.
- **Enrich the gameplay** experience by adding some elements, turning it into a more unpredictable, fun and enjoyable game to play.
- **Improve the model representation** in the game, which could be obtained by providing more information to the player.
- **Perform a testing experience** with students.

ExergyX was first implemented using GODOT[4], which is an engine design for game development. However, since we are not working with game elements such as light, shadow or textures, we decided to switch from this game engine to a web development technology, since the game is not a desktop application but a web application.

4 *https://godotengine.org/*

5. ExergyX: Beta Version Analysis

In this section, we will explain in detail our work in regard of taking *ExergyX* to the next level, improving its design, playability, and implementation. At the end, we do a summary of which objectives were fulfilled and which were not. The new version of the game is available at ***http://exergyx.tecnico.ulisboa.pt*** (last accessed on 31/10/2021).

As discussed in a previous section, the pioneer version of our game had a poor interface, since at that time the focus was on developing the simulation model running in the game. One of our goals was to enhance the aesthetics, but also enrich the game with new dynamics and user interactions.

5.1. Technologies

During the process of analysing and discussing the old version and enhancement needs, one of our conclusions concerns the technology used for the development phase. As we previously state, the first version of the game was developed using a game engine, GODOT, which is a powerful tool when dealing with textures, shadows, lighting or 2D elements. The source code was written using GDScript, which is a high-level, dynamically typed programming language used to create content. It uses a syntax similar to Python. Its goal is to be optimized for and tightly integrated with Godot Engine, allowing great flexibility for content creation and integration [13]. However, despite being a game, *ExergyX* does not contain any of these elements, so we debated on switching the technology used from GODOT with GDScript to any technology available more towards web development. We decided to go along with Angular, which is an application design framework and development platform for creating efficient single-page applications (SPA) [14]. Since we would perform more data representation, such as tables or charts and decided to have a lot more dynamic components integrating the UI, like navigation bars, scrollable tables or tab navigation, we gladly transited between these two technologies.

5.1.1. Angular

Angular is an open source framework supported and wielded by Google, for the development of web and mobile applications. It was made with the main objective of facilitating the development of SPA (Figure 8).

Angular has adopted a methodology in which it sees an application as a collection of components and, where all page elements are purposeful components that can be reused in different stages of the application, which promotes their reuse. Angular recommends using TypeScript language while developing. However, it is possible to use JavaScript instead. TypeScript is a JavaScript Superset, which forces the developer to produce a better and more organized code and offers other advantages for producing code like the object-oriented programming. Using Typescript with Angular made the code

more sustainable and readable. This brings more simplicity for development, but it is one more language that is necessary to learn, which will result in greater learning complexity of the framework.

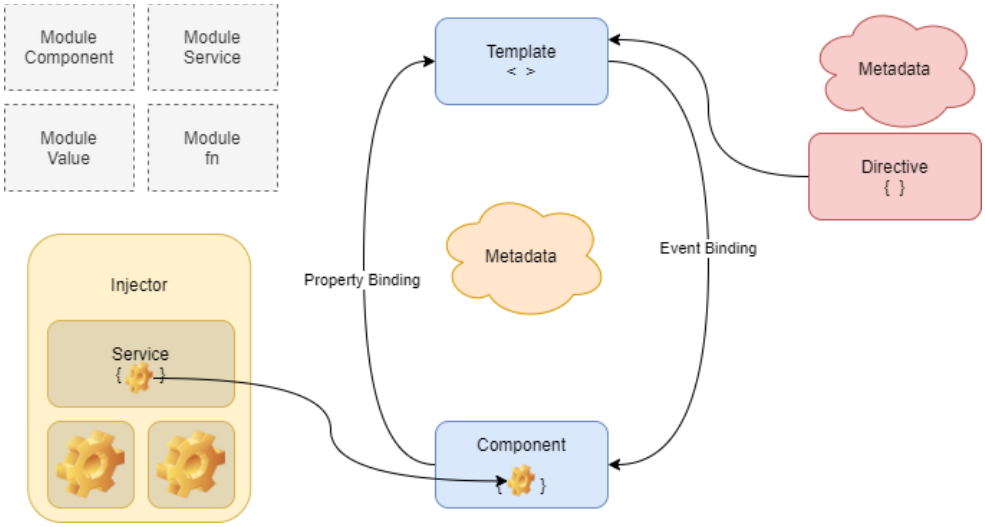

Figure 8 - Angular framework

The main advantages of Angular are as follows:

- Typescript: TypeScript offers many advantages such as object-oriented programming (classes, interfaces, etc.); type validation; error detection while writing code with IDEs like Visual Studio. Having such tools is almost a mandatory requirement for the development of major projects.

- Bidirectional Data Binding: Angular uses Bidirectional Data Binding. This allows the framework to be able to bind the Document Object Model (DOM) to the data model (database) through a controller. Briefly, that is, when users interact with new inputs and give a new value to the application, does not only the interface is changed, but also the Model (database) automatically. Consequently, it is not necessary to find a method or write code to account for all of these modifications.

- Model-View-Controller: The Model-View-Controller pattern allows splitting the project's code into three components: model, view and controller, allowing the separation of concerns that keeps the code tidy, clean allowing possible changes to be easily implemented. This way, changing each component can be done independently where each segment of the code only serves one purpose, with everything not being mixed up, increasing quality of the final product.

- It is a framework: Since Angular is a framework, it offers a more complete solution with more possibilities and functionality, which helps you start a project faster without needing additional libraries or other framework tools.

On the other hand, its disadvantages are as follows:

- Learning curve: In order to use Angular, it is not only necessary to learn a new framework, it is also advisable to understand how the files configuration works and how Angular works, and also learn a new language - TypeScript.

- Typescript: It is possible to use Angular with JavaScript, but it can be laborious and more difficult due to the lack of documentation and support in this subject, as the most used is TypeScript. Most Angular courses and lectures are done using TypeScript. This makes learning this language almost mandatory.

- Regular DOM: Angular manipulates DOM directly, this makes it slower when compared with other technologies such as React, which uses a virtual DOM that only makes necessary changes to the normal DOM. Also due to the use of bidirectional data bindings, there are observers in each component to alert whenever there is a change, which also affects performance.

5.2. Project Structure

The project's structure is divided in three main segments, which are Components, Interfaces and Services. Components represent the building blocks that compose an application (Figure 9). They have a view template, which is implemented using HTML, and its code behind class written in TypeScript. Additionally, it is possible to include a CSS, SCSS or SASS file containing the styles for the respective component template. In our project, we used SCSS, which is an extension of CSS syntax. This means that every valid CSS stylesheet is a valid SCSS file with the same meaning. Finally, a SASS compiler transforms SCSS into standard CSS.

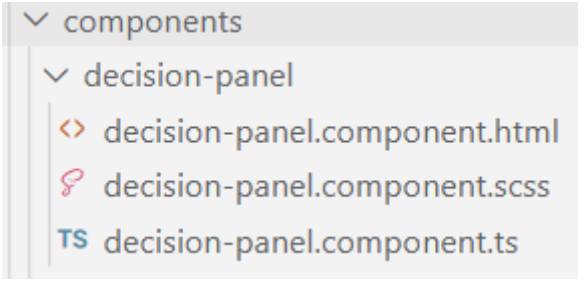

Figure 9 - Example of a component structure

On the other hand, we have services. Services, in angular, are a great way to share information across classes unknown to each other. In our case, each component has its own class and so, the

only possibility of sharing information is trough services. In addition, components should not focus on fetching data; those operations must be delegated to services.

In *ExergyX* we have a set of services with different responsibilities (Figure 10). The game-model service is responsible for containing the game model that runs after each submission and it also keeps other variables. Then we have the player-variables service, where all the players' information is stored, as well as their decision after each submission. This service also keeps a history of the previous values to make it easier when displaying the information on the history panel. Finally, we implemented a current-state service, responsible for keeping track of the gameplay state when the user navigates through the application. This way previous selected values are not lost if the user switches between views. Then, after the submission we clear the current state avoiding having undesired values pre-selected. The configuration-variables service contains some variables used to initialize some values in the game.

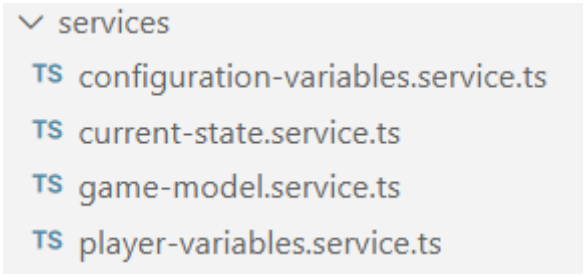

Figure 10 - Services implemented on the project

Regarding the interfaces, we use them to define custom types, each one contains their set of properties, and then we use them as data types. What that means is that the data populating a variable must exactly match the properties set forth in the Interface, which we created first. This allow us to define strongly typed variables.

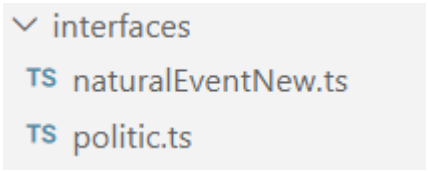

Figure 11 - Interfaces implemented on the project

5.3. User Interface

As stated before, one of our major objectives was to make a user friendly and appealing UI.

We did an analysis on the previous UI, identifying some problems and enhancement opportunities, and defined some musts. One of the most relevant topic, also referred by some specialists, is the lack of feedback about what happens in the system. Analysing the old screen, we were able to observe that the information panel is small, providing so little information from a complex simulator.

