João Pedro de Vasconcelos Danen
Licenciatura em Ciências de Engenharia do Ambiente

Economic potential of human motion for electricity production in gymnasiums

Dissertação para obtenção do Grau de Mestre em Engenharia do Ambiente, Perfil de Engenharia em Sistemas Ambientais

Orientador: Doutor Rui Jorge Fernandes Ferreira dos Santos, Professor Associado com Agregação da FCT-UNL
Co-orientador: Doutor Francisco Manuel Freire Cardoso Ferreira, Professor Associado da FCT-UNL

Júri:

Presidente: Prof. Doutor Nuno Miguel Ribeiro Videira Costa
Arguente: Doutor João Pedro Costa Luz Baptista Gouveia
Vogal: Prof. Doutor Rui Jorge Fernandes Ferreira dos Santos

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

September 2018

LOMBADA

Economic potential of human motion for electricity production in gymnasiums

João Danen

2018

Economic potential of human motion for electricity production in gymnasiums

Acknowledgements

I would like to thank both my mentors, Professor Rui Santos and Francisco Ferreira, for all the support in the making of this project and all the guidance offered along the way. In addition, I would like to thank Professor Francisco Ferreira for helping me to finance this dissertation and putting me into contact with Mr. Carlos Martins.

I would like to especially thank Mr. Carlos Martins for everything he has done for this study. From designing and building the prototype to finding a gymnasium that would let us do the tests, everything was possible with the help of Mr. Carlos. Thank you for all the patience and help along this arduous path to completing this dissertation.

I would like to express my gratitude to every collaborator from the gymnasiums that were featured in this study. Mr. Wellington Almeida on behalf of *Be Gym Fit*, Mrs. Melanie Bessa on behalf of *Be-Fit Setúbal*, Mr. Marcos Coutinho on behalf of *Feelgood* and Mr. Jorge Oliveira on behalf of *Arena Club Oeiras*. Thank you for offering the necessary information and doing everything possible to help me complete this study.

Finally, I would like to thank my friends and family for all the support offered along this last year of this project. Without the guidance with writing this study and the emotional support I wouldn't have been able to complete this project.

Abstract

With the continuous rise of energy demand at a global scale and, the significant environmental impacts that the current energy sector causes, political decision-makers feel the need to increasingly invest in renewable energy sources, such as solar and wind energy, and find new ways to produce electricity with minimal environmental impact.

The use of human movement to produce energy has already been a study subject, but with very few applications in the current market. This is mainly due to the relation between the investment costs and the electric output that current generators are able to produce. A scarcity of studies about the economic potential of these technologies is noted, which contributes to the weak interest of potential investors in their implementation.

In this work an attempt is made to synthesize the results related to the analysis of the economic aspects associated to the technologies that use human motion, which already have real-life applications and have been extensively studied. Simultaneously the concept is developed, and a prototype is constructed of a system capable of using linear human movement, of which the performance is evaluated.

As such, it becomes possible to compare the electric output of the rotational system, based on existing literature, with the output of the linear system based on the results acquired during the preliminary tests of a developed prototype. These values are used to calculate the reduction of greenhouse gas emissions that these systems enable.

The experiments with the prototype were developed in a gymnasium, because these establishments concentrate a considerable amount of daily human motion. Currently, that movement is wasted in the machine's resistance. Meanwhile, the economic analysis and potential GHG savings of these systems are studied in four different gymnasiums with varying characteristics.

It was determined that the use of rotational human motion to produce electric energy has a considerable economic potential in the current market, which is supported by the fact that a few establishments have already incorporated equipment that permit their exploitation. However, linear human movement is incapable of reaching an acceptable return period in almost all scenarios. Only large-scale gymnasium, such as *Be-Fit Setúbal*, possess the capacity to adopt this technology and reach a return period with economic viability

Keywords: Microgeneration, renewable energy, human motion harvesting to produce electricity, economic analysis, gymnasiums

Resumo

Com o aumento contínuo da procura de energia a nível global e, os impactes ambientais significativos que o setor energético atual causa, os decisores políticos sentem a necessidade de investir crescentemente em fontes de energias renováveis, tais como a energia solar e eólica, e de encontrar novas formas de produzir eletricidade com um impacte ambiental mínimo.

A utilização do movimento humano para a produção de eletricidade tem sido objecto de estudo, mas com muito poucas aplicações no mercado atual. Isto deve-se principalmente à relação entre o custo de investimento e o *output* elétrico que os atuais geradores conseguem produzir. Verifica-se uma carência de estudos sobre o potencial económico destas tecnologias, o que contribui para o fraco interesse de potenciais investidores na sua implementação.

Neste trabalho procura-se sintetizar os resultados da análise dos aspectos económicos associados às tecnologias de utilização de movimento humano, que já têm aplicações na vida real e que foram extensamente estudadas. Simultaneamente desenvolve-se o conceito e constrói-se um protótipo de um sistema capaz de utilizar movimento linear humano, cujo desempenho é avaliado.

Assim, torna-se possível comparar o *output* elétrico do sistema rotacional, baseado na literatura existente, com o *output* do sistema linear baseado nos resultados adquiridos durante os ensaios preliminares de um protótipo desenvolvido. Estes valores são utilizados para calcular as reduções nas emissões de gases com efeito de estufa que estes sistemas permitem.

As experiências com o protótipo foram desenvolvidas num ginásio, pois estes estabelecimentos concentram uma quantidade considerável de movimento humano diário. Na situação atual esse movimento é desperdiçado na resistência das máquinas. Entretanto, a análise económica e as poupanças GEE potenciais são estudados em quatro ginásios different com características variadas.

Foi determinado que a utilização do movimento rotacional humano para a produção de eletricidade tem um potencial económico considerável no mercado atual, o que é suportado pelo facto de alguns estabelecimentos terem já incorporado equipamentos que permitem o seu aproveitamento. Contudo, o movimento linear humano é incapaz de atingir um período de retorno aceitável em quase todos os cenários. Apenas ginásios de grande dimensão, como o *Be-Fit Setúbal*, possuem capacidade para adotar esta tecnologia e atingir um período de retorno com viabilidade económica.

Palavras-chave: Microgeração, energias renováveis, utilização de movimento humano para a produção de energia, análise económica, ginásios

Table of Contents

List of Figures

List of Tables

Abbreviations and acronyms

AC Avoided Cost

EDP Energias de Portugal

EIA Energy Information Administration

EPBT Energy Payback Time

EROI Energy Return on Energy Invested

EU European Union

FiT Feed-in Tariff

GHG Greenhouse Gases

HuP Human Unit of Power

IEA International Energy Agency

OECD Organisation for Economic Co-operation and Development

O&M Operations and Maintenance

REN Rede Elétrica Nacional

RP Return Period

T&WD Temperature and Working Days

UPAC Unidade de Produção para Autoconsumo

UPP Unidade de Pequena Produção

VOC Volatile Organic Compound

WEPS+ World Energy Projection System Plus

WHO World Health Organization

1 Introduction

1.1 Framework

The rising demand for electricity is currently one of the biggest problems the world is facing. Countries that are facing exponential growth, such as India and China, are experiencing severe electricity shortages and are looking for cheap and renewable sources of energy as to not make the same mistakes that currently developed countries made. This has proven to be a difficult task, because developing countries lack funds to pay for the most common renewable sources of energy, such as solar, wind and hydro. This has forced these countries to resort to the cheaper way of producing electricity, mostly in the form of coal or natural gas, which has an extremely damaging effect on the environment and human health. [1]

Studies into other, less commonly used, methods have been done, but none of these have surged in the market as a possible solution to producing cheap and renewable electricity. Humans are constantly in motion and the possibility of harvesting this movement in gymnasiums has been studied in the past, albeit at a mostly theoretical level. The economics behind this potential source of energy are scarcely explored, turning it into more of an enthusiast's technology, despite its high potential. [2]–[7]

Gymnasiums are establishments directed at allowing people to freely exercise to maintain their physical condition, with a periodical fee associated. These establishments use a huge amount of electricity in the form of lighting, acclimatization and technologies, such as exercise machines, sound systems and network technologies. As such, these gymnasiums commonly consider reducing their consumption through the installation of solar panels or wind turbines on the roofs of the buildings.

Due to the high amount of human motion inside gymnasiums, these establishment should consider using this movement to produce electricity. Rotary movement with bicycles and cross trainers has been studied and are already implemented in the market [8], [9], but with a low amount of success due to the high entry price and low output of electricity, resulting in a high return period. Linear movement is a less observed source of energy but is much more common movement inside gymnasiums than its rotary counterpart. The downside of linear motion is that the electric output is theoretically much lower and it is more difficult to harvest, needing a linear generator or a system capable of adapting the movement to be used by a rotary generator.

With a large amount of human motion and a low entry price for the technology, human motion could become a reliable source of electricity to appease the growing electricity demand, while turning a profit for gymnasiums that decide to implement this technology.

1.2 Objectives and organization

The aim of this thesis is to study the economic potential of linear and rotational human motion harvesting technologies in gymnasiums. For rotational human motion, pre-existing data will be used to test this potential, while for linear human motion a novelty system will be built to test the possibility of using this technology in future endeavours. The most important aspects for the success of this project is the electricity output that these systems are capable of achieving and the return period they offer to their adopters to start becoming profitable. An additional aspect that will be explored is the greenhouse gases (GHG) emissions savings this technology can offer as gymnasiums turn to this kind of electricity production.

This dissertation is organized in five chapters. The first chapter introduces the dissertation through the themes that are explored, the objectives of this thesis and the way it will be structured. The second chapter is dedicated to offering a background to the current project. This is where the current electricity production paradigm is explored and the microgeneration technologies that are currently used in the market and the economic support that they receive. The third chapter is dedicated to doing a literature to discuss the previously developed human motion harvesting technologies, as to give an insight into what previous authors have researched and what the conclusions were that they achieved. This data will be used in the rest of this study to aid the assessment of the electricity production and economic success of the studied systems. The fourth chapter is used to explain the methodology used in this project. Here is where the materials used to build the linear harvesting system are shown, the different scenarios used and the reasoning behind them and the business models used to explore the economic potential of these technologies. Additionally, the data and formulas used to study the potential GHG savings that these systems can achieve are also shown. The fifth chapter contains the results of electricity production and the economic analysis of these technologies, alongside the GHG savings that can be achieved by using these technologies. The results are also discussed in this chapter as to give an insight into what they mean for the future of human motion harvesting. The last chapter is where conclusions are made in relation to the economic potential of microgeneration with human motion and the degree of success of electricity production in the observed gymnasiums, alongside future directions that will be given to further develop these systems and the studies that might be developed by other authors. The environmental benefits that these systems offer will also be explored and observations will be made on their potential to combat the current emissions related to the energy sector.

2 Microgeneration and the current energy sector

2.1 Current trends

2.1.1 Electricity consumption and demand

World

With a current world population of 7.4 billion and an estimated 9 billion or more in 2040, expansion and innovation in the field of electricity production is mandatory to solve the impending electricity crisis. This population growth translates into a rise of electricity demand, which, in turn, is accompanied by an upturn of electricity consumption, which has already been noted in the last few decades, as can be seen in Figure 2.1. [10]

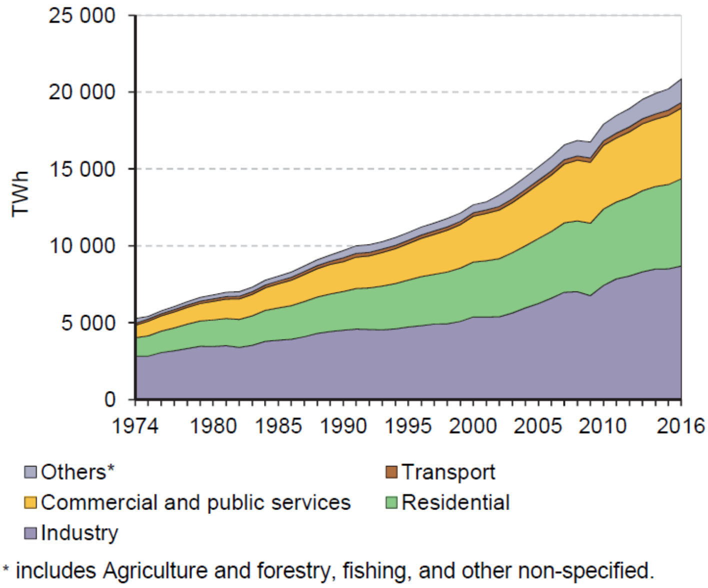

Figure 2.1 – World electricity consumption by sector (TWh) [11]

From observing the above figure, the sector that consumes the most electricity and shows to be continuously needing more electricity is the industry sector, which consumed more than half the electricity in the last century but has since been diminishing in contrast to the rise of electricity consumption in the residential and commercial sectors. In the near future, with the electrification of transport, this sector will also rise.