5.3.1. Information Panel

To overcome this difficulty, we decided to split the main screen of the game in two different views, being the information panel one of them, where many details are available as well as the difference between decision years (Figures 12). This additional value facilitates the process of analysing the decisions' impact from the previous simulation, since it is clear how much a value changed after the submission. This panel is always available through the side navigation bar, where the user can easily switch back and forth between the different views.

Still in this panel, the user has access to a news box, where he is able to see some information about random events that occur from time to time. He can also see the impact associated with each one. This is an addition we made to the gameplay and it is described in more detail on the next subsection "Gameplay".

Additionally, we added tooltips to every label, making it easier for the user to clarify a specific topic. In comparison with the previous version, where the tooltip was not assigned individually but to a group of labels, making it harder to read and relate the description with the respective label.

Figure 12 - Information panel on the new system

5.3.2. Decision Panel

The second view originated by splitting the main screen, is the decision panel. Here is where the player interacts with the game (Figure 13). This view is divided in three columns, where the first one contains a summary of the relevant information so the user does not have to always switch between views to analyse the data.

The second column contains the interaction elements, which are a policies table, containing investment policies, organized by sector, with which the user interacts by selecting them to see more details or adding/removing them to/from the shopping cart, and a certain amount of renewable power to install. This column also contains a card with the detailed information about any selected policy, such as title, sector, description, price and an image allusive to the sector.

Finally, on the third column, the user can see a summary of the investments he is making on the respective year, in real time. This information concerns the total amount of renewable power to be installed, the list of policies added to the cart, policies and renewable power costs and lastly, the remaining budget, which is also a new concept that was added and we explain it in the “Model” subsection.

Afterwards, when the user is ready to submit any decisions, he sees a confirmation popup, summarizing all the decisions that he is submitting, as well as a message reminding the player that once the submission is confirmed, he will not be able to undo this action (Figure 14). Then, after confirming everything, he has the option to submit and proceed to the next decision moment or to go back and change any decisions.

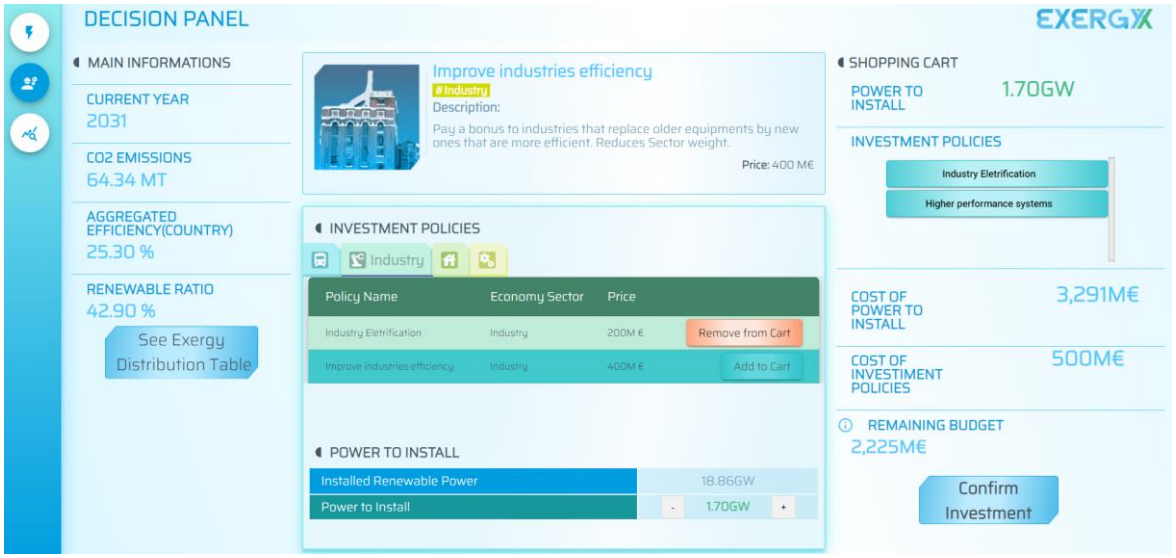

Figure 13 - Decision panel on the new system

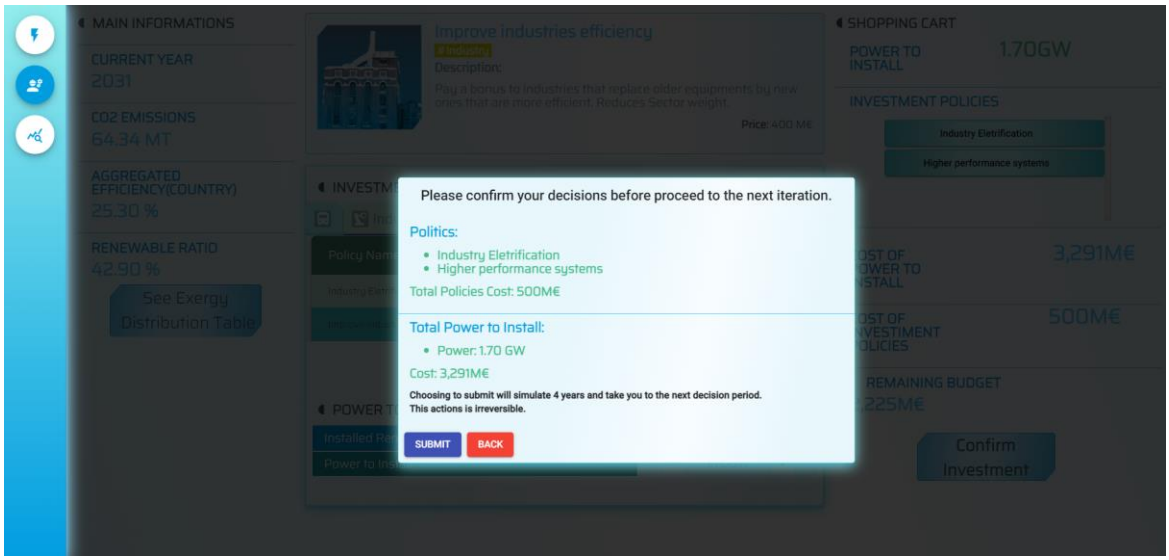

Figure 14 - Confirmation popup on the new system

5.3.3. History Panel

Once concluding a submission, the application redirects the player to the information panel, where the updated information is presented to him.

However, at any moment of the game duration, he is free to navigate to the history panel (Figure 15). In this page, the user can analyse and compare data from the past decisions years. Additionally, he has the opportunity of seeing the CO2 and population happiness progress through a line chart.

This view is divided in two columns, where the first one contains a line chart with the records for CO2 emissions and population happiness through the years until the moment he is at, which are the two goals to win the game. The player is able to filter the chart by showing or hiding lines, he can even observe the actual value at any available year. Still on the first column, there is a section, “Achievements”, which is not implemented yet and we talk about it in the “conclusion” section of this document.

For the line charts, we used an open source library, available under the MIT license[5], called Chart.js. When used together with ng2-charts, which is another node.js library, we obtain good looking and dynamic charts. In our application, we only use line chart, but there are more options available.

On this same view, on the second column, the user is able to see the history so far by choosing one of the previous decision years. Once one option is selected, all the relevant information of the respective year is available for the player. This contains not only the value of parameters but also all the decisions made on that year.

[5] *https://opensource.org/licenses/MIT*

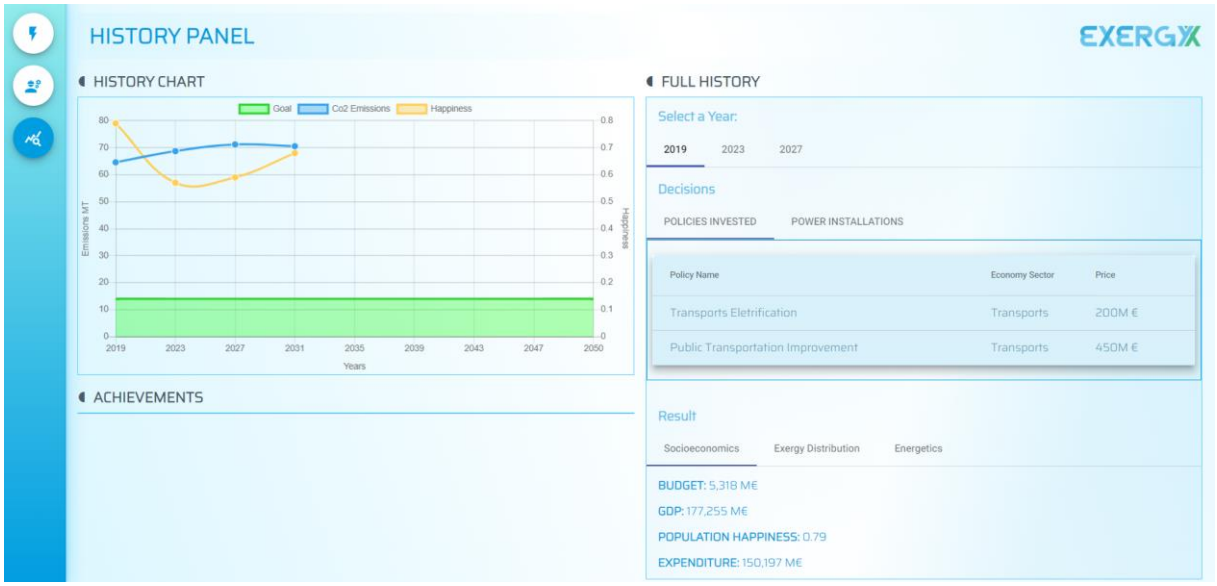

Figure 15 - History panel on the new system

5.3.4. Complementary Views

The three main views are described in detail above. However, we developed two more views to complement *ExergyX*.