Globally, the trend is to continually need more electricity which has already been verified for a few decades but has recently become even more evident as the increase of electricity demand continually approaches an exponential growth and can be noted in the figure above. [10]

In 2017 the world electricity demand increased by 3.1%, with China and India accounting for 70% of this growth. This electricity demand increase is strongly linked to the strong economic progress that in-development countries are making. Already developed countries saw a slight decrease, in the case of the United States, or an increase of 2.3% which was matched by the increase in economic output, in the case of the European Union. [12]

Portugal

The current state of electricity demand in Portugal (Figure 2.2) is very positive considering the global paradigm. The demand for electricity in Portugal has stabilized in the last few years mainly due to the economic crisis, but also due to the stagnation of population growth and possibly due to better electricity conservation efforts by its residents, which are the result of many campaigns that are promoted throughout the country. [13]

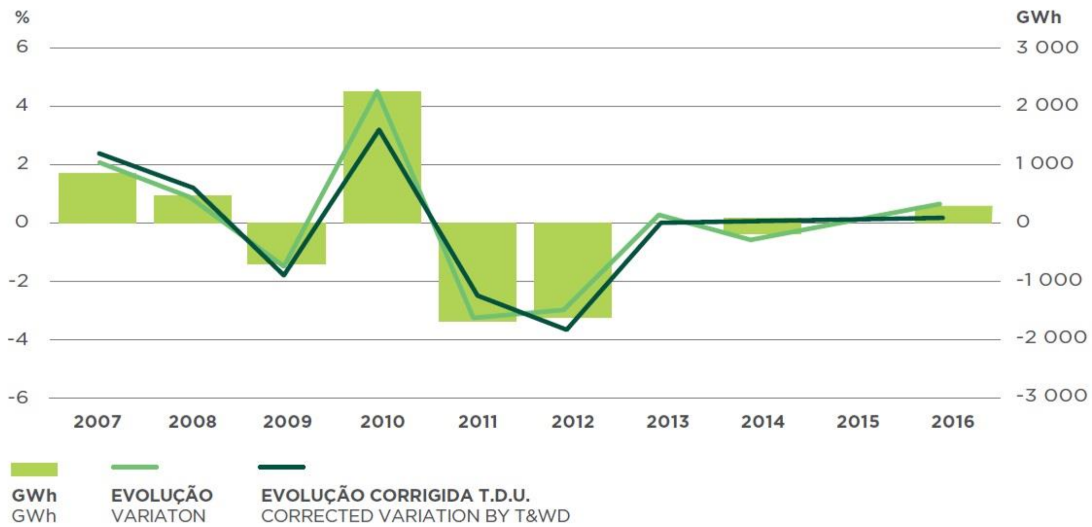

Figure 2.2 - Electricity demand variation (%) in Portugal [14]

The evolution of electricity demand needs to be corrected by temperature and number of working days (T&WD) to account for temperature changes and to balance weekend days and working days. However, this stabilization has recently been disrupted by the growth of the Portuguese economy which has caused the electricity demand to start rising again, albeit at a lesser extent than the global paradigm. [13] Due to the electricity producing infrastructure built in the last decades and the ever-increasing harvesting of renewable energy, Portugal has no problem in meeting the electricity demand of their citizens, as can be seen in Figure 2.3:

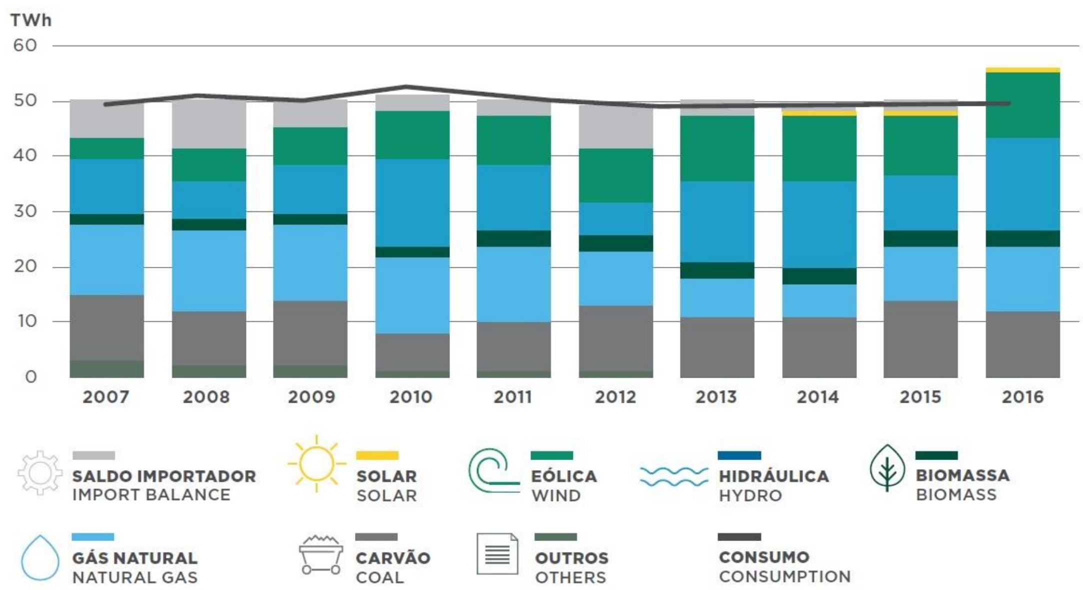

Figure 2.3 - Electricity demand, by power source (TWh) in Portugal [14]

Portugal is able to appease this demand due to heavy investments into renewable energy sources, especially hydro and wind. Solar energy has a small share in the global electricity production, while biomass also contributes a fair amount. However, Portugal still needs to burn coal and use natural gas to fuel the remaining electricity demand that their renewable counterparts cannot cover. This trend has been declining in the last few years with the help of investments by the government and the ever-lowering price of renewable technologies. [14]

2.1.2 Electricity production

World

Globally the electricity production sector is dominated by the use of fossil fuels, consisting of coal and natural gas. Of the 25000 TWh of electricity predicted to be produced in 2020, around 15000 TWh comes from non-renewable sources. The tendency in the future is to shift the current form of electricity production, as can be seen in Figure 2.4, although not at a pace that would eliminate the need for fossil fuels in the near future. In the projections made for 2040, renewable energy is to equate coal in the amount of electricity it produces globally (31% each). This change in the current electricity production paradigm is believed to be due to technological improvements and government incentives to support the adoption of renewable energy. [10]

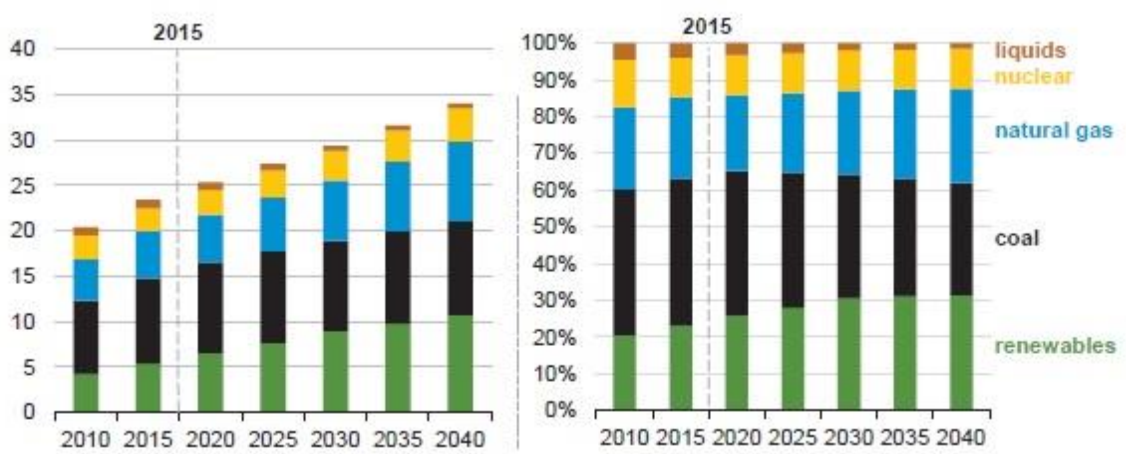

Figure 2.4 - Current and projected world net electricity generation by fuel in trillion kWh (left) and share of net electricity generation (right) [10]

The projections made in the image above are based on the World Energy Projection System Plus model (WEPS+). [10]

From Figure 2.4 it can also be noted that the electricity production is believed to almost double in the next 30 years, since the study was published. This huge increase in production needs to be supported by government financing to aid the technological advancements in renewable technologies, as to not force countries with less economic power to burn fossil fuels to accompany the continually increasing electricity demand.

In 2017 the use of renewables saw a considerable increase of 6.3% (380TWh), which made it account for 25% of the global electricity generation. This growth was mostly due to countries, such as the United States and China heavily investing into adopting renewable technologies, alongside the European Union. This increase is mostly in the form of the most common renewable technologies which are: wind power (37%), solar PV (27%) and hydropower (22%). Other sources, such as bioenergy (12%) also saw a substantial increase. [12]

Despite this increase in renewable methods of producing electricity, coal and natural gas still observed an increase last year. Natural gas grew by 3% and coal by 1%, which had been in decline for the last two decades, but has recently increased due to the demand in Asian countries, primarily China and India. [12]

Portugal

The current situation of electricity production in Portugal differs from the current global overview. Portugal, being part of the European Union, has adopted several measures to develop their renewable energy infrastructure and the results of this effort can be seen in Figure 2.5:

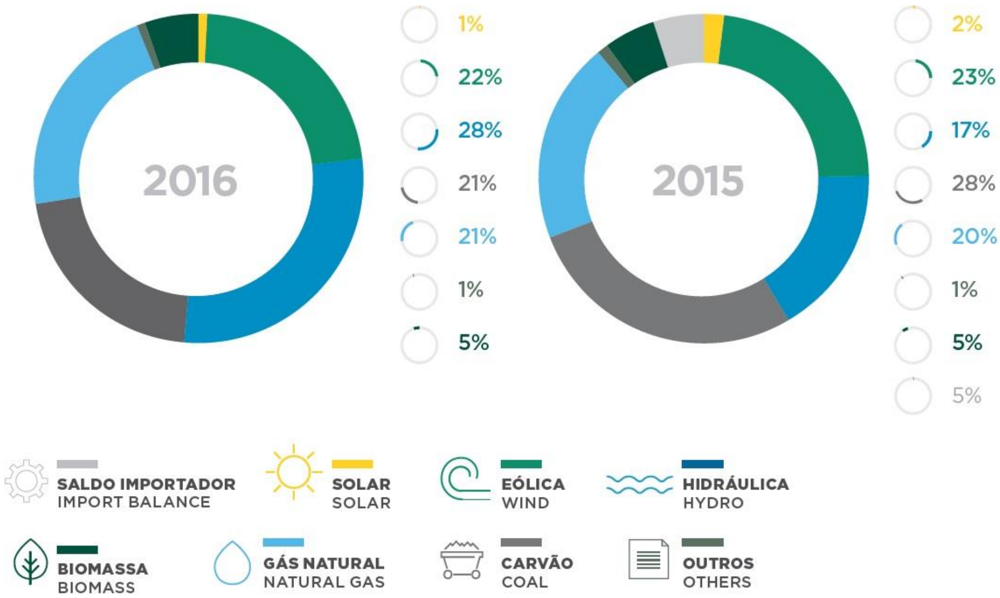

Figure 2.5 - Electricity production by source (%) in Portugal [14]

In 2016, 57% of Portugal's electricity production came from renewable sources. This poses a 10% increase from the previous year, showing an increasing growth in terms of renewable energy production. The biggest producers are hydro and wind energy, with 28 and 22% respectively, which are explored by the numerous dams spread across Portugal and the wind turbine fields that are commonplace in most regions. Coal is still explored at a large-scale, with power plants such as *Sines Power Plant*, but the use of this source is lessened along the years due to the high emissions that are caused by their combustion. Natural gas is on the rise for Portugal seeing a slight increase between 2015 and 2016. This natural gas is imported mostly from Algeria and Nigeria. [14]

However, the electricity production in Portugal can vary greatly depending on the weather conditions that the country sees in the corresponding year. Portugal is able to appease a large amount of its electricity demand through hydro in a year with high hidraulicity or through wind. Solar can also contribute to this production, albeit at a small scale, if there are a high number of solar hours and low nebulosity in that year. The remaining need is complemented by fossil fuel electricity generation referenced before, amongst other types of electricity production.

2.1.3 Emissions in the energy sector

World

The energy sector, of which the electricity producing sector is a substantial contributor, is responsible for a large part of air pollution that nowadays causes millions of deaths every year. [15] This is mostly due to the combustion of fossil fuels and bioenergy, but also coal extraction and other industrial activities that have indirect ties to the energy sector. [16] The primary pollutants that derive from electricity production are sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter (PM), which can be seen in Figure 2.6:

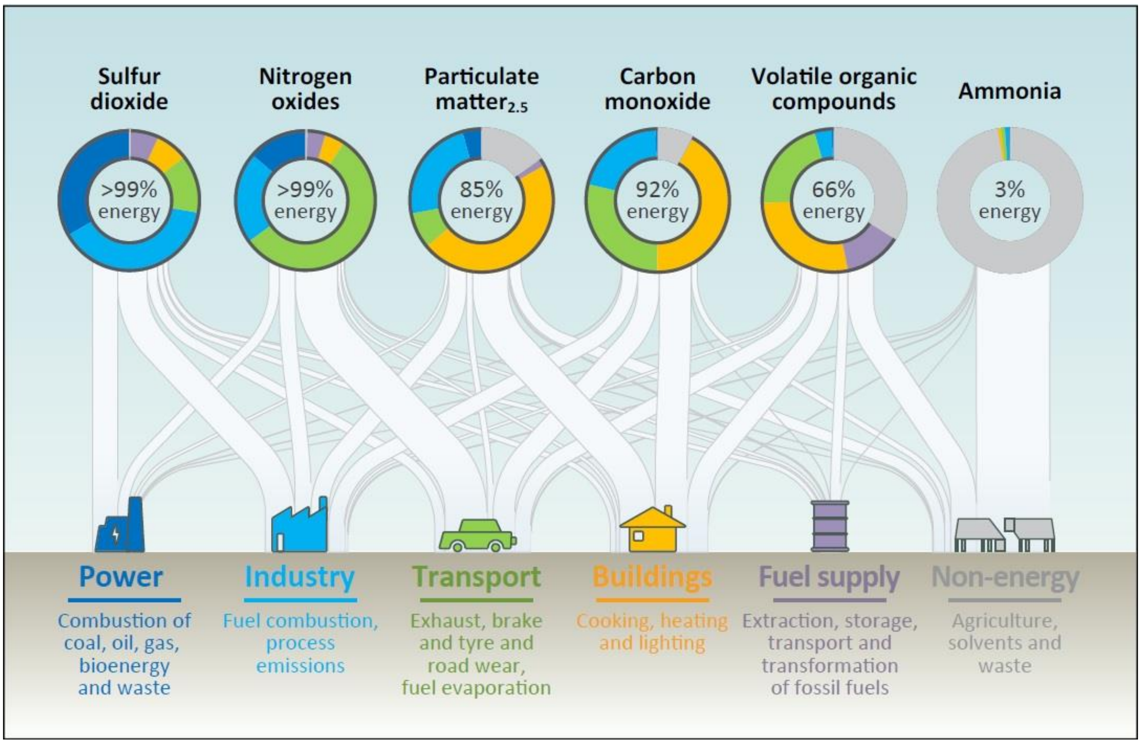

Figure 2.6 - Energy sector related air pollutants and their sources [17]

As seen in the above figure, sulphur dioxide comes almost exclusively from the combustion of many energy sources such as coal, oil and natural gas. This gas is related to a series of adverse health effects and can be a precursor to the formation of particulate matter. [16]

Nitrogen oxides also primarily come from combustion and are considered toxic gases. This gas contributes to the formation of particulate matter and contribute heavily towards the greenhouse effect by being the precursors to the formation of ozone. [16]

Lastly, particulate matter comes mostly from vehicle emissions and brake, tyre and road wear. Particulate matter can be divided into PM_{10} and $PM_{2,5}$, depending on the size of the particle. $PM_{2,5}$ is particularly alarming since it causes a plethora of respiratory diseases, accumulating in the lungs of the person who inhales it. [16]

All the aforementioned gases, with the exception of particulate matter and sulphur dioxide, are considered to be greenhouse gases, with the addition of methane and fluorinated gases. These gases are responsible for the continuous rise of the greenhouse effect that is observed all over the world. This effect is characterized by the increase of the world's surface temperature, which can cause serious issues in the near future if the current emissions paradigm is not controlled in a sustainable matter. [16]

Historically, the average global amount of GHG emissions related to the energy sector in 2013 was 528 gCO_2eq/kWh. [18] This value differs greatly depending on the majority method of electricity production, which, in turn, is directly tied to the wealth of the countries. In-development countries, such as India, observe an inflated 926 gCO_2eq/kWh in 2012 [19], while more developed countries, especially in the European Union (EU), mostly see values lower than the global average, with some even reaching around 200 gCO_2eq/kWh in 2013. [20]

Nowadays, these values are slightly higher in the case of Portugal, while India sees a slight decrease to around 800 gCO_2eq/kWh. Some European countries, such as France and most of Scandinavia are able to reach a carbon intensity under 100 gCO_2eq/kWh through their efforts made in reducing the use of fossil fuels, amongst other policies. [21]

In 2017 the global CO_2 emissions related to the energy sector reached a historic peak of 32.5 gigatonnes (Gt), which represented an increase of 1.4% compared to last year's emissions. [12] The development of the global GHG emissions can be observed in the following figure:

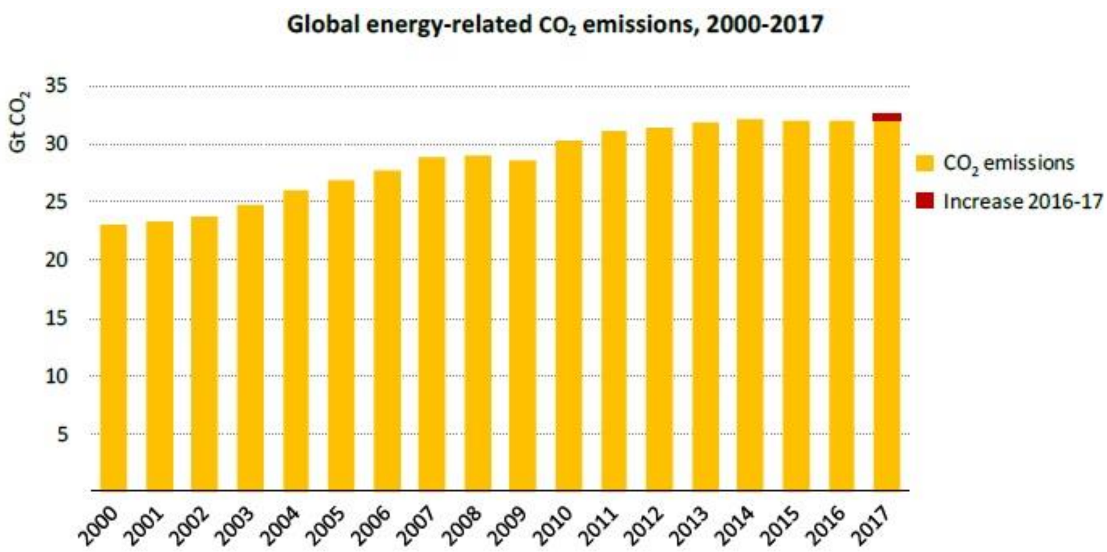

Figure 2.7 – Global energy-related CO_2 emissions (Gt CO_2) [12]

The amount of GHG emissions has been increasing gradually in the two decades, despite the slowdown observed in recent years due to the increased adoption of renewable energy technologies. This increase is associated to the exponential growth that countries, such as India, are experiencing in the last few decades, as has been referenced before. [12]

Portugal

In Figure 2.8 the emissions caused by electricity production in Portugal are observed. These emissions can be divided into 2 categories: Coal emissions from the combustion of coal at power plants, such as *Sines/Pego Coal Plants* and natural gas.

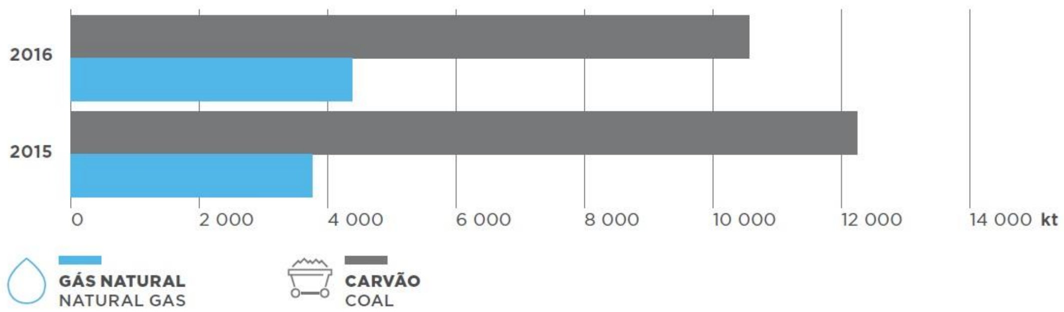

Figure 2.8 - Emissions from electricity production in Portugal by source [14]

Coal combustion derived emissions are in the form of carbon dioxide, sulphur oxides, mercury, nitrogen oxides, particulate matter and methane. Natural gas is most damaging for emitting high amount of methane during transport and storage, but also emits some of the previous mentioned gases, albeit at a reduced quantity compared to other fossil fuels. [22]

In Portugal the amount of GHG emissions related to the biggest electricity producer in the country, EDP, is 187.85 gCO_2eq/kWh for the residential and small businesses sector, while the large-scale commercial side sees emissions of up to 280.96 gCO_2eq/kWh. [23]

2.1.4 Environmental impacts

There is a plethora of adverse environmental impacts related to the current methods of producing electricity. Aside from the massive amount of emissions released every year by power plants, as discussed in the previous chapter, there are various direct and indirect consequences. [13]

The emission of excess amounts of carbon dioxide and other GHG, such as, methane, nitrous oxide and halogen compounds contribute heavily to climate change and ozone layer depletion. Sulphur dioxide, nitrogen oxide and ammonia emissions are responsible for the on-going air acidification. VOCs (Volatile Organic Compounds) are causing the increasing appearance of tropospheric ozone and the general local air quality is diminishing all across the world due to air pollution originating from the energy sector, alongside transportation, agriculture and other polluting sectors. [13]

Water pollution can be associated to runoff from power plants, which occupy a large amount of land to be operational, contributing to the reduction of biodiversity and deforestation. If it is not properly taken care off, solid and dangerous waste can end up being introduced into the surrounding wildlife and contribute to soil degradation and water pollution. Oil rigs and the transport of compounds through tubing can cause the degradation of coastal areas, primarily through erosion, and marine ecosystems. [13]

2.1.5 Human health impacts

According to the *World Health Organization* (WHO), air pollution kills around 7 million people every year. 4.2 million are due to ambient pollution characterized by gases, such as carbon dioxide and sulphur oxides, which are emitted heavily by the energy sector amongst other contributors such as car emissions and households. [15]

These deaths are caused by various diseases linked to air pollution of which lung cancer (25%) and acute lower respiratory infection (17%) are the most commonly caused by pollutants. Strokes (16%), ischaemic heart disease (15%) and chronic obstructive pulmonary disease (8%) are other major diseases that are seen to be caused by daily exposure to excess amounts of pollutants. [15]

The energy sector is also indirectly contributing to other human health issues through the various environmental impacts that this industry causes, as has been discussed in the previous chapter. One example of this can be the consumption of water, polluted by runoff originating in power plants, by the population or the infection of fish in the sea, through the presence of an oil rig that is then consumed by us.