The firs view that we added was a welcome screen (Figure 16), which is the first thing the user sees when accessing the website. Our intentions with this view were to create an appealing first impact instead of a page with great amount of information right away, which happens in the old version. Two elements, an inviting title and a “start system” button compose this view.

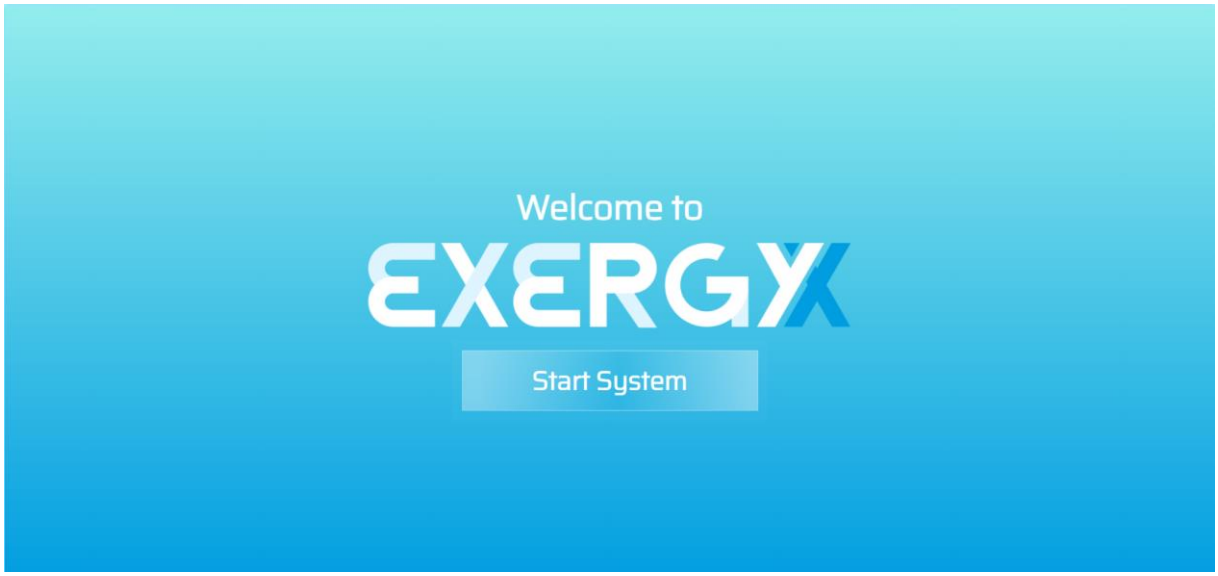

Figure 16 - Welcome screen on the new system

In addition, since the game is not trivial, we needed a good solution to provide some background information and some kind of tutorial. We already described some reasons why we believe the information screen on the old version is not suitable for this game.

All things considered, we implemented a sequential tutorial, where the user sees an image of the actual game with some elements highlighted, and a text explaining on how to use those elements in order to achieve something (Figure 17). With this approach, the user is able to relate a small text portion with specific elements of the game.

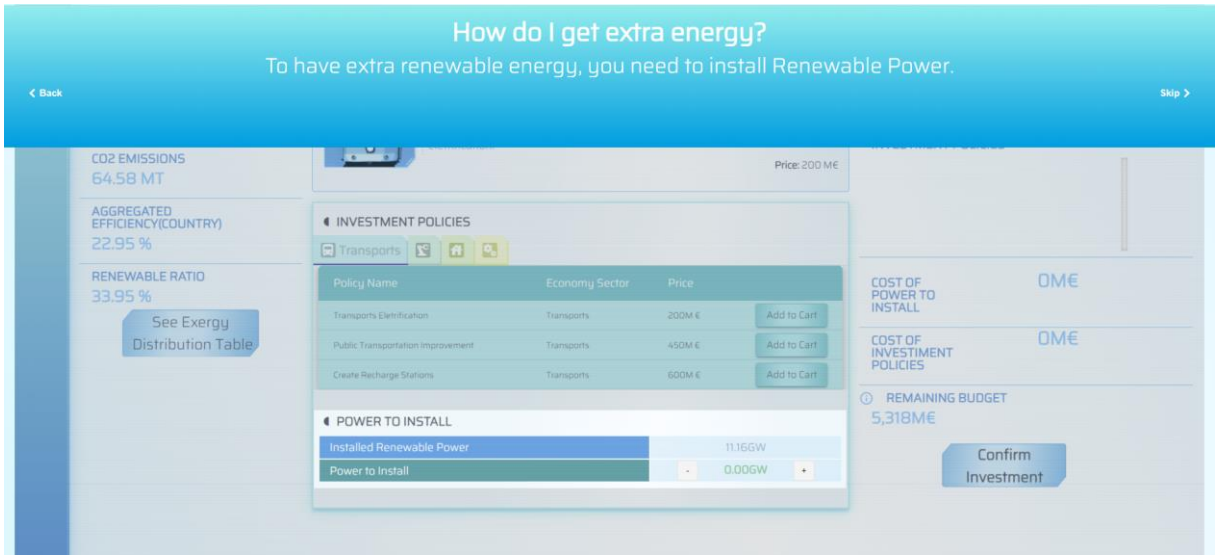

Figure 17 - Example of a tutorial step on the new system

5.4. Gameplay

After analyzing the previous version of the game, we concluded that the gameplay needed improvements. The interaction between the player and the environment was lacking on diversity and engagement.

Since the feedback that we received, from the testers of the previous version, contained a lot of statements on how boring the game could become for the player, as result of 35 simulation periods. To overcome this, we decided to change from every year to every four years, aiming to reduce the amount of decisions and also bring some reality to the model, because some of the decisions are infeasible in one year. With this adaptation, the total power to install is no longer performed annually (as represented on figure 7), but every 4 years instead.

The first step was to define clear objectives that ideally every player would obtain from the playing experience. Some of those topics regard theoretical aspects, since this is an educational game, with

the purpose of helping students understand and apply the course subject. We explain those goals below.

Understand the relation between energy and economic growth:

a. Greater exergy efficiency (useful exergy/final exergy) leads to greater economic growth (increase in GDP);
b. A higher GDP value implies an increase in useful exergy needs;
c. As a result of a. + b. the increase in exergy efficiency may result in an increase in the final exergy needs and, therefore, the increase in efficiency cannot be the only answer to the demand of decreasing the final exergy needs. There is a concept called the rebound effect, which is the reduction in expected gains from new technologies that increase the efficiency of resource use, because of behavioral or other systemic responses. Another answer to this topic is electricity production from renewable sources.

Realize what exergetic efficiency depends on and how it is possible to increase it:

a. The composition of the economy because the industry is more efficient;
b. The electrification of different sectors because the electrification of a given end-use is typically associated with greater efficiencies;
c. On GDP per capita because a larger GDP per capita is associated with a greater preponderance of the residential sector, which has a lower efficiency;
d. On technological evolution (worldwide) because greater technological evolution allows greater efficiencies and electrify more end-uses;
e. Energy efficiency measures and policies for certain sectors (examples: incentives to purchase electric cars, industry efficiency legislation, building efficiency legislation, etc.).

Understand the paths for the carbon neutrality of the economy:

a. More renewable electricity is the way to have less GHG;
b. Non-renewable electricity is very GHG-emitting (coal worse than natural gas) and, therefore, electrifying without renewable production capacity is counterproductive in terms of GHG emissions;
c. Fossil fuels are always associated with GHG production;
d. There are "natural" processes that capture GHG (forest or agricultural growth) but that depend on the structure of the economy and some investments;
e. There are industrial processes not associated with energy use that emit CO2 (eg cement production).

Understand the difficulties/limitations of renewable electricity:

a. There are storage needs due to the production-consumption mismatch that have an economic cost, the greater the fraction of renewable electricity, the greater this cost;
b. Need to invest in production capacity;
c. Unpredictability of hydro from year to year and wind from day to day and solar throughout the day;
d. There are uses for which electrification is not yet a possibility (certain industrial uses).

In order to attain these goals, we tried to introduce some new concepts in the game, hoping to enrich the playing experience with new dynamics.

One of those news concepts, policies, is one of two ways used by players to invest in the game. Each policy has an economic sector associated with it, representing where it will have impact. Policies can represent an investment in electrification of the respective economic sector, which rises the sector's electrification percentage, or a modification on the sector's weight, which means the respective sector's share of used energy is changed. Through these policies, we can guide the player to think about the current state of the country and decide which policy would suit best. We created policies that are viable in the real world but also makes sense in the context of the course where they are to be applied.

We found it challenging to define reasonable prices for each policy, keeping them more or less realistic and not causing problems on the gameplay. With the introduction of this structure, we also had to update the investment cost in renewable capacity on our game model.

In the game model, we created a structure "Politic" (Source code 1, Source code 2) containing all its properties, necessary to its integration in the already implemented model. Each policy is essentially composed by a title, simple captive text, a description, containing essential information such as what to expect from it, a type, identifying to which sector it belongs, a price, which will be withdrawn from the budget and an impact reflecting how much it will affect a certain parameter. The impact is an array, where the first element represents the impact on the exergy shares of the policy's sector, and the second element defines the impact on the sector electrification. With this adaptation, the model from figure 7 no longer has the user inputs "changes on shares distribution of final exergy among sectors" and "changes on the electrification of each sector" since these types of investment are now performed through policies.

```
export interface Politic {
  id: number;
  title: String;
  price: number;
  desc: string;
  isUsed: boolean;
  remove: boolean;
  type: string;
  impact: Array<number>;
}
```

Source code 1 – Politic interface definition

```
{
id: 1,
title: "Transports Eletrification",
price: 200,
prob: 0.5,
desc: "The government subsidizes the purch
ase of electric cars. Improves sector elet
rification.",
isUsed: false,
remove: false,
type: "Transports",
impact: [0,5]
}
```

Source code 2 - Example of a politic construction

All the remaining properties we use for validations, sorting and management.

Another new concept that we added to the model were natural events (source code 3, Source code 4). Since the previous version of the game was somehow predictable when a good combination was found, we researched and debated possible solutions for this problem.

For the purpose of overcoming this inconvenient, we implemented a new dynamic in the game model, which is not directly associated with user actions. The natural events, as we implemented it, occur every other simulation year, and mainly contains negative events such as dry season or a tornado occurrence, which will affect hydropower or destroy renewable power capacity, respectively.

There are also some motivational news with no negative impact in the model. To avoid repetition, we imposed a limit of one occurrence per event. This information is available at any time in the “Information Panel”, which can be accessed at any time. As it was previously said, there is no possible interaction by the user regarding this topic.

```
export interface naturalEventNew {
    id: number;
    title: string;
    description: string;
    used: boolean;
    effect: string;
    amount: number;
    type: string;
    affects: string;
}
```

Source code 3 - Events interface definition

```
{
  id: 1,
  title:"A tornado strikes the country!",
  description:"A tornado strikes the count
ry, partially destroying its installed cap
acity.",
  used:false,
  effect: "capacity",
  amount: -10,
  type:"weather",
  affects:"Renewable capacity"
 }
```

Source code 4 - Example of a natural event construction

5.5. Summary

After the development phase, we believe that the previously defined objectives were fulfilled, with the exception of one.

- **Remake the user interface**: we believe that the new interface has nothing to do with the previous one. We designed a new concept for the game, very distinct from the original, by taking in consideration all the feedback we received and all the inputs from outside. Also with the purpose of delivering a good looking and appealing game to the students who will play this game, hoping to increase their engagement with the course and also enrich their learning experience with a new tool.
- **Improve the interaction**: This goal was achieved by adding policies to the game, which represents a new way of interacting with the game, emerging new feelings and experiences.
- **Enrich the gameplay**: We believe the gameplay was greatly improved with the addition of policies and natural events. These elements bring more diversity to the gameplay, and also unexpected events, causing the player to constantly adapt his strategy.
- **Improve the model representation**: With the implementation of an information panel, we believe we have achieved this goal, since the user has more information to see and analyse in a proper view, specially dedicated to this purpose.
- **Perform a testing experience**: This objective was not fulfilled. We conducted a testing phase with a random set of users to support our work and identify possible problems. However, due to all the formalities and the development period, it was impossible to conciliate a testing phase since during our development phase the course was not being taught.

6. Evaluation

As we previously mentioned, this project has already undergone a user testing phase where some problems were detected, regarding user experience. We then restructured the frontend layer, to address the problems detected and improve the gameplay experience.

We decided to conduct a user experience test, to evaluate the new user interface and to get feedback from participants about the new design and layout, and their experience while playing the game. Additionally, it would be very helpful if those same users could report new bugs, or even suggest improvements for the application.

6.1. Procedure

For this test, we gathered a group of people, most of them IT professionals, as volunteers for this testing process. However, there were a few requirements. Users must use a computer (either laptop or desktop) and internet connection is required since the game is deployed online, preferably using chrome as the internet browser. Finally, the user should complete a form, allowing us to collect detailed feedback.

First of all, the user has to read a consent form, containing a brief overview of the conducted study as well as all the ethic guarantees and data protection policies. After accepting the consent form, they proceed to the study itself. It is also important to state no personal information were collected from the participants. The form only contained questions regarding the game itself. Therefore, it is a completely anonymous and voluntary participation.

As a first step of the study, users must access, via web browser, the site where the game is deployed, via the URL: "*exergyx.tecnico.ulisboa.pt*". Once in the webpage, they had to undergone and conclude the tutorial, as we also wanted to collect feedback about it. Afterwards, they were asked to finish the game at least one time (users were allowed to play more than one time). Additionally, it did not matter if the obtained result was a win or a loss. As previously mentioned, users had to fill a user experience and player experience form to measure their thoughts regarding some topics, such as their engagement, layout attractiveness, and others. We will use a "User Experience Questionnaire" (QUE) [15,16,17,18] to measure user experience and, to measure usability, we will ask them to answer a "System Usability Scale" (SUS) [19,20] questionnaire.

Additionally, the form also contained three open answers, which were the following:

"*Please describe any negative topic from your playing experience*", where they could right anything bad about the game, helping us to understand where we may have failed;

"*Please describe any positive topic from your playing experience*", again, any positive topics would help us define and align our path;

"*Please provide any suggestions for future improvements*", with this sort of suggestion box, our goal was identify some topics that not necessarily makes their experience bad, but maybe could improve their feelings while playing the game.

Concluding, one of our goals with this test was to understand what we can do better, helping us define future work and improvements to the game, as well as shortening the distance that separates *ExergyX* from a game ready to be used in an educational context.

6.2. Results

As we previously said, the form we handled to the users was divided in three sections. The first one containing a User Experience Questionnaire (UEQ), the second one, containing a System Usability Scale (SUS) and finally, on the third section, a group of three open answers.

For this study, we add a total of 24 participations from people with different backgrounds and professional experience, which represents our sample for this experience. Every volunteer answered the three components of the form, and their responses were used in the following analysis.

We will divide this section in three, accordingly to the form's sections, in order to provide an analysis on each one of those parts.

6.2.1. User Experience Questionnaire (UEQ)

Since an important component of our game is the UI, we felt the need of conducting a UEQ, in order to evaluate the work done so far regarding not only the UI, but also the gameplay.

For that reason, we used a UEQ (Figure 19) where both classical usability aspects (efficiency, perspicuity, dependability) and user experience aspects (originality, stimulation) are measured.

The questionnaire consists of 26 pairs of contrasting attributes that apply to our product. The user can express his agreement with the attributes by ticking the circle that most closely reflects his impression (Figure 18).

Example:

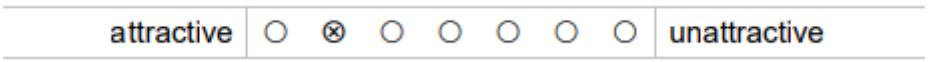

Figure 18 - Example item of UEQ

In this example, the user is stating that he finds the game more attractive than unattractive.

This questionnaire measures some topics:

-**Attractiveness,** overall impression of the product, do users like or dislike it;

-Perspicuity, if it is easy to get familiar with the product and to learn how to use it;

-Efficiency, if users can solve their tasks without unnecessary effort, if it reacts fast;

-Dependability, if the user feel in control of the interaction or if it is secure and predictable.

-Stimulation: Is it exciting and motivating to use the product? Is it fun to use?

-Novelty: Is the design of the product creative? Does it catch the users' interest?

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Figure 19 - UE questionnaire provided to the participants

Regarding the analysis phase, we compiled all the answers and then loaded them as data input in an excel sheet, made by the same organization who provided the questionnaire, which produced some results and conclusions.

The order of the positive and negative terms for an item is randomized in the questionnaire. Per dimension, half of the items start with the positive and half with the negative term. The input data had a classification from one to seven. The first step was to transform the data into a range from -3 to +3, where the +3 represent the most positive and the -3 the most negative value.

The UEQ does not produce an overall score for the user experience. Because of the construction of the questionnaire it does make no sense to build such an overall score (for example by calculating the mean over all scales), since this value cannot be interpreted properly. The values for the single items are listed (Table 1), allowing us to detect outliers in the evaluations. If an item shows big deviations to the evaluations of the other items of the same scale this can be a hint that a higher number of participants misinterprets the item (for example, because of a special context in your evaluation).

UEQ Scales (Mean and Variance)		
Attractiveness	1.021	1.02
Perspicuity	0.250	2.13
Efficiency	0.844	1.54
Dependability	0.438	0.56
Stimulation	0.844	0.98
Novelty	0.875	1.16

Table 1 - Results by UEQ's scale

Values between -0.8 and 0.8 represent a more or less neutral evaluation of the corresponding scale, values > 0,8 represent a positive evaluation and values < -0,8 represent a negative evaluation. The range of the scales is between -3 (horribly bad) and +3 (extremely good). However, in real applications, in general, only values in a restricted range will be observed. It is due to the calculation of means over a range of different persons with different opinions and answer tendencies (for example the avoidance of extreme answer categories) extremely unlikely to observe values above +2 or below -2. Thus, even a quite good value of +1.5 for a scale looks from the purely visual standpoint on a scale range of -3 to +3 not as positive as it really is.

Afterwards, the above table is plotted into the following bar chart (Figure 20), providing a more visual understanding of the obtained results.