2.2 What role for microgeneration in future electricity production?

2.2.1 What is microgeneration?

The *Energy act,* published in 2004, defines microgeneration or micro-scale electricity production, as: *"the use for the generation of electricity or the production of heat of any plant which in generating electricity or producing heat relies wholly or mainly on a source of energy or technology* *that is renewable, such as biomass, wind and solar, or the capacity of which to generate electricity or to produce heat does not exceed 50 kW, in the case of electricity, or 45 kW thermal, in the case of heat.".* This document created by the Government of the United Kingdom is one of the first studies to acknowledge the concept of microgeneration and how it can be an effective method to produce electricity. It delineates the policies needed to make this technology have a place in the electricity production market through economic aid, such as feed-in tariffs (FiT) and tax incentives. [24]

Other countries have followed suit incorporating policies to make microgeneration a viable technology to be used to satiate the current energy demand. Most European countries, such as France, Germany and Portugal, and some US states have used feed-in tariffs and tax breaks put into place to incentivize consumers to adopt microgeneration technologies, most commonly based on solar and wind energy. [25]

For this thesis, microgeneration can be defined to simply being the production of electricity from a renewable source, or low carbon source, with a capacity under 50 kW. [26], [27]

Microgeneration commonly includes technologies such as photovoltaic cells, micro wind turbines and micro-combined heat and power. Other, non-traditional installations, such as fuel cells or biomass-based technologies are also on the rise, alongside other future technologies that may be adopted, such as movement-based technologies as the ones explored in this thesis. All these technologies are made to be used at a small-scale, for domestic or community use, in the form of housing or other singular buildings, such as offices or schools. [28]

Photovoltaic cells are one of the most common way of producing electricity using a renewable source of energy, which in this case is the radiation emitted from the sun. This type of technology can be divided into several categories based on the type of material the cells are made of. The most popular categories include the crystalline silicon-based cells, represented by mono-crystalline silicon and poly-crystalline silicon, and thin film cells, which includes cadmium telluride, copper indium gallium diselenide and amorphous silicon. [27], [29], [30]

Micro wind turbines are installed on top of the roofs of residential buildings and offices or on land to use the wind as a driver of the blades attached to a wind turbine or generator. The amount of electricity generated by this technology depends on two factors: the speed of the wind passing through the blades, which is common to be in places with a high altitude and little to no obstructions, and the area swept by the blades. The electric output of the generator is directly proportional to the area the blades covers, which means that the more area is covered, the more electricity is produced by the wind turbine. [27], [30], [31]

These wind turbines can be divided in the following categories: Savonious rotors, which are characterized by having only two blades that are the halves of a cylinder which enable them to have a fast start up speed but lacks the long-term efficiency of the other setups, such as the multiblade rotors that can have up to 24 blades. The high number of blades offer them a high starting torque, but the low rotation speed that these rotors observe make them a less than optimal option in most cases. [30]

Other rotors include the darrieus rotors that have two or more in form of a rope that is held by their extremes, which helps the efficiency and the rotation speed of the wind turbine but hurts the technology but having a low starting torque. [30]

Micro-combined heat and power technologies take existing power sources, more commonly solar, to produce electricity and use the heat created in the production process and the direct heat from the sun to provide heating to the establishment that decide to incorporate thigs technology. This in turn enables the technology to achieve a higher efficiency, since it is using more of the energy provided by outside sources in the form of heat and radiation to produce both heat and power. [27], [30]

Fuel cell technology is based on the use of electrochemical transformations to produce electricity. The type of fuel cell is based on the type of chemical used, which can vary between hydrogen and derived hydrocarbons, such as alcohols. This type of production has a potentially high efficiency, low emissions and can be used as a source of heating as well. [30]

The large diversity of chemicals that this technology can use makes it have a large number of types of cells, as referenced before. The most common fuel cells are: alkalines, proton exchange membranes, direct methanol, phosphoric acid, molten carbonate and solid oxide. [30]

2.2.2 Why microgeneration?

One of the primary reasons for the shift to microgeneration is due to the inherit reduction of CO_2 emissions granted by the fact that these technologies are entirely dependent from renewable sources with minimal impactful emissions related to their use. This can be a powerful driver towards carbon reduction and can induce behavioural changes in the users of these technologies to become entirely independent from the big centralized fossil-fired power plants that currently feed the electricity grid. This subsequently leads to carbon reduction due to the lesser use of fossil fuels, primarily coal. [27], [31]

The increasing adoption of microgeneration technologies used can be translated into various environmental benefits, the most obvious being the reduction in GHG emissions. A large amount of GHG emissions are a result of fossil fuel combustion, such as coal, which is currently the most used method of producing electricity due to its low cost and high accessibility. The reduction in use of fossil fuels to produce electricity can also cause the elimination of existing power plants, which in turn will also remove the associated environmental risks these establishments pose to the surrounding area.

In any type of distribution of public resources, such as water, gas and electricity, there are always losses involved, because of the ways we currently use to allocate these resources. Just in Portugal, in 2005, losses in transport and distribution accounted for 9% of total electricity production, which is equivalent to 4212 GWh. To eliminate these losses, moving the electricity source closer to big cities, through distributed microgeneration, will shorten or even eliminate the travel time of electricity to consumers, reducing these huge losses of electricity. [27], [31]

Microgeneration technologies also reduce the need for a big range distribution system, since the source of electricity is located at the consumers. This lowers the investment needed in distribution and transportation, which can then be allocated to other resources, bringing more microgeneration installations to more households. Due to the lesser use of distribution systems, the need for maintenance of these lines can be reduced and extend the service life of these gateways. [26], [31]

Other authors also point out that microgeneration can promote user education, through changing consumption patterns towards lower levels of energy consumption and load shifting. [26], [31]

2.2.3 Current barriers to microgeneration

Microgeneration is currently trapped in a cycle that many emerging technologies have faced throughout history. This cycle revolves around the high cost of entry for the technology that causes the demand to stay low. While the government does not offer economic incentives, such as tax breaks or feed-in tariffs, or a considerable financial investment, to change this situation, the demand will remain low, making the technology not economically appealing for the masses in the foreseeable future. [26]

The lack of a defined infrastructure for energy trading between microgenerators and energy companies is something that should be built before microgeneration can be a real source of producing electricity and income for the users that adopted this technology. [26]

Regulations are also a good way to make microgeneration gain traction. Capital grants can be put into place or implementing regulations that make new structures adopt microgeneration technologies can help in the uptake of the technology. [26]

However, a short payback for microgeneration does not automatically mean that individuals will take-up this option. Consumer decisions are affected by a range of other factors including risks, imperfect information, bounded rationality and a lack of access to capital. [32]

2.2.4 The economy behind microgeneration

Microgeneration technologies are commonly used to supplement the energy supply of small-scale buildings, such as household and offices, in a practice called auto consumption. This means that the electricity produced by the technology is directly used by the building on which it is installed. This benefits the consumer by reducing their electricity consumption from the electricity grid and giving them more independence to produce electricity for their own needs.

Under the current Portuguese legislation, microgeneration technologies are divided into two categories: Small-scale production units or *Unidades de Pequena Produção* (UPP) and Production units for auto consumption or *Unidades de Produção para Autoconsumo* (UPAC). UPP are renewable energy installations with a small electricity production which are used to sell back the electricity produced to the electricity grid to supplement the electricity supply, while the latter is used solely for auto consumption by the establishment in which it is implemented. [33]

Both types of technologies are commonplace in today's global and Portuguese market, mostly in the form of solar and wind installations on households or commercial buildings. Production units for auto consumption are more widely used due to the inherit increased savings of consuming the electricity directly on-site as opposed to selling it back to the electricity grid at a reduced price, which is the current situation in Portugal and most other countries.

As mentioned before, upfront costs are the biggest barrier to the widespread adoption of microgeneration technologies. The uncertain nature of the payback time of these technologies also tend to dissuade consumers from adopting this technology, since it may take decades to earn back the high initial investment that characterizes this type of electricity production.

The preferred return period for renewable energy technologies sits around seven years, with a select few, more popular technologies, such as solar, demanding a return period close to four years due to its low price in the current market and the relatively high electricity production this renewable source can output. [29]

In the last few years, two new terms have surged to better explore the economic potential of renewable energy. These terms are EROI and EPBT and are used to express the same idea of a return period, but more focused on the electric output of the studied device. Energy return on energy invested or EROI is considered to be the more meaningful metric, since it more accurately describes the relation between investment and returns. This unitless value shows the amount of energy that was used to produce the machine, as opposed to the energy the system manages to yield in its lifespan. If this value is under 1:1 it is considered not viable in an electric standpoint and, by extension, wouldn't be economically viable as well. EPBT or energy payback time is more closely related to return period as in it describes the time a system needs to operate to equate the amount of energy that was used to create it. This essentially means that EPBT reaches the same conclusion as the return period, but at an electric standpoint, as opposed to the economic value the return period offers. [29]

To offset the high upfront costs of microgeneration technologies, primarily solar and wind, grants were offered by governments to aid consumers in adopting these systems into their households and businesses. The grants were determined proportional to the cost of the technology in the respective country. This business model was heavily used at the start of microgeneration technologies to incentivize early adopters, but has since then been declining in use in recent years with some countries abandoning it completely in the last few years. [28]

In the last decade, a more popular way of financing microgeneration technologies is through Feed-in Tariffs (FiT). These tariffs do not cover the upfront costs of the electricity producing systems, but instead offers a payment based on the performance of the technology to produce electricity. In basic terms, it pays the user based on the amount of kWh they manage to produce from the installed setup. The tariff is given a base value influenced by the country's economy and then is modified based on the costs of the different technologies and the demand for that particular technology. [28]

Feed-in tariffs prove to help shortening the payback time for consumers while avoiding the pitfall of investing into these new technologies and not using its full potential. However, this new incentive model has the problem of balancing the revenue it gives to benefactors. Set the FiT too low and nobody will want to invest since the payback time is too high, but set the value too high and you risk having users exploit the system by "dumping" electricity and trigger renewable technology investment at an exponentially increased cost to other consumers. [28]

These FiTs are limited by a reference value imposed by each government in terms of its annual production proportional to the installed capacity of the system. This limitation is put into place to avoid exploitative attitudes that may plague this program.

In Portugal the reference value for feed-in tariffs is 95 €/MWh. This value is adapted depending on the type of technology used. Solar receives the full benefit of the reference tariff, while systems that use biomass or biogas receive 90%. Wind power receives 70% of the reference tariff, while hydro is at the lower end with 60%. The production of these microgeneration technologies is limited by 2.6 MWh/year to benefit from FiTs while hydro receives an up scaled limit of 5 MWh/year. However, human movement technologies are not considered UPP nor UPAC under the current Portuguese legislation, which makes these technologies ineligible to receive financial backing in the current Portuguese market. [34], [35]

2.2.5 Human motion harvesting

There are two types of human motion harvesting: active and passive harvesting of human motion. According to J. Pierce and E. Paulos (2012): *"The active powering of electronic devices takes place when the user of the electronic product has to do a specific work to power the product that otherwise the user would not have done. The passive powering of electronic devices takes places when the user does not have to do any task different to the normal tasks associated with the product. The energy is harvested from the user's everyday actions (walking, breathing, body heat, blood pressure, finger motion, ...)."* [36]

The human movement used in this study is described by the distance (d) and time (t) is involved in each rep. These two variables result in a certain velocity (v) through this equation:

$$v = \frac{d}{t} \quad (1)$$

Since, in the case of the linear motion harvesting system, the linear human motion is converted into rotational movement through the mechanism explored previously, this movement is translated into rotational speed (ω_{cyc}) by the expression:

$$\omega_{cyc} = \frac{v}{2\pi r} \quad (2)$$

Where r is the radial distance and v the velocity.

For linear motion, half of the movement used to produce electricity is wasted in the recovery of the machine. This means that the power it produces is essentially halved during the process. In both cases of human motion, the speed at which the user moves can be turned into the number of turns the coil inside the generator does, depending on the size of generator's coil.

This mechanical energy is turned into electricity through the use of a rotational generator. This conversion is made possible due to the electromagnetic properties inside the generator, which uses Faraday's law as its ruling principle. This law states that: "*The induced electromotive force in any closed circuit is equal to the negative of the time rate of change of the magnetic flux enclosed by the circuit*." And is represented by the following equation:

$$V_{gen} = -N \times \frac{\Delta(BA)}{\Delta t} \quad (3)$$

Where V_{gen} is the voltage generated, N the number of turns, Δ(BA) the variance of the magnetic flux, A the area of the coil, B the external magnetic field and Δt the variance of time. This law can also be considered to be:

$$Emf = -N \times \frac{\Delta\Phi}{\Delta t} \quad (4)$$

Where Emf is the induced voltage, N the number of turns, ΔΦ the magnetic flux and Δt the variance of time. The direction of the electromotive force if given by lenz's law.

This resulting voltage multiplied by the amperage of the machine during human exercise results in the total power (W) generated, as can be seen below:

$$P = I \times V \quad (5)$$

Where P is the electric power, I the electric current and V the voltage.

Looking at previous literature about human motion: "*A human unit of power (HuP) has previously been defined as 75 W, the amount of power that a healthy human can sustain for 8 hours before exhaustion—approximately one tenth of a horse-power*." [36]. However, this value is entirely theoretical and isn't reflected in practical situations due to high number of variables involved in harvesting electricity, such as the user's physical condition, the machine's efficiency and losses during harvesting.

3 Human motion harvesting

3.1 Active human motion harvesting

3.1.1 Rotary human motion

The use of rotary human motion to produce electricity is a concept that has been already been studied by many authors and put into practice by a select few gymnasiums, as previously mentioned. This type of movement is more commonly used, because of the high potential rotations per minute (RPM) it can reach, and rotational movement is easier to use, since most generators have a rotational orientation.