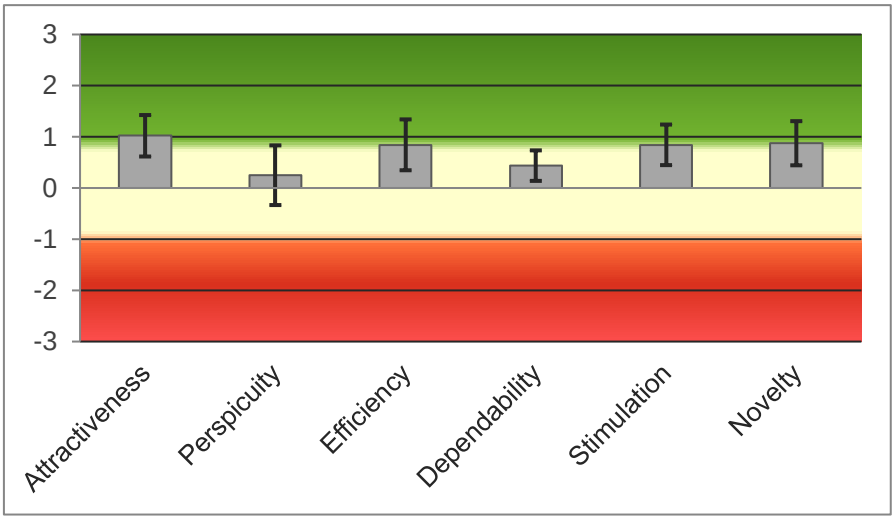

Figure 20 - Mean and variance from UEQ responses

After analysing this data, we can now provide a conclusion for each scale and also determine what it is necessary to obtain better results. In general, it is motivating to understand that *ExergyX* did not get any negative mean score on any scale.

Regarding the **Attractiveness** scale, we got a score of 1.021, which represents the higher from every scale. We believe this is a very positive result since one of our main goals was to improve the user interface, providing a more attractive, user friendly and engaging application. However, we are aware that there is still some work to do, based on the feedback and suggestions we received. We can conclude that overall, users enjoyed our product and found it appealing.

The second scale, **Perspicuity**, is where we got the lowest score of 0.250. Despite being a neutral result, which ranges between -0.8 and 0.8, we believe that due to the complexity of the game, and it being inserted in a very specific scope, was a determinant for the result. We are also aware that the difficulty of winning the game could lead some user to frustration, influencing their decisions about this topic. Therefore, for future work, the game model should be reviewed in order to deliver a challenging, difficult but not impossible experience.

Regarding **Efficiency**, we obtained a result of 0.844, which is a positive score that once more demonstrates *ExergyX* is a well-integrated system, with a great potential. Again, we should understand what could be improved, and for that, the analysis of the suggestions provided is crucial.

Next comes the **Dependability** of the system, where we obtained a result of 0.438. Once again, it is a neutral evaluation, maybe reflecting the difficulty reported by some users, to identify the impact of their decisions in some parameters of the game. Since it is a complex model, it is not trivial to understand the direct impact of some actions because some values are a result of several operations on the background, with different variables and not only related with user inputs.

For the **Simulation** scale, we obtained a result of 0.844, showing that users found our game exciting to use. No doubt, that climate changes and the need of a cleaner future, are becoming a popular

theme every day. We believe the users felt that the game's topic is very relevant for these days and interesting for someone not from this professional area, to simulate and try to discover a solution.

Finally, on the **Novelty** scale, we obtained a result of 0.875, which is the second higher value. In our opinion, the users felt that our game was different from other energy management games, and maybe addresses climate problems in a more serious way. For us it is a positive feedback, since our goal was not only develop an energy management game, but also teach the player with real world scenarios and a reliable simulation model.

6.2.2. System Usability Scale

The second evaluation questionnaire was a System Usability Scale. It offers a quick and effective way to evaluate the usability of our product and design. This approach was developed by John Brooke to address the problem of evaluating a system usability. This questionnaire was composed by ten sentences, which the user should classify from "strongly disagree" to "strongly agree" (Figure 21).

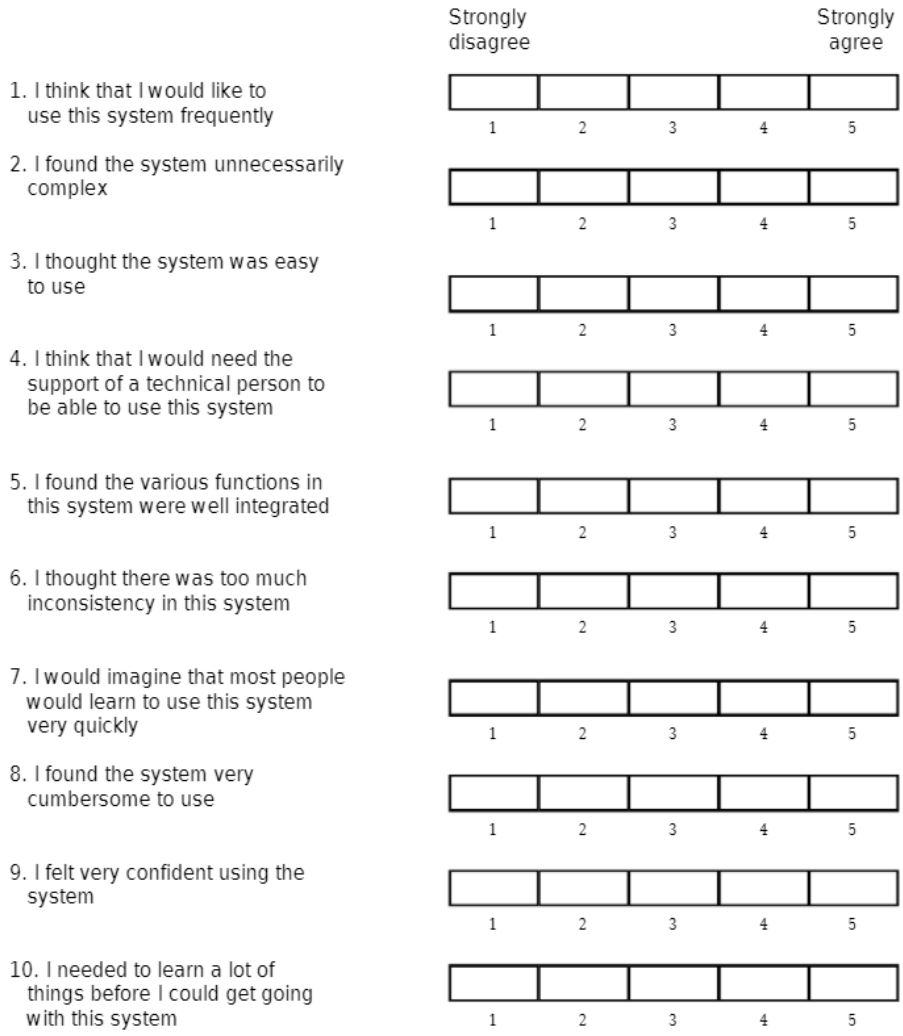

Figure 21 - SUS questionnaire provided to participants

The SUS is generally used after the respondent has had an opportunity to use the system being evaluated, which in our case was *ExergyX*. To calculate the SUS score, we first gave each option a score from 1 to 5, being 1- strongly disagree and 5 – strongly agree. Then summed the score contributions from each item. Each item's score contribution will range from 0 to 4. For the odd items, the score contribution is the scale position minus 1. For the even items, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SU, which have a range of 0 to 100 that does not represent percentage.

We used an equivalent function for the calculation, where for the odd numbers we add up the total score for all odd-numbered questions, then subtract 5 from the total. And, for the even numbers, we add up the total score for all even-numbered questions, then subtract that total from 25.

For this calculation, we computed the means for each one of the 10 items, and then we proceed with the remaining calculation, obtaining the following table (Table 2).

Item	Mean	Rounded Mean
1	2.96	3
2	2.33	2
3	3.63	4
4	2.21	2
5	3.83	4
6	2.25	2
7	3.71	4
8	1.50	2
9	3.54	4
10	2.17	2

Table 2 - Mean calculation for each item of the SUS questionnaire

Now, for the next steps of the calculation let us consider $O(x)$ the function to calculate the result of the odd-numbered items and $E(x)$ the function to calculate the even-numbered items. Considering $M(i)$ the raw mean of the item i.

For the odd items, we got:

$$O(x) = [\sum_{n=1}^{5} M(2n-1)] - 5$$

For the even items:

$$E(x) = 25 - [\sum_{n=1}^{5} M(2n)]$$

Additionally, we can use these equations to compute the final value for the rounded mean as well, obtaining the following table containing all the calculated results (Table 3).

Function	Mean	Rounded Mean
O(x)	13.17	14
E(x)	15.50	15
SUM	28.67	29
SUS Score	**71.67**	**72.5**

Table 3 - Odd and even-numbered calculations, and final SUS score

The next step is to find where, in the rating scale, our project is. For that, we will use a rating scale, containing rating elements such as, NPS, Acceptable, Adjective and Grade (Figure 22).

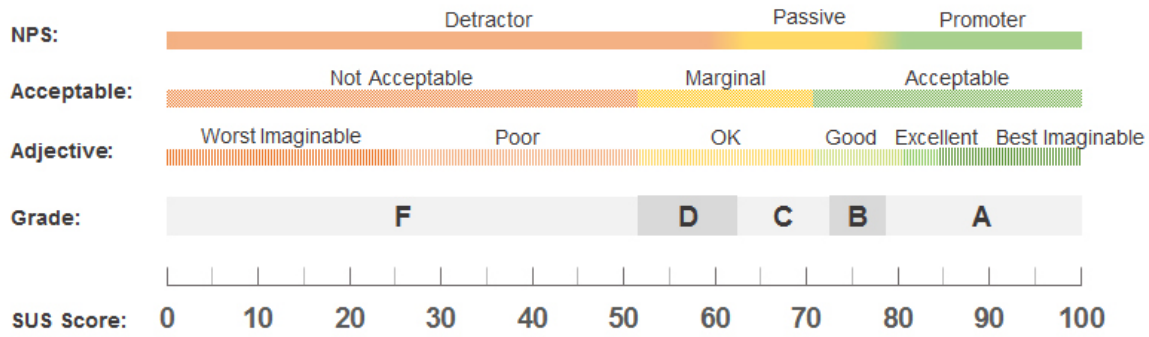

Figure 22 - SUS rating scale

The **Net Promoter Score (NPS)** designates three classes of recommenders based on the results. They reflect the user's willingness to recommend the application, classifying it in Promoter – high chance of being promoted by the user, Passive – the user may or may not promote, or Detractor – the user will recommend to not use the application, which obviously is the worst-case scenario.

The **Acceptable** is one way of using words to classify the application. Generally, an overall score roughly below 50 will be classified as unacceptable, a score above 50 is labelled as marginally acceptable, and a score above 70 is classified as acceptable.

Regarding the **Adjective** classification, it is another example of word classification. Roughly below 50 is classified as poor, and below 25 as worst imaginable. Between 50 and 70's is classified as OK, between 71 and 80's as good. Between 81 and 84 is classified as excellent, and finally, above that is labelled as best Imaginable.

The table below provides an overview of these values, helping to visualize the differences (Table 4).

Grade	SUS	Percentile range	Adjective	Acceptable	NPS
A+	84.1-100	96-100	Best Imaginable	Acceptable	Promoter
A	80.8-84.0	90-95	Excellent	Acceptable	Promoter
A-	78.9-80.7	85-89		Acceptable	Promoter
B+	77.2-78.8	80-84		Acceptable	Passive
B	74.1 – 77.1	70 – 79		Acceptable	Passive
B-	72.6 – 74.0	65 – 69		Acceptable	Passive
C+	71.1 – 72.5	60 – 64	Good	Acceptable	Passive
C	65.0 – 71.0	41 – 59		Marginal	Passive
C-	62.7 – 64.9	35 – 40		Marginal	Passive
D	51.7 – 62.6	15 – 34	OK	Marginal	Detractor

Table 4 - Evaluation table for SUS score [21]

After analysing this data, we can classify, based on users' opinions that our application is **good**, it is **acceptable,** it is **passive** when it comes to create the desire of promoting the system, and finally it receives a **C+** grade.

In our opinion, we believe that the downside of our game is the impossibility of reaching good results throughout the gameplay, leading the player to victory. We will discuss this is the next subsection, based on the open answers that we received.

6.2.3. Open Answers

In the third component of the user test, we asked the participants to answer three open questions. Our main goal is to understand any problems they had during the experience, analyse where we succeed and collect ideas and suggestions for future work improvements.

Now we will analyse some relevant topics obtained from the answers provided. We will go one by one, exposing the most relevant answers and describing possible solutions for each one of them. In the end, we will summarize the results in negative topics, positive topics and suggestions.

Please describe any negative topic from your playing experience.

Regarding this question, from the 24 participants 5 did not have anything negative to report. For the remaining 19 answers, we decided to group them accordingly to the underlying matter. Therefore, we decided to create categories and then insert the answers in the respective one. Since the answers can cover more than one subject, each answer can belong to one or more categories. We will organize the answers by the following labels: Accessibility, User Interface, Model Representation, and Game Model.

Regarding the **Accessibility**, we received 2 answers with negative topics about it. The first problem stated was related with the game only being available in English. We decided to only make it available in English to promote globalization, since the game will be part of a MOOC and inserted in a course

where it is possible to have foreign students attending. However, we can definitely work on this problem by adding an option to switch between languages (English and Portuguese). The second answer on this category stated the layout was not fit for safari browser. We are aware that our application is not yet responsive and versatile, for that reason, we recommended that all the users used chrome browser for a better experience. We know this is not a solution but, for the available time, we could not make it responsive or versatile as we desired. It is a relevant suggestion for future work.

Regarding **User Interface** category, we received 5 answers. One of those answers stated that the objective zone, in the line chart belonging to the history panel, was not clear about which of the goals it was related to. Our immediate solution is update the zone label to specifically refer “Emissions goal”, since it does not apply for population happiness. Another answer pointed out that the tutorial was only available in the beginning of the game, and should be available at any time. We definitely agree with that. Since the game has some complex terms, it is mandatory to have a tutorial available all the time, which can be accomplished by adding a tutorial button on the side navigation bar redirecting the user to the tutorial when clicked.

Finally, the last critic about the UI was towards one label, “sector Weight”, which represents the exergy share of a sector, and the relation was not explicit. Our solution for this topic consists on changing the label, making it easier for the user.

The **Model Representation** received 7 answers, where the majority referred the difficulty of relating their decisions with population happiness. Based on these opinions we believe that we should review the model representation to identify which aspects could be improved in order to provide a more understandable relation between concepts. We also received an answer, stating that there was too much information in the game, but also received a different one stating that the game lacks on information. In our opinion this is subjective topic, nevertheless, we will revise and proceed with any adaption we may find necessary.

Finally, regarding the **Game Model,** 7 answers were towards this topic, standing out the difficulty of achieving the goals and winning the game. Regarding this aspect, this is something we are aware and plan revising the game model, which will be done in future work.

Please describe any positive topic from your playing experience.

To this question, 2 of the total answers were not considered, since they did not contain any information. From the remaining, we also split them in three categories, being these, User Interface, Gameplay, and Thematic.

Regarding the **User Interface**, a total of 13 participants had something positive to say. Some of the answers stated that the UI was appealing, clean and enjoyable, some referred the information was well represented and others considered the UI very user friendly. For us, this is a very important feedback, since one of our major objectives was to develop a better, functional and appealing

interface. We believe based on all these answers, that our goal has been achieved, although there is still some work to be done.

The **Gameplay** category received about 11 answers. Most of them classify their experience as fun and enjoyable. Some participants pointed out that it was easy to play the game, while others highlighted the decision process and its variety. All these opinions are very relevant to us, because the old version was much criticised regarding the gameplay, and how tedious and repetitive the experience could be.

Finally, the last category, **Thematic**, received 4 contributions. All those answers stand out the importance of this topic, referring to it as a very current theme and very suitable in these days. This helps to support our idea of introducing *ExergyX* as an educational tool.

Please provide any suggestions for future improvements.

After collecting all the suggestions, provided by the participants. We can observe that about 8 participants focus on the tutorial, giving ideas on how to improve it, and how to make it easier to understand the model representation in the game. We also received suggestions regarding the game user interface, which are essentially ideas on how to improve some topics that were already discussed in the previous analysis on the negative topics.

We took all these suggestions in consideration when defining what is left to do for future work.

6.2.4. Summary

In summary, from the test we conducted, we are able to conclude that the participants overall enjoyed the game. Some more than others, as expected. We were able to conclude that, from their perspective, we still have some work to do, mainly regarding the model itself, but we also need to fix some issues on the interface as well as on the model representation.

We also believe that some issues that were raised are related to the subject where the game is inserted, which is strange and unknown to some participants. This condition partially influences their understanding on some topics and concepts. Nevertheless, the model will certainly be reviewed.

In Conclusion, we are very satisfied with the obtained results on both UEQ and SUS, which help us understand that *ExergyX* is on the right path to become a serious and reliable tool for education, expanding the boundaries of education.

7. Conclusion

This dissertation proposes a new version of *ExergyX,* a serious energy management game. We believe the developed product is a short step away from becoming an educational game. We have strong convictions about the impact of integrating the game as a learning tool, representing an innovation in the learning system, potentiating students' motivation in the course. We carefully analysed the previous version, identifying which aspects of the game needed improvement. Afterwards, we defined a strategy to overcome those limitations, aiming to deliver an enjoyable and useful tool for students.

From the conducted study, we concluded that *ExergyX* is in the right path to achieve the desired goals, although there is still work to be done.

7.1. Contributions

To achieve the objectives of this research, the most important contributions of this dissertation can be summarized as follows:

(i) Definition of clear objectives and concepts, which need to be represented in the game;
(ii) Implementation of a new front-end layer of *ExergyX*, providing a more engaging experience to the players;
(iii) Improvements on the gameplay, enhancing user interactions, and by adding clear and specific tooltips to each label;
(iv) Improvements on model representation, providing more content and information about some parameters of the model;
(v) Conducting a user experience test, which allowed us to collect information about the current state of the game, and to support the developed work.

7.2. Future work

For future work, we defined some topics, which we believe are essential before integrating *ExergyX* with both IST's course and MOOC.

The most important and critical issue, is to revise the game model, proceeding with any necessary adaptations, in order to improve the game's playability. In the current version, it is not possible to win by any means. We believe this happens because of the realism of the model.

Second, we shall carefully analyse the open answers to the questionnaire and proceed with any enhancements to the game. We already have some topics in mind, which need improvement, such as

the tutorial, which was much criticised in the evaluation, but also the clarification on some concepts that are hard to relate throughout the game. Some of these topics are:

(i) Improvements on the tutorial, making it more clear and accessible for the players;
(ii) Improve the cohesion of game concepts during the gameplay;
(iii) Implementation of an achievements system, where the player is rewarded during the gameplay, as he achieves some milestones;
(iv) Improve the accessibility, making the game compatible with more browsers, and responsive;
(v) Fix minor UI problems, identified during the testing phase.