The study conducted by the *University of Zielona Góra* in conjunction with the *Gdynia Maritime University* explores the possible energy that a stationary bicycle with a generator coupled to it can generate. The system showed to be capable of producing 250 W in a one-hour session which amount to 1.5 kWh in a cycle of work (6 hours). The authors also did an economic analysis of their project, concluding that it could take up to 4 years to earn back the initial investment if the cost of the exercise bike is not added on the 510$ used to build the system. [2]

A hybrid system of linear and rotary human motion harvesting was developed by the team from the *Rajshahi University of Engineering & Technology*. This system includes a paddling system and a chin-up pulley system, which will be discussed in the next chapter. The paddling portion of this technology yielded higher rotations per minute (RPM) and, consequently, a higher amount of electricity was produced. The system yielded 83.6 W/h with 1300 RPM under ideal conditions. [3]

The *Mymensingh Engineering Collower bodye* used a generator system to harvest the input of mechanical energy during cycling to produce electricity, which is stored in a battery. They estimated that the efficiency of the designed system was close to 60%, causing the yield of electricity to only be 67.5 W during an one hour cycle. Since the gymnasium that was used to study the system has a reported daily activity of 20 hours of cycling, they reached a production of 1.35 kWh each day. [4]

One of the major constraints on Bangladesh's economic growth is the energy crisis the country is going through. The *Chittagong University of Engineering & Technology* and the *Technical University of Dupper bodystadt* (CUET) studied the potential electricity generation from wastage energy of human activity using gymnasium bicycles. The system developed of a flywheel connected to the pedal that would rotate the generator to produce electricity. With a calculated approximate of 48% efficiency they managed to produce an average of 63.36 W/h across all 10 gymnasiums taken into consideration. [5], [6]

The *Masdar Institute of Science and Technology* discusses the potential of producing electricity with lost human power in gymnasiums. They studied various machines, such as bicycles, rowing machines and stair-stepper, and, based on the past literature and surveys conducted in different gymnasiums, they concluded that the treadmill, stair-stepper and cross trainer could produce up to 100 W/h. The stationary bike reported a generation of 80 W/h and lastly, the rowing machine produced only 68 W/h. Alongside these estimates, they also determined the possible CO_2 emissions saved and the payback period, which resulted in approximately a tonne of CO_2 saved and 75 years, respectively. [7]

3.1.2 Linear human motion

Linear human motion harvesting to produce electricity is a topic that is scarcely studied. This can be due to the low potential electricity that this type of movement yields, due to the low RPM it creates or because it is a more difficult type of movement to harvest, requiring the conversion to rotational movement or the use of a linear generator that tends to be costlier and more inefficient.

At the *Jeppiaar Engineering Collower bodye* a permanent magnet linear generator was used to test the potential electricity that can be harvested by a machine called the *belly reducer*. The generator that was designed and built consists of four stators that managed to generate 34 W/h of energy, resulting in 136 W/h in total across the entire system. [37]

A stationary pulley machine in conjunction with an alternator is used to produce electricity by the team at the *North Maharashtra University*. They estimated an output of 60 W/h from the system and used an incandescent lamp of 40 W in the form of load to test the system's capacity. Theoretically it was determined that the lamp could be powered entirely through this system. In addition to the electrical aspect, they showed a simple framework to calculate the associated costs of the system. [38]

In addition to the rotary element of the study conducted by the *Rajshahi University of Engineering & Technology* they also observed the linear potential of this technology, as stated before. The linear movement harvesting mechanism proved to yield a lesser amount of electricity compared to the rotational part. Despite the diminished returns, it still generated 62.5 W/h at 1150, which is still a considerable amount of electricity. [3]

3.2 Passive human motion harvesting

This type of human motion harvesting requires no additional work from outside sources, as explained before. The studies that have already been conducted around this subject mostly involve walking, since it is an activity that everybody does in their daily life. Other motions that were explored was finger, elbow and oscillating cycling movements.

Various methods are used to harvest the energy from regular walking. These methods mostly consist of differing generators, such as a rotary microgenerator that yields 416.6 µW, when the generator was installed close to the ankle. [39] Other generators include a piezoelectric energy harvester installed in a shoe that yielded 1 mW [40], a non-resonant, rolling-magnet energy harvester that creates voltage output levels of ~80–700 mV [41], A complete backpack with two piezoelectric straps, that showed that 45.6 mW of power could be obtained from the system [42] and a prototype generator that generated 0.3–2.46 mW when placed inside a rucksack which was worn during walking and slow running. [43]

Other, less explored methods, were elbow motion with a piezoelectric shell structure that created 0.21 mW of power [44], tapping finger that yielded 0.1-0.5 V using a series connection of four nanogenerators [45] and the oscillation of a bicycle while cycling which, with the aid of a nonlinear electromagnetic energy harvester, showed 6.6 mW of power [46]

The *University of the Negev* studied the power generation from the heel strike, concluding that 2 W could be harvested from a person weighing 80 kg and walking at approximately 4 km/h. On top of studying external methods of producing electricity from human movement, they also studied the possibility of an on-human harvesting machine, in the form of a joint-mounted device based on generative braking. They concluded that the joints generating the most power are the knees (34 W) and the ankles (20 W). [47]

3.3 Why are linear generators not used?

A trend that is apparent throughout former literature is the distinct lack of linear generators. This is mostly due to the maturity of its rotary counterpart, which has been used for much longer and has since then been optimized to achieve a much higher electricity output with many more advantages, such as less space requirements and higher efficiency.

Another major issue with linear generators is that it is still a technology that is relatively new and is still seeing active developments in its design to make it competitive with rotary generators in the near future. This makes these technologies very costly in terms of power output and necessary investment, which sets back its economic viability to a point where it is sparsely used in the existing literature.

4 Methodology

4.1 Case studies

This study will take place in four different gyms with different scales, with the most notable difference being the number of daily users, the machinery available and the number of hours spent on them. These establishments will be used as a benchmark to exemplify the economic potential and GHG savings of these technologies in other gymnasiums with a similar scale. Additionally, the large-scale gymnasiums Be-Fit Setúbal will be used as a test site for the linear human motion harvesting system developed during this study, which will be explored later in the chapter.

Considering the vastly different circumstances observed in gym activity at these establishment, a few simplifications have to be made. Each person has a personalised training cycle tailored to their current health conditions and the enormous variety of body types, in terms of physical condition and genetic aptitude make it near impossible to observe and study every single variant. This entails that the potential electricity production will be generalized into an amount representative of a normal gym user using the machinery at a regular pace.

4.1.1 Feelgood

Feelgood is a gymnasium in the *Charneca da Caparica* area with a usable space of 200 m^2, being classified as a small-scale gym. With a user count of 100, it is mostly focused on personal training and sporadic free use of the machines by other users. On weekdays it sees a daily user count of 50 and on weekends it is closed to the public. The peak hours are close to its closing time and sees a user count of 20 at most.

The fact that this gym is primarily used for personal training can be seen in the machine use reported by its owners. The low amount of machinery the gym has, and the low use of these machines make it a gym with a low amount of human motion to be harvested for the designed system.

This gym's characteristics can be seen in the table below:

Table 4.1 – Description of Feelgood

Feelgood description

Name	Feelgood
Area (m^2)	200
Monthly electricity consumption (kWh/month)	1000
Total amount of users	100
Working days in 2018	252
Normal schedule (Monday through Friday)	8:00 - 21:00
Average daily users on normal schedule	50
Peak hours	18:00 - 20:00
Maximum number of users at peak hours	20
Nº of lower body machines	5
Nº of upper body machines	4
Nº of cardio machines	6

4.1.2 Be Gym Fit

Be Gym Fit is another small-size gym with an area of approximately 280 m^2. This gym is in the centre of Lisbon and is more focused on classes, rather than muscle training using machinery. This makes the gym only have a total of 9 machines. With 180 users that have a membership at this establishment, it sees a daily user amount of 60 on a normal schedule, while on Saturdays (reduced schedule) it only has 25 users using the equipment. The peak hours of this gym are between 7:00 and 8:00 and from 18:00 to 20:00, on which the maximum number of users reaches 25 people.

As referenced before, *Be Gym Fit* is an establishment more focused on classes, which reflects on the amount of time spent on the existing machinery. The usual amount of daily use a machine sees is around one hour. Some machines, such as the lower body press, see increased use, but considering the amount of time the gym stays open, it is still a very low amount. On Saturdays this gets reduced even further to some machines only seeing 15 minutes of use.

A summary of the gym's characteristics can be found in the table below:

Table 4.2 – Description of Be Gym Fit

Be Gym Fit description

Name	Be Gym Fit
Area (m^2)	280
Monthly electricity consumption (kWh/month)	1400
Total amount of users	180
Working days in 2018	252
Normal schedule (Monday through Friday)	7:00 - 22:00
Average daily users on normal schedule	60
Saturdays in 2018	52
Reduced schedule (Saturdays and holidays)	8:00 - 13:00
Average daily users on reduced schedule	15
Peak hours	7:00 - 8:00
	18:00 - 20:00
Maximum number of users at peak hours	25
Nº of upper body machines	4
Nº of lower body machines	5
Nº of cardio machines	6

4.1.3 Arena Club Oeiras

Arena Club Oeiras is a medium-size gymnasium located in Oeiras with an area of approximately 700 m^2. This establishment has 595 active users with peak hours between 8:30 - 12:00 and 18:00 - 21:00, where the maximum number of concurrent users can reach 25. The gym has two distinct schedules: A normal schedule, which is the one used on normal weekdays, where it opens at 7:00 and closes at 21:00. When this schedule is enforced it observes a daily user count of 120. During weekends and holidays, it has a reduced schedule between 9:00 and 13:00. On these days it sees around 55 users using the establishment.

According to the observations made in the gym, an average of 3 hours is spent each day on each exercise machine, with the most popular ones, such as the lower body press, adjustable pulley and pulley row, have a total daily use of 4 hours on the regular schedule. On the reduced schedule, this amount is reduced, with 40 minutes on regular machines and 1 hour on the popular ones.

Table 4.3 provides a summary of the gym's characteristics:

Table 4.3 – Description of Arena Club Oeiras

Arena Club Oeiras description

Name	Arena Club Oeiras
Area (m^2)	700
Monthly electricity consumption (kWh/month)	3500
Total amount of users	595
Working days in 2018	252
Normal schedule (Monday through Friday)	7:30 - 22:00
Average daily users on normal schedule	120
Weekend days in 2018	104
Reduced schedule (Weekend)	9:00 - 13:00
Average daily users on reduced schedule	55
Peak hours	8:30 - 12:00
	18:00 - 21:00
Maximum number of users at peak hours	25
Nº of upper body machines	6
Nº of lower body machines	5
Nº of cardio machines	8

4.1.4 Be-Fit Setúbal

Be-Fit Setúbal is a large-scale gymnasium, part of a gymnasium franchise in Portugal. The establishment is located in the Setúbal municipality with an area of around 3000 m^2. With a considerable amount of 4500 total users enrolled in the gymnasium, it sees a daily tally of 1000 users using the gymnasium's equipment. On Saturdays this number gets reduced to 700 users and on Sundays it is further reduced to 500 users.

Due to the massive number of users that this gym has compared to the previously studies gyms, it sees a considerable increase in equipment use. On a normal the minimum amount of use of a machine is 8 hours, which is already much higher than the highest values for *Arena Club Oeiras* and *Be Gym Fit*. This amount is doubled in some machines, such as the lower body press and pec fly.

A brief description of this gym can be found in Table 4.4:

Table 4.4 – Description of Be-Fit Setúbal

Be-Fit Setúbal description

Name	Be-Fit Setúbal
Area (m^2)	3000
Monthly electricity consumption (kWh/month)	15000
Total amount of users	4500
Working days in 2018	252
Normal schedule (Monday through Friday)	6:30 - 23:00
Average daily users on normal schedule	1000
Saturdays in 2018	52
Reduced schedule (Saturdays)	9:00 - 20:00
Average daily users on reduced schedule (Saturdays)	700
Sundays in 2018	52
Reduced schedule (Sundays)	9:00 - 14:00
Average daily users on reduced schedule (Sundays)	500
Peak hours	10:00 - 12:00
	16:00 - 20:00
Maximum number of users at peak hours	200
Nº of upper body machines	18
Nº of lower body machines	12
Nº of cardio machines	25

4.2 Rotational Human motion

Electricity production using rotational human motion is a subject that has already been extensively studied and already put into practice in a select few gymnasiums, as has been referenced before.

As such, this study will take the electricity production determined in previous studies and use these values to do an economic overview of its potential in today's market. From the studies done previously, most values of electricity production are consistent with the exception of the study made by *Strzelecki et al., 2007*. This study had an outlying electricity production of 250 W, due to the use of a more powerful system to produce electricity. For this reason, this study created two different scenarios, to cover both types of electricity production that have been concluded.

The study conducted by *Strzelecki et al., 2007* will be considered scenario 1 to study a more powerful, but more expensive energy harvesting system. For scenario 2 the remainder of studies will be used, since their observed values are all approximately the same. In order to be able to cover all the remaining existing literature, an average of the electricity production is made, as can be seen in the following table:

Table 4.5 - Electricity production scenarios and authors considered for each scenario

Electricity production from rotational motion

Scenario 1		Scenario 2	
Author	**Electricity production (W/h)**	**Author**	**Electricity production (W/h)**
Strzelecki et al., 2007	**250**	**Mustafi et al., 2017**	83.60
		K. M. Ullah & Alam, 2017	67.50
		Khan et al., 2015; M. T. Ullah et al., 2015	63.36
		Chalermthai et al., 2015	80.00
		Average electricity production	**73.62**

4.3 Linear human motion

As referenced at the start of the chapter, a prototype of a machine capable of using linear human motion to produce electricity was developed during this study and tested in one of the establishments mentioned previously. The materials used to build the system are seen in Table 4.6:

Table 4.6 - Description of the components used in building the linear motion harvesting system

Component description

Component	Quantity	Parameters
Toothed belt	1	Perimeter – 1.05 m
Gutter	2	Total course – 0.55 m
Crank	1	Size varies on machine used
Reel	3	Generator spindle diameter - 16 mm
		Support axis diameter - 8 mm
Stainless-steel plate	2	Thickness - 2.5 mm
Plywood	1	Thickness - 20 mm
Stainless-steel lid	1	Thickness - 0.8 mm
Three-phase Generator	1	Rated power - 100 W
		Rated voltage - 12/24 V
		Rated RPM - 600 RPM
	1	Rated power - 300 W
		Rated voltage - 12/24 V
		Rated RPM - 600 RPM
Rectifying bridge	2	Rated amperage - 35 A
Battery	1	Rated voltage - 12 V
		Rated amperage - 18 A
Ammeter	1	
Voltmeter	1	

The highlighted materials are the components that are essential to building the harvesting system. The toothed belt is placed between two gutters, supported on a stainless-steel plate, and held up by two reels on each side to stretch it as far as possible. This toothed belt is used to translate the linear motion that is being inserted through a crank or other fixating object. The third reel is directly connected to the three-phase generator's spindle as to directly use the movement of the belt to produce electricity. Rectifying bridges are used to correct the output of the generator into usable electricity that can be stored inside a battery or directly used on any device with the use of an inverter.

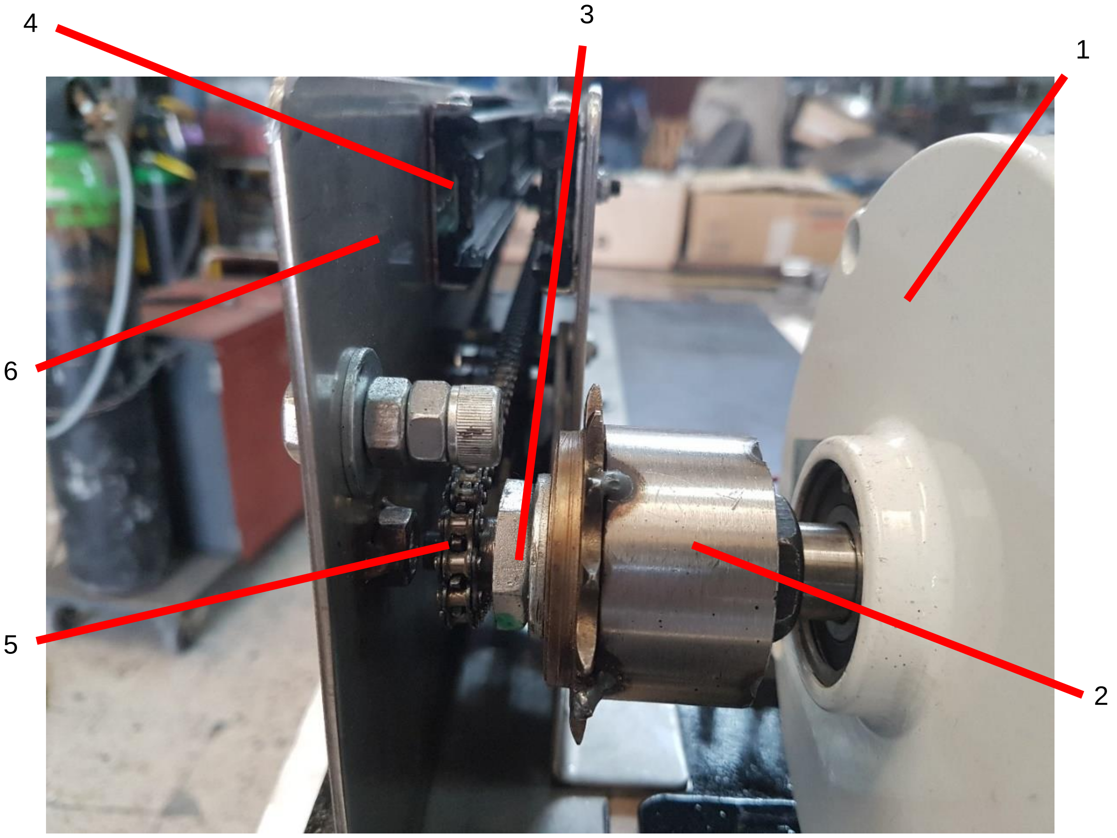

Figure 4.1 - Generator (1), generator spindle/ primary reel (2), secondary reel (3), gutter (4), toothed belt (5) and stainless -steel plate (6)

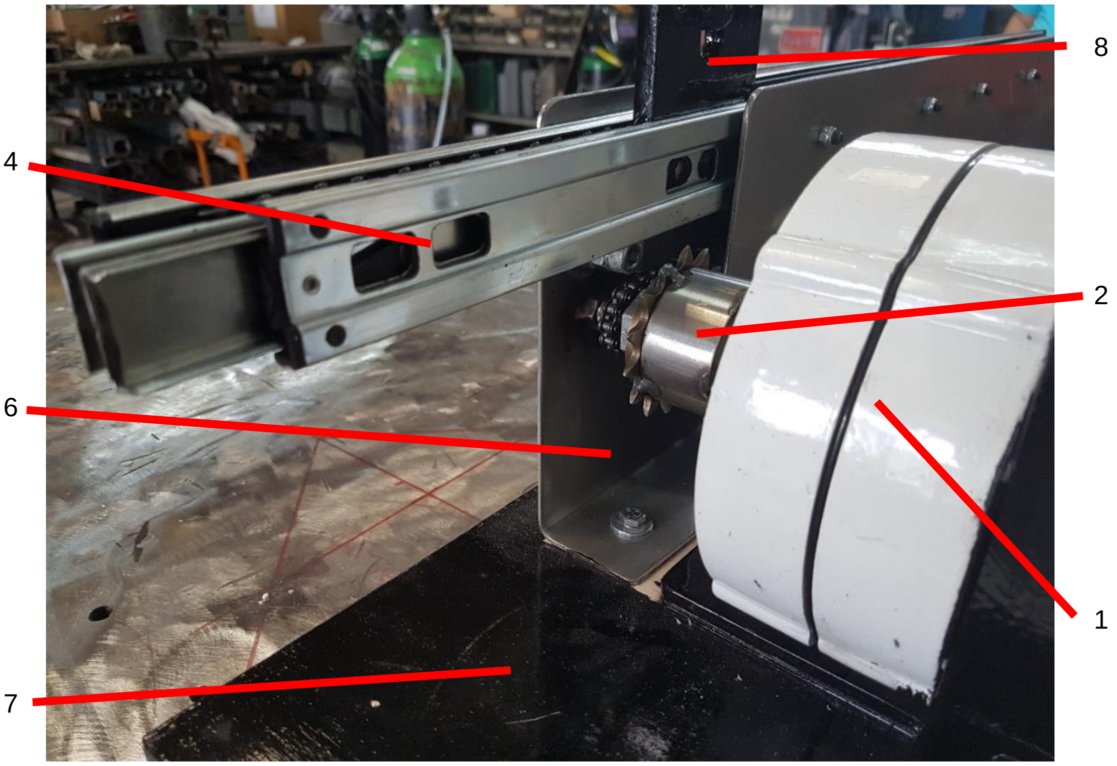

Figure 4.2 - Generator (1), generator spindle/ primary reel (2), gutter (4), stainless-steel plate (6), plywood base (7) and crank (8)

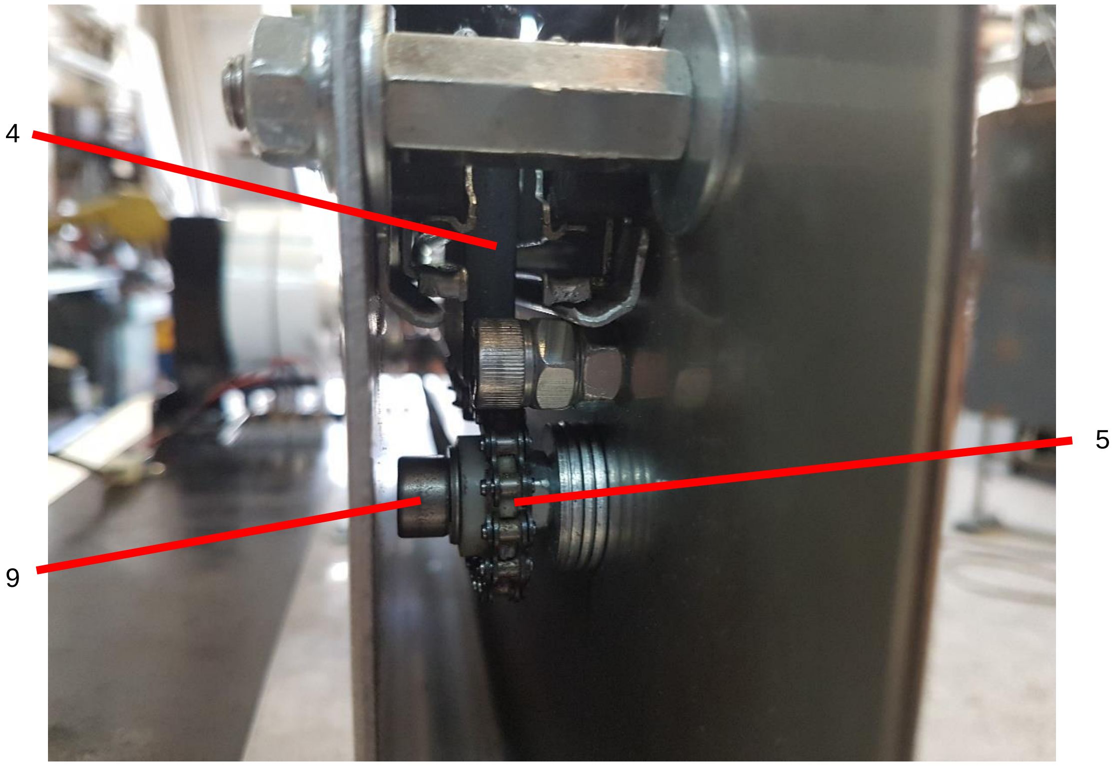

Figure 4.3 - Gutter (4), toothed belt (5) and tertiary reel (9)

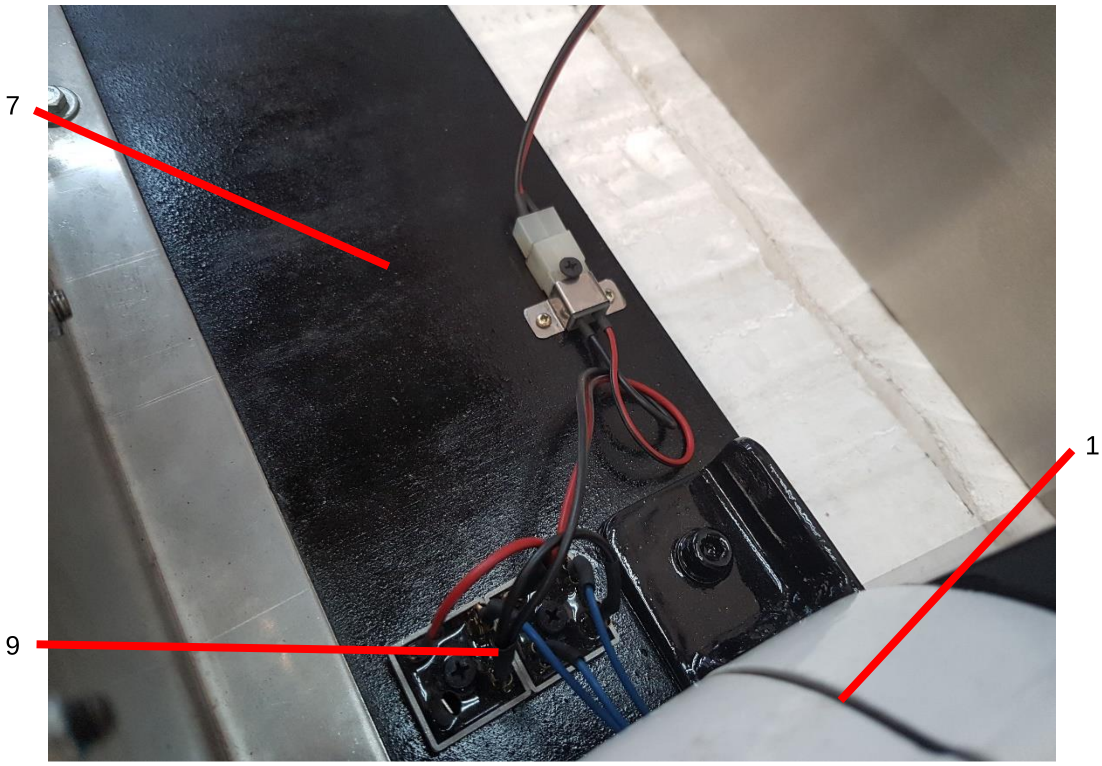

Figure 4.4 - Generator (1), plywood base (7) and rectifying bridges (9)

The stainless-steel lid is to cover up the system, so it is not exposed to outside sources and to avoid interference with the system's function. The reduction of noise it emits is also an advantage that this protection offers. The plywood serves as a ground support for the system, so it is not directly placed on the floor. Both these components are only used for protection and can easily be replaced by any other material or setup that serves the same purpose.

An ammeter and voltmeter can be acquired to directly interpret the output of the system while it is working. Gymnasiums may consider this option to let the users of the establishment be able to see the fruits of their labour and offer some kind of feedback to the user as to possibly further motivate him/her to exercise.

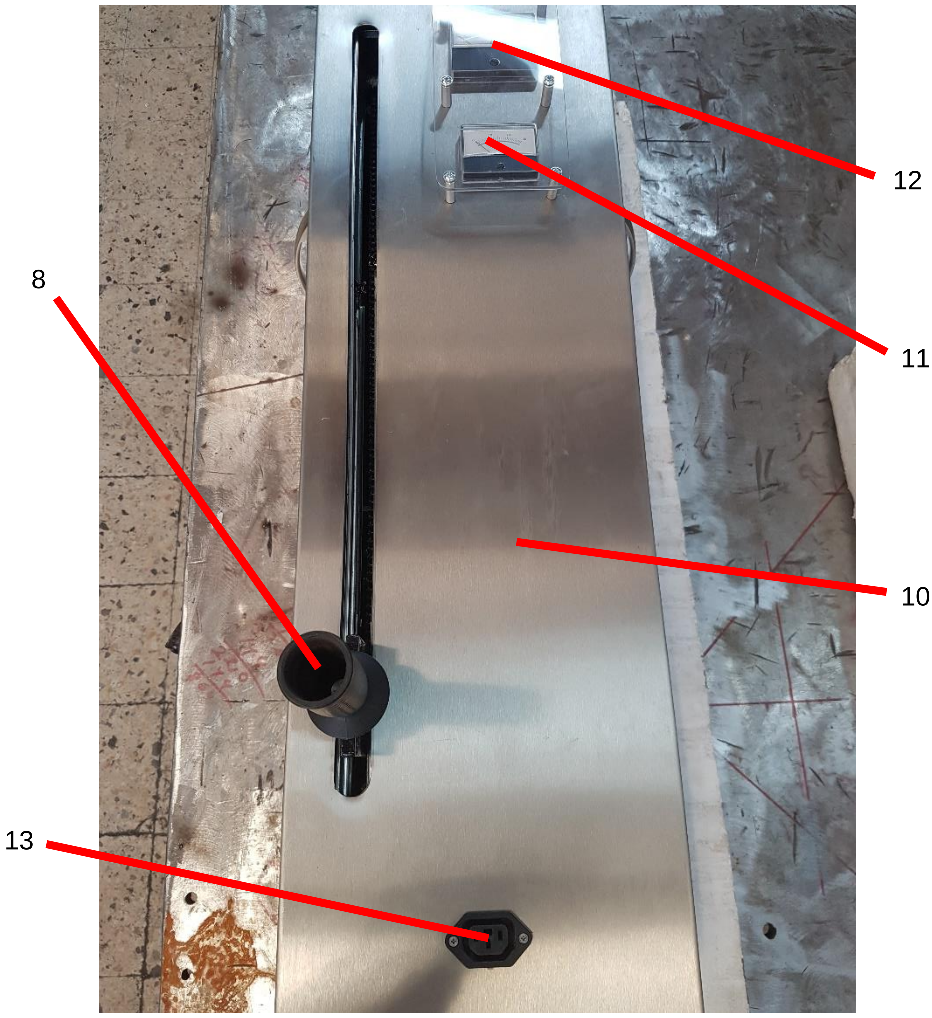

Figure 4.5 - Crank (8), stainless-steel lid (10), voltmeter (11), ammeter (12) and output socket (13)

In order to store the electricity produced by the system a battery is used. The battery used in this prototype, which can be seen in Figure 4.6, is a used battery with low capacity, which managed to store the electricity produced in the preliminary without hiccups. However, for the heavy use that the system might see in more frequented gymnasiums or the higher intensity from some users, a more powerful battery has to be used. For the purpose given to the system, a 40 Ah battery would be ideal to handle any input offered by the daily users of the establishments that were studies. As to not waste any electricity produced, the ideal way of harvesting would be to have one battery be used to power up equipment, while another battery is being actively charged by the gymnasium's users with the purpose of not having any downtime harvesting human energy.

Another option is to use an inverter, shown in Figure 4.6, to be able to consume the electricity directly from the system or to send it to the grid. The latter option is rarely practiced nowadays, because of losses and the poor buyback rates energy companies may offer. Using the electricity directly to power up devices can be possible, but due to the unstable nature of the source of electricity, since a machine might not be used for a large amount of time, the device that is coupled to a certain machine can possibly not be powered for the entire duration it is used.

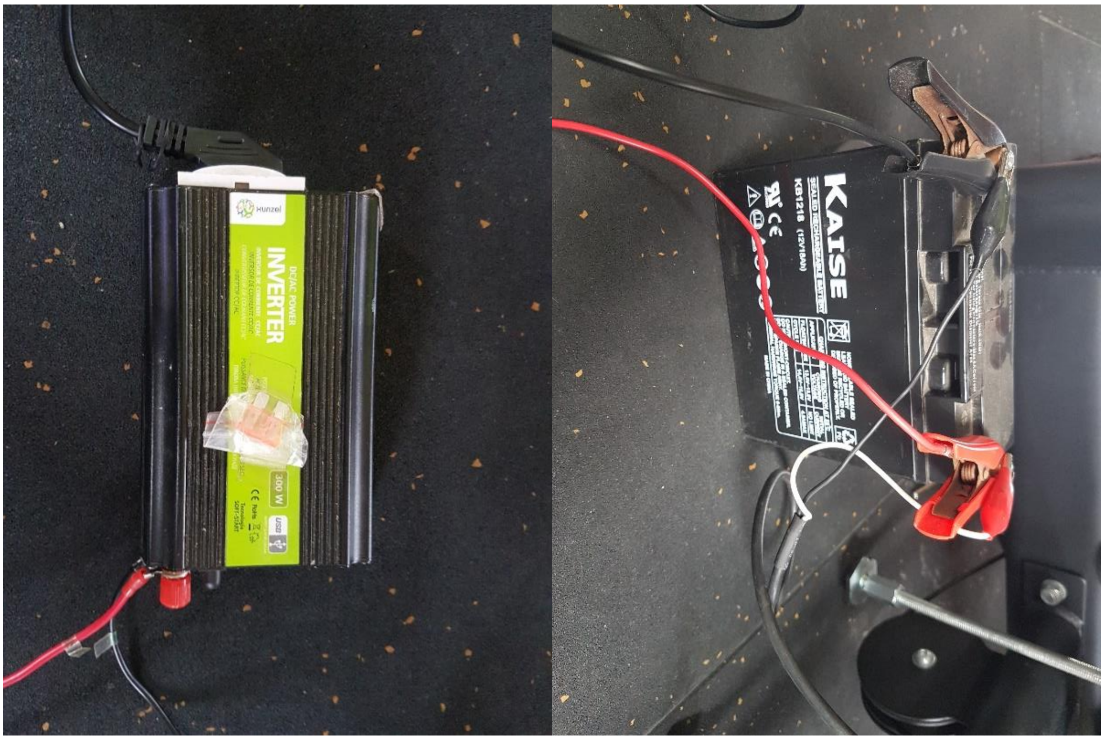

Figure 4.6 - Inverter (left) and battery (right) used in the preliminary tests of the motion harvesting system

This prototype was developed solely for the purpose of testing the electricity production capabilities of a human motion harvesting in a real-life scenario. These tests were developed in the largest gymnasium observed in this study, *Be-Fit Setúbal*, in the month of July of 2018. These tests consisted of having an average build person doing several different exercises and measuring the voltage and wattage output that the ammeter and voltmeter showed during the sessions, as to determine the electrical output combining both metrics. The objective of these tests was to determine the electrical output of this machinery to serve as a base for the following economic analysis of these technologies in the other establishments.

After gathering all the necessary components and building the prototype, it was taken to *Be-Fit Setúbal*, as previously mentioned, to test its capabilities in a real-life scenario, which can be observed in Figure 4.7. In order to use the human motion from the machinery, a pin was used to connect the crank from the system to the machine’s weights, which can be seen in Figure 3.8. This method is temporary, since in a prolonged session this method would not work, due to the bending of the pin during use or the instability of the connection causing the release of the pin from the weights. The output of the system, which can be seen in Figure 3.8, was firstly connected to a battery to test the charging of the battery during the tests. After that, a more real scenario was tested with the use of an inverter, which was connected to a 25 W blowing fan. The system was able to maintain the 25 W fan working throughout the entire testing session. The electric output that this system yielded was 35 W/h in the case of linear human motion, while rotary human motion managed to generate 75 W/h.

Figure 4.7 - Finished prototype used for the preliminary tests (left) and machine setup at the test site (right)

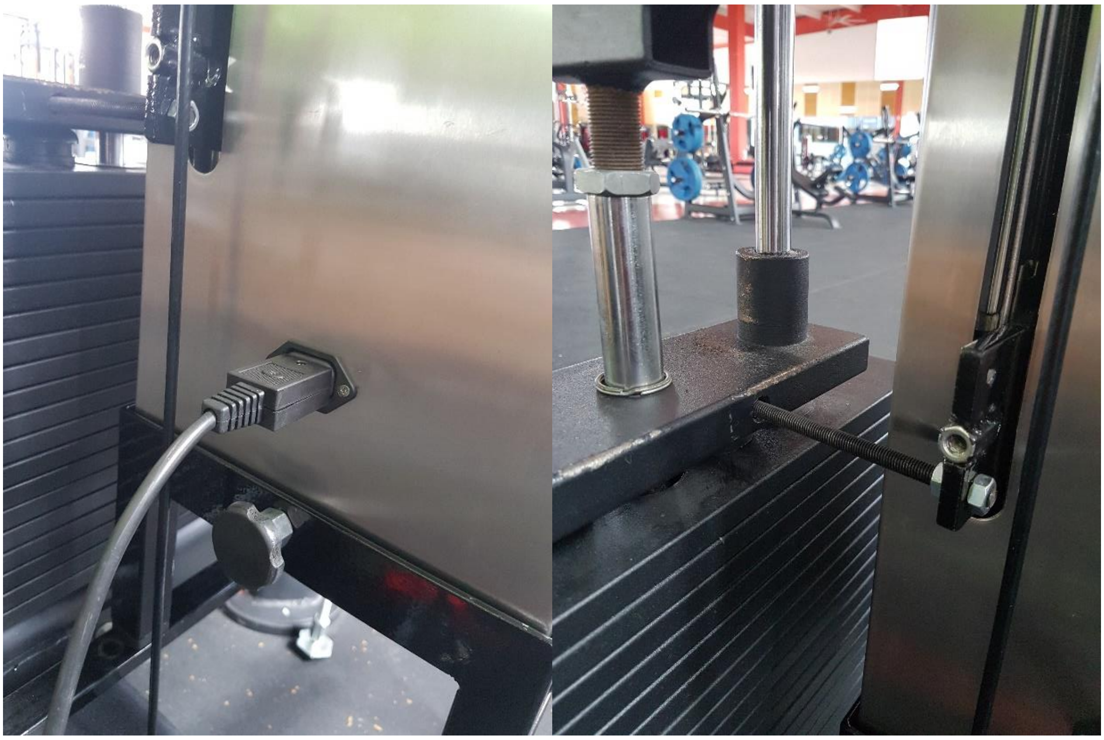

Figure 4.8 - Machine connection to weights (right) and socket used to transfer the electricity to a battery or inverter (left)

4.4 Business models

In order to establish the economic potential of this technology, a variety of economic models should be established to see which one is potentially the most beneficial. Based on existing literature surrounding microgeneration business models, there are three different models that are currently used in the electricity market by consumers, which in this case are gymnasiums, and electricity producing companies to implement these microgeneration technologies:

Table 4.7 - Business models for microgeneration technologies (Adapted from [48])

		Plug & Play	Company Ownership	Leasing
Ownership		Consumer	Electricity producing company	The electricity producing company, but consumer at end of leasing period
Operation		According to consumer needs for power	To help the electricity producing company balance supply and demand	To help the electricity producing company balance supply and demand, taking into account consumer preference
Costs	Consumer	Pays the initial investment and O&M costs	-	Pays back the investment done by the electricity producing company during leasing period and covers O&M Costs
	Electricity supplier company	-	Pays the initial investment and covers O&M costs	Pays the initial investment, but the value is reimbursed at the end of the leasing period
Benefits	Consumer	Reduces the cost of their electricity bill by producing electricity to consume on-site	Receives a % discount on electricity bill	Reduces the cost of their electricity bill by producing electricity to consume on-site
	Electricity supplier company	-	Avoids electricity production costs	-

Put into simple terms, Plug & Play requires an upfront payment, but grants the consumer complete liberty to utilize the electricity as they deem fit for their purposes. The barrier to entry for this option can be high due to the potentially high initial investment cost, making it a less desirable option in for the future. Feed-in tariffs can be implemented to soften the blow for consumers and make this option more attractive.