Finally, we are considering another test, this time inserted in the IST course, with the enrolled students, as an experience to measure the impact of *ExergyX* as a learning tool. We believe the introduction of *ExergyX* in "Management of Energy Systems" course at Instituto Superior Técnico (IST) [2], which has an attendance of about 80 to 90 students, would represent an improvement on the current learning system at IST serving as a complement to the theoretical and practical classes where students could apply and test their previously acquired knowledge. We would like to provide a more attractive learning experience, potentially motivating more students.

Another way to measure *ExergyX*'s impact would be the integration with the IST MOOC course "Energy, Economic and Environmental Scenarios" [3], which consists in an online course addressing similar topics and subjects as the IST course that we previously brought to discussion. We strongly believe that having an online learning tool is taking advantage of the technological progress, using it for the good of education, by providing new learning possibilities to students anywhere on the globe. Therefore, having an educational game as a complement would be a small but important step in innovating the learning system, as we know it today.

8. References

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Appendix A

Item	Mean	Variance	Std. Dev.	No.	Left	Right	Scale
1	1.0	1.4	1.2	24	annoying	enjoyable	Attractiveness
2	0.6	2.3	1.5	24	not understandable	understandable	Perspicuity
3	0.4	2.9	1.7	24	creative	dull	Novelty
4	0.3	2.5	1.6	24	easy to learn	difficult to learn	Perspicuity
5	0.5	2.3	1.5	24	valuable	inferior	Stimulation
6	1.0	1.1	1.0	24	boring	exciting	Stimulation
7	1.5	0.8	0.9	24	not interesting	interesting	Stimulation
8	-0.5	2.2	1.5	24	unpredictable	predictable	Dependability
9	0.4	2.5	1.6	24	fast	slow	Efficiency
10	0.9	3.5	1.9	24	inventive	conventional	Novelty
11	0.9	0.8	0.9	24	obstructive	supportive	Dependability
12	1.1	2.1	1.5	24	good	bad	Attractiveness
13	-0.1	2.9	1.7	24	complicated	easy	Perspicuity
14	0.9	0.9	0.9	24	unlikable	pleasing	Attractiveness
15	1.1	1.2	1.1	24	usual	leading edge	Novelty
16	0.9	1.0	1.0	24	unpleasant	pleasant	Attractiveness
17	0.8	2.0	1.4	24	secure	not secure	Dependability
18	0.5	2.1	1.4	24	motivating	demotivating	Stimulation
19	0.7	2.1	1.5	24	meets expectations	does not meet expectations	Dependability
20	1.0	1.2	1.1	24	inefficient	efficient	Efficiency
21	0.3	3.6	1.9	24	clear	confusing	Perspicuity
22	0.9	1.7	1.3	24	impractical	practical	Efficiency
23	1.0	3.3	1.8	24	organized	cluttered	Efficiency
24	1.0	2.3	1.5	24	attractive	unattractive	Attractiveness
25	1.2	2.8	1.7	24	friendly	unfriendly	Attractiveness
26	1.1	1.0	1.0	24	conservative	innovative	Novelty

Table 5 - Results for each item of UEQ

Appendix B

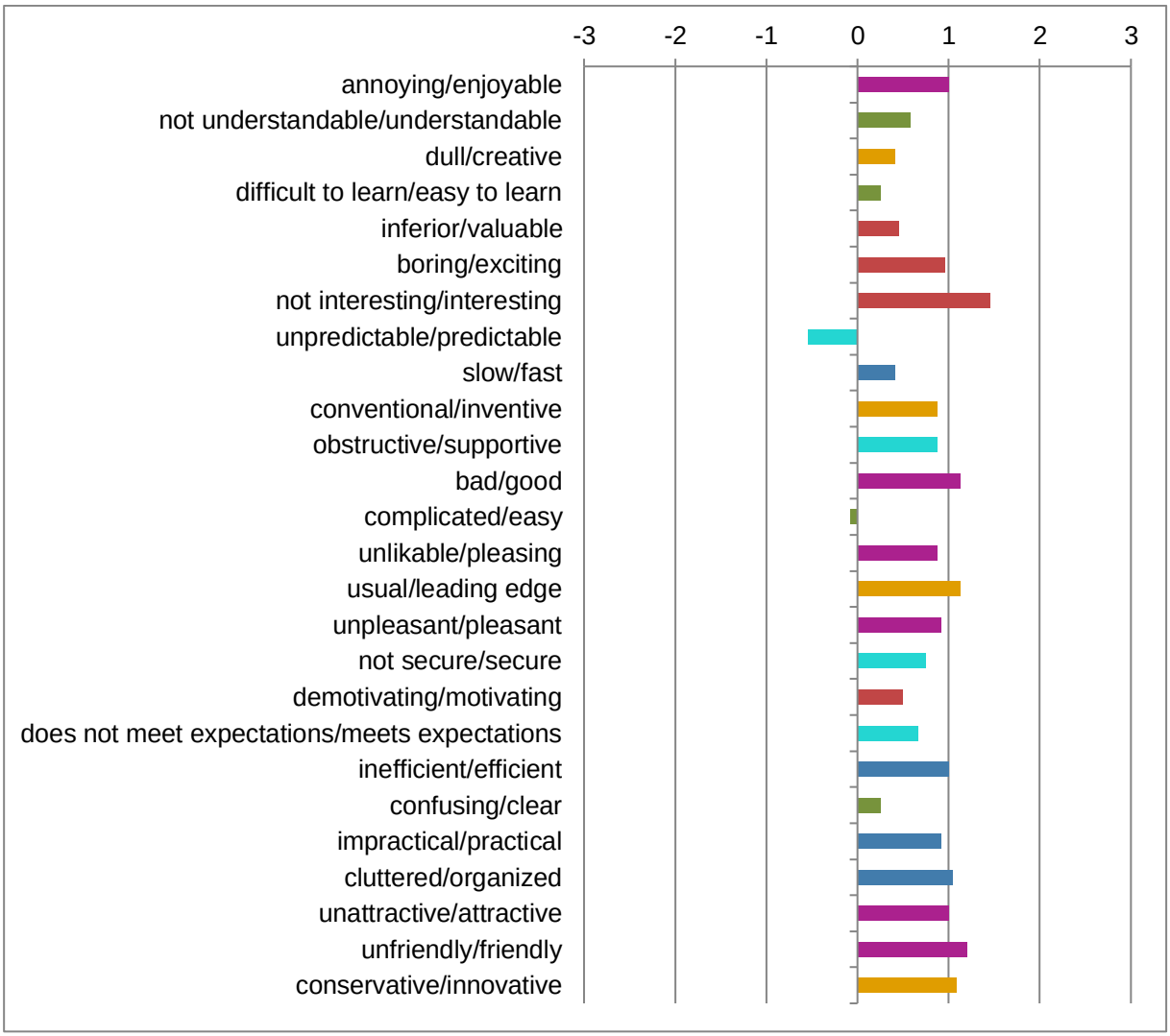

Figure 23 - Mean value per item (UEQ)

Appendix C

Confidence interval (p=0.05) per item						
Item	Mean	Std. Dev	N	Confidence	Confidence Interval	
1	1.000	1.180	24	0.472	0.528	1.472
2	0.583	1.501	24	0.601	-0.017	1.184
3	0.417	1.692	24	0.677	-0.260	1.094
4	0.250	1.595	24	0.638	-0.388	0.888
5	0.458	1.503	24	0.601	-0.143	1.060
6	0.958	1.042	24	0.417	0.542	1.375
7	1.458	0.884	24	0.354	1.105	1.812
8	-0.542	1.474	24	0.590	-1.131	0.048
9	0.417	1.586	24	0.634	-0.218	1.051
10	0.875	1.872	24	0.749	0.126	1.624
11	0.875	0.900	24	0.360	0.515	1.235
12	1.125	1.454	24	0.582	0.543	1.707
13	-0.083	1.717	24	0.687	-0.770	0.604
14	0.875	0.947	24	0.379	0.496	1.254
15	1.125	1.116	24	0.446	0.679	1.571
16	0.917	1.018	24	0.407	0.509	1.324
17	0.750	1.422	24	0.569	0.181	1.319
18	0.500	1.445	24	0.578	-0.078	1.078
19	0.667	1.465	24	0.586	0.081	1.253
20	1.000	1.103	24	0.441	0.559	1.441
21	0.250	1.894	24	0.758	-0.508	1.008
22	0.917	1.316	24	0.527	0.390	1.443
23	1.042	1.829	24	0.732	0.310	1.773
24	1.000	1.532	24	0.613	0.387	1.613
25	1.208	1.668	24	0.667	0.541	1.875
26	1.083	1.018	24	0.407	0.676	1.491

Table 6- Confidence intervals for items

Confidence intervals (p=0.05) per scale						
Scale	Mean	Std. Dev.	N	Confidence	Confidence interval	
Attractiveness	1.021	1.012	24	0.405	0.616	1.426
Perspicuity	0.250	1.458	24	0.583	-0.333	0.833
Efficiency	0.844	1.242	24	0.497	0.347	1.341
Dependability	0.438	0.745	24	0.298	0.139	0.736
Stimulation	0.844	0.991	24	0.397	0.447	1.240
Novelty	0.875	1.078	24	0.431	0.444	1.306