Company Ownership removes the barrier of entry completely by financing the technology but reserving the rights over what the technology is used for. The downside of this scheme is that the consumer does not typically have the decision of what the electricity is used for, despite the reduction in their electricity bill being a viable option. This reduction is dependent on the electricity producing capability of the technology invested in as to become lucrative in a short period of time. This option is mostly dependent on the willingness for a company to invest into microgeneration technologies, which may take an excessive amount of time to earn its money back for it to become profitable for the energy company.

Both previously mentioned models can be combined into a leasing scheme. The consumer gradually pays back the investment that the company made into the technology and in the end of the determined period of time, the consumer keeps the technology to further produce electricity for personal use.

4.5 Economic analysis

To determine the economic potential of this technology, an extensive analysis of the costs and benefits for the alternative business models is necessary. Here we present two different perspectives of analysis: a) the cases where the gymnasium is the investor in the new technology; b) the case where the electricity supplier company is the investor in the new technology and the gymnasium is used to produce electricity

4.5.1 Plug & Play / leasing model

Both these models are analysed in the perspective of the gymnasium investing in this technology. The gymnasium is the one paying the costs necessary to installing these systems and maintaining their condition, but also benefit from the electricity production that these systems offer to the establishments which will use all the electricity produced under an auto consumption regime.

In these cases, the costs associated to this technology would be the investment costs associated with the acquisition of the different components and the labour effort associated to the installation of the device and the operation and maintenance (O&M) costs to ensure the system operates in good conditions along the expected lifetime. Another cost could involve the adaptation of the existing gym apparatus to give some sort of visual feedback about the amount of electricity produced, but this kind of intervention may prove to be expensive.

So, in the computation of the costs associated to these technologies we consider that:

$$TC = \sum_{t=0}^{T} \frac{Inv_t + OM_t}{(1+i)^t} \quad (6)$$

Where TC represents the Present Total Costs, Inv_t shows the Investment Costs in the period t and OM_t shows the Operation & Maintenance Costs in the period t. All these variables are expressed in €. The opportunity costs of capital are represented by i.

The benefits provided by the system are in the form of savings or avoided costs on the gymnasium's electricity bill, due to the inherit auto consumption capabilities that these systems offer. Considering the amount of electricity that a gym uses along the time, it is highly unlikely that there will be any time where the electricity produced by the system is higher than the gym's demand. Therefore, all benefits are, in the end, calculated in the form of cost savings. These savings or avoided costs in the period t can be calculated through:

$$AC_t = Q_t \times Pe_t \quad (7)$$

Where Q_t is the Electricity Production in kWh in the period t and Pe_t represent the Price of Electricity paid by the gymnasium in €/kWh in the period t.

So, the total avoided costs of the project result are calculated as:

$$TAC = \sum_{t=0}^{T} \frac{Q_t \times Pe_t}{(1+i)^t} \quad (8)$$

Where TAC is the Present Total Avoided Cost.

This makes the net present value to be calculated as:

$$NPV = \sum_{t=0}^{T} \frac{Inv_t + OM_t}{(1+i)^t} - \sum_{t=0}^{T} \frac{Q_t \times Pe_t}{(1+i)^t} \quad (9)$$

Where NPV shows the Net Present Value expressed in €.

The return period (RP) is a very important metric for evaluating the economic potential of emerging technologies. T is defined by the time it takes for an investment to pay itself and starts earing more benefits than the costs it accrues. The RP is the value of T that equals NPV to zero:

$$\sum_{t=0}^{T} \frac{Inv_t + OM_t}{(1+i)^t} - \sum_{t=0}^{T} \frac{Q_t \times Pe_t}{(1+i)^t} = 0 \quad (10)$$

4.5.2 Company Ownership model

For the Company Ownership model, the calculation of the economic potential is done in the perspective of an electricity supplier company that will be investing in the technology installation. The success of this business model is entirely dependent on the willingness to invest of the company in this type of technology which is exclusively dictated by the return period it can expect.

The company's costs will be the sum of the investment and the O&M that the system requires and, additionally, the discount the company offers the consumer (gymnasium) on the electricity bill. The formula to calculate the Present Total Cost is:

$$TC = \sum_{t=0}^{T} \frac{Inv_t + OM_t + D_{ebt}}{(1+i)^t} \quad (11)$$

Where D_{ebt} represents the discount on the electricity bill of the gym offered by the electricity company expressed in €.

Since in the case of the Company Ownership model the electricity produced by the gymnasiums is to benefit the energy company in supporting their electricity production, avoided costs can be considered as the costs the company needs to support to produce an equivalent amount of electricity. So, the Total Benefit is the product of the amount of electricity production in each period by the corresponding average cost of production:

$$TB = \sum_{t=0}^{T} \frac{Q_t \times AC_t}{(1+i)^t} \quad (12)$$

Where TB is the Present Total Benefit expressed in €.

The project Net Present Value (NPV) for the electricity company will then be:

$$NPV_{company} = \sum_{t=0}^{T} \frac{Q_t \times AC_t}{(1+i)^t} - \sum_{t=0}^{T} \frac{Inv_t + OM_t + D_{ebt}}{(1+i)^t} \quad (13)$$

From the perspective of the consumer, the net benefit is solely provided through the discount on their electricity bill.

$$NPV_{consumer} = \sum_{t=0}^{T} \frac{D_{ebt}}{(1+i)^t} \quad (14)$$

To determine the value of the discounts that each gymnasium would benefit it was requested to the gymnasiums to give information about the amount of electricity these establishments consume each month and the price of electricity they pay. Considering the absence of answers, mostly due to confidentially or lack of information, an estimation of the consumed electricity was developed using the consumption reported by *Be Gym Fit* and the area of the gymnasiums.

This resulted in the following consumptions, estimated prices of electricity and potential discounts based on the yearly electricity payments made by the studied gymnasiums:

Table 4.8 - Electrical analysis of each gymnasium and potential discounts with the Company Ownership model

Gym	*Feelgood*	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Contracted power (kVA)	13.8			20.7
Price of electricity (€/kWh)	0.1531			0.1649
Area (m^2)	200	280	700	3000
Monthly electricity consumption (kWh/month)	1000	1400	3500	15000
Monthly electricity payment (€/month)	153.10	214.34	535.85	2473.50
Annual electricity payment (€/year)	1837.20	2572.08	6430.20	29682.00
1% Discount on yearly electrical bill (€)	18.37	25.72	64.30	296.82

The only discount considered in this analysis is a 1% discount since this discount poses to be considerably high compared to the potential electricity production these establishments can yield, which will be explored in the next chapter when studying the Company Ownership model.

4.6 Environmental benefits

Based on the values observed previously, two distinct scenarios were elaborated to represent different types of electricity production scenarios. The low scenario will represent the current emissions related to the electricity production in Portugal which is 200 gCO_2eq/kWh and the high scenario will use showcase a situation in which a coal powered facility is producing electricity, which is characterized by a very high amount of emissions of 900 gCO_2eq/kWh. [19], [23]

The calculation of the amount of CO_2 that will be reduced for each kWh produced by this technology is done through the equation:

$$CO_2\ savings = Em \times Q_t \quad (15)$$

Where Em shows the emissions and is expressed in gCO_2eq/kWh.

The remaining environmental benefits offered by the adoption of this technology are extremely difficult to determine due to the wide array of variables involved in the resulting value. This will result in a great range of uncertainty and, as such, these parameters will only receive a qualitative discussion.

5 Results and discussion

5.1 Electric output

5.1.1 Rotational human motion

To able to calculate the yearly electricity production of each gymnasium, a survey was done to determine the number of compatible machines the space had and the daily use each machine sees, which can be seen in the table below:

Table 5.1 - Number of rotational motion machines and daily use in each gymnasium

Gym	Nº machines	Daily machine use (h)
Feelgood	6	36
Be Gym Fit	6	16
Arena Club Oeiras	8	80
Be-Fit Setúbal	25	422

It can be observed that every gym except *Be-Fit Setúbal* has a small amount of compatible machinery. The difference lies in the machine use, *Feelgood* and *Be Gym Fit* see a low usage due to their reduced user count, while *Arena Club Oeiras* sees a sizable amount of machine use. *Be Fit Setúbal* with its huge pool of users and available machinery manages to observe up to twenty-five times more machine use than the other establishments.

This tendency in machine use is reflected on the amount of electricity these establishments can potentially yield from these systems, which can be observed in the following table:

Table 5.2 - Yearly electricity production from rotational human motion harvesting in each gymnasium

Gym	Scenario	Yearly electricity production (kWh/year)
Feelgood	1	1312.42
	2	779.03
Be Gym Fit	1	808.00
	2	237.92
Arena Club Oeiras	1	3042.43
	2	1473.31
Be-Fit Setúbal	1	7953.25
	2	6344.62

Be Gym Fit is the gymnasium that would produce the least amount of electricity, followed up by *Feelgood*, which sees a somewhat considerable increase in production. *Arena Club Oeiras* could produce more than double the electricity of the previous establishment proportionally to the increase in machine use. *Be-Fit Setúbal* is estimated to be a behemoth in terms of scale, producing a massive amount of electricity compared to the rest of the establishments that were studied. However, this increase does not accompany the difference in machine use due to the low number of bicycles *Be-Fit Setúbal* has, despite its size, which could make its electricity production mostly dependent on the other, more common, cardio machines, such as cross trainers.

A more detailed analysis of these results are located in annex IX to XVI, which shows the data provided by the gymnasiums and the calculations used to determine these values.

5.1.2 Linear human motion

The built prototype to harvest linear human motion successfully produced a steady amount of electricity during the preliminary tests. These results were used, in combination with the reported machine use from each gymnasium, which can be seen in Table 5.3, to determine the potential yearly electricity production of each establishment. The results are shown in the following tables:

Table 5.3 - Number of linear motion machines and daily use in each gymnasium

Gym	Equipment type	Nº of machines	Daily use (h)
Feelgood	Upper body	4	7
	Lower body	5	10
	Total	9	17
Be Gym Fit	Upper body	4	6
	Lower body	5	10.5
	Total	9	16.5
Arena Club Oeiras	Upper body	6	25
	Lower body	5	20
	Total	11	45
Be-Fit Setúbal	Upper body	18	472
	Lower body	12	351
	Total	30	823

Table 5.4 - Yearly electricity production from linear human motion in each gymnasium

Gym	Type	Yearly electricity production (kWh/year)
Feelgood	Upper body	61.74
	Lower body	189.00
	Total	250.74
Be Gym Fit	Upper body	42.42
	Lower body	149.70
	Total	192.12
Arena Club Oeiras	Upper body	194.60
	Lower body	333.60
	Total	528.20
Be-Fit Setúbal	Upper body	2595.04
	Lower body	3543.90
	Total	6183.94

In annex I to VIII are located the data provided by the gymnasiums and the calculations used to determine the results presented above.

5.2 Economic review

To be able to determine the economic potential of these technologies, estimations have been made to simulate a close to real life scenario.

The maintenance cost for every scenario has been set to 10€ for each machine, each year, to cover expenses such as lubrication of the machines and potential replacement of pieces, such as the spools or cables. The longevity of each mechanical part is near impossible to determine, since it depends on various variables, some of which are the quality of the materials used and the use the machine sees in each situation.

The excess payment associated to the leasing model is assumed to be an extra 5% on top of the original price. This percentage is commonplace in today's market and it does not pose to be an excessive amount to warrant the loss of potential buyers. The payback period is fixated at five years, allowing the costumer to payback the initial investment in a timely way, without exhausting the consumer's budget at the start of the leasing period.

The discount rate on the electric bill of adopters of the Company Ownership model will adapted to strike a balance between the consumer's savings and the company's earning to payback the investment and maintenance. The standard payback rate for household consumers is 10% due to the low electric expenditure, but for big spender like gymnasiums this discount rate has to be set much lower to accommodate the large amounts of electricity these establishments spend. The base payback rate for this project will be set to 1% as to make this technology turn a profit for both the consumer and the energy company.

The opportunity costs of capital are set to 3% to simulate the development of the costs and benefits along the technologies' lifetime. This lifetime will be set to a maximum of 10 years, due to the degradation from the machine's use, which can vary between 5 and 15 years, depending on the use it sees, and the return period that investors are willing to invest in, which, as previously mentioned, is around 7 years, with a few technologies already requiring 5 or less years to be considered worthwhile.

Lastly, in terms of scheduling, working days will be set to 252 days, which is representative of the year 2018. For Saturdays and Sundays there are 52 days each. Holidays