Table 7 - Confidence intervals for scales

Appendix D

Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10
Neutral	Disagree	Agree	strongly disagree	Neutral	strongly disagree	Agree	strongly disagree	Agree	strongly disagree
Agree	strongly disagree	Agree	strongly disagree	Strongly Agree	Disagree	Strongly Agree	strongly disagree	Strongly Agree	strongly disagree
Neutral	strongly disagree	Agree	strongly disagree	Agree	strongly disagree	Agree	strongly disagree	Neutral	Disagree
Neutral	Disagree	Agree	strongly disagree	Agree	strongly disagree	Agree	strongly disagree	Neutral	Disagree
Neutral	Disagree	Disagree	Disagree	Agree	strongly disagree	Neutral	strongly disagree	Neutral	Neutral
Neutral	Disagree	Neutral	Disagree	Strongly Agree	Disagree	Agree	Disagree	Agree	Disagree
Neutral	strongly disagree	Agree	strongly disagree	Agree	Neutral	Strongly Agree	strongly disagree	Strongly Agree	strongly disagree
Agree	strongly disagree	Neutral	strongly disagree	Strongly Agree	strongly disagree	Strongly Agree	strongly disagree	Strongly Agree	Neutral
Agree	strongly disagree	Strongly Agree	strongly disagree	Strongly Agree	strongly disagree	Strongly Agree	strongly disagree	Strongly Agree	strongly disagree
Neutral	Neutral	Neutral	strongly disagree	Agree	Neutral	Disagree	Agree	strongly disagree	Neutral
Neutral	Neutral	Agree	Neutral	Neutral	Neutral	Neutral	Disagree	Neutral	Neutral
Agree	strongly disagree	Strongly Agree	strongly disagree	Strongly Agree	Disagree	Strongly Agree	strongly disagree	Strongly Agree	strongly disagree
Disagree	Disagree	Disagree	Neutral	Neutral	Neutral	Neutral	Neutral	Disagree	strongly disagree
Neutral	Disagree	Strongly Agree	strongly disagree	Disagree	strongly disagree	Strongly Agree	strongly disagree	Agree	strongly disagree
Agree	Neutral	Neutral	Disagree	Agree	strongly disagree	Neutral	strongly disagree	Agree	Disagree
Neutral	strongly disagree	Strongly Agree	Disagree	Agree	Disagree	Agree	strongly disagree	Neutral	Disagree
Neutral	Disagree	Agree	strongly disagree	Agree	Neutral	Agree	strongly disagree	Agree	Neutral
Strongly Agree	Neutral	Agree	Disagree	Neutral	Neutral	Agree	Disagree	Neutral	Disagree
Neutral	Disagree	Strongly Agree	strongly disagree	Agree	strongly disagree	Agree	strongly disagree	Agree	Disagree
Disagree	Disagree	Agree	Neutral	Agree	Neutral	Agree	Disagree	Neutral	Neutral
Agree	Agree	Disagree	Agree	Neutral	Neutral	Disagree	Disagree	Disagree	Disagree
Agree	Disagree	Agree	Disagree	Agree	Agree	Agree	Disagree	Agree	Agree
Disagree	Neutral	Neutral	Neutral	Neutral	Agree	Neutral	strongly disagree	Neutral	Neutral
Disagree	Neutral	Agree	Disagree	Agree	Disagree	Disagree	Disagree	Neutral	Neutral

Table 8 - SUS answers by item

Appendix E

Answers on "*Please describe any negative topic from your playing experience.*"

(1) .

(2) Although I tried a few different strategies, none seemed to be effective, in order to win the game. Some feedback about the player's decisions could be given, during or after the game.

(3) Could not win by any strategy

(4) Could not win.

(5) I'm not from this area, but i think if i play enough times I'll understand the logic behind it. There are a lot of information that I need to read through the ""i"" icons that helps me understand what to do. I took sometime to understand that the ""Reduction of Sector Weight"" Had to do with the Exergy's Values. The bars of the CO2 and Population Hapiness don't seemt to work yet - they would help understand what I did worng or not on my investiments. The historic graph is a bit strange to understand - is the goal to pu Both values underneath the green area? Sometimes I increase so much the Population Hapiness that it escapes from it,"

(6) Nothing

(7) did not win yet

(8) .

(9) Nothing negative, felt really good and enjoyable.

(10) Hard to relate decisions to outcomes even though they are stated. Population happiness is complicated to understand. "Sector weight" is complicated to understand. Hard to understand what decision caused what outcome.

(11) Wanted to see instructions once again. Progress felt confusing at times.

(12) Don't have any.

(13) I felt completely lost. Hard to understand, see suggestion box below.

(14) The feedback from your plays is not shown instantly.

(15) Switching tabs didn't feel very intuitive

(16) It seems to be impossible to win with the game. I made several attempts and didn't win.

(17) Only available in english.

(18) The use of "CO2" emissions, when in real world we tend to use CO2e or GHG. The game should strive for GHG emissions rather than CO2; (2) The use of the term "happiness" - its a relatively well

defined in the literature. I would suggest using other terms such as "population satisfaction", "population comfort", or even "population wellbeing".

(19) It was very hard to achieve good results. The Happiness icon was always smiling even when the population was not happy. The results were always green even if they were negative.

(20) impossible to hit targets

(21) Too much information at the same time.

(22) Not enough information about the investments and what they will do or affect

(23) The layout of the game is not fit for Safari users, as there was a value of cost that couldn't be seen unless I scroll horizontally.

(24) It was hard finding a relationship between the upgrades and people happiness.

Answers on "*Please describe any positive topic from your playing experience.*"

(1) .

(2) The interface was appealing, responsive and it was easy to understand how to play the game.

(3) Very user friendly

(4) Good interface and good dynamic.

(5) I liked that the events functioned as kind of Hint to understand what i could do to reach for teh goals. The tutorial kinda helped understand the game but i still felt confuse on what I should invest or not to reach for the goal.

(6) quick execution and cool layout

(7) it is like playing a sim game, kind of fun.

(8) .

(9) I liked the UI. This looks like a good game to test some scenarios about renewable energy

(10) The UI is very clean and easy to navigate, responsive and readable.

(11) Reducing CO2 emissions and improving happiness felt good.

(12) The interface is very intuitive and easy to understand. Simple but very game-like. It's fast and easy to get invested in.

(13) it's a great idea and it made me think.

(14) The UI is simple and intuitive

(15) Clear information

(16) allows for several investment options, which can be easily used and are all on the same page.

(17) Very easy to use the game

(18) The game was addictive, round after round to understand if policies had the desired outcome.

(19) The experience was fluid and challeging.The thematic of the game is very interesting and current. The interface is clean and enjoyable.

(20) organized

(21) the game idea is interesting

(22) Spending a lot of money

(23) The design and organization of information is pleasant to see.

(24) The design and functionality is very good

Answers on "*Please provide any suggestions for future improvements.*"

(1) .

(2) "The game could be extended with more decision. The application could hold more similar games and information to educate players about this topic."

(3) Improvements on the model, or hint on a strategy to win

(4) Achievements

(5) "I believe the achievements area could be interesting to function as hints of other opportunities just like the events. There should be a button for Options where I could see who did this work, the terms that appear on the begining and a button that redirects to this form. There should be a kind of information that appears after submiting the investiment that shows how well or not i did to reach for my goals.... but the events also help with that and the bars for CO2 and Happiness do it as well"

(6) an walkthrough

(7) maybe, a preview about how much energy every upgrade will use.

(8) .

(9) Make it usable in smartphones maybe

(10) Definitely would recommend adding a more hands on tutorial that tells you what each of your decisions (more power, different spenditure plans) will impact in each metric, and then scale the difficulty by adding more variables that affect them.

(11) Make it more intuitive

(12) Don't have any. It's pretty solid already.

(13) Check in real time how your choices will afect the hapinness of the population and CO2 emition ratio. I believe it could help in the decision making process as I was completely clueless of how I should move forward. Also the tutorial should be refined as I only noticed that it was a tutorial the second time I played. I was too focused on the text at the top. Maybe push the box to the lower part as it was in the beggining and highlight more the boxes that should be highlighted (maybe a border around the section we should pay attention to). What might also help is the tutorial part, to be the first year and, for instance, how upgrading the bus infrastructure would help? I just remembered, there was a section of some type of warning in the information tab that mentioned a disaster that happened and 10% of renewable energy was lost, now this part I understoud but there were other warnings that I failed to see how it would affect my next choices.

(14) After each turn, show the impact of the plays.

(15) Easier way to access all the information

(16) It might be useful to have an option in the menu to reread the "tips" that are displayed at the beginning of the game. There could also be the option to play a new game after completing a game.

(17) To get the most out of the game it is necessary to know the main themes well.

(18) Maybe a prediction of the impact of the policies, when we are selecting policies in each round, for example, electrification of transport - how much is expected to increase in terms of electricity demand? (2) Maybe at the beginning provide a brief explanation on what contributes to CO2 emissions and to happiness (to happiness there is an explanation, but I was not sure all information was disclosed in this explanation as I felt, when playing, that when I invested in energy efficiency at home/residences, happiness would increase - and this effect was not stated at the beginning).

(19) "In the end of one game show some tips to improve on the next game. The happiness icon should be sensible to the current happiness of the population. The result numbers should be green when good and red when bad. The tutorial could have a ""next"" botton near the ""skip"" botton. The ""next botton should do what the ""skip"" does currently and the ""skip"" should skip directly to the begining of the game (it gets a bit annoying when you have to go through the tutorial every time you want to restart the game). "

(20) dont know

(21) a better explanation of the game

(22) More information about what the investment will do

(23) Test the game in various browsers and computers to see if the layout is appropriate to conduct the study and not cause confusion.

(24) Maybe a video tutorial on how to use the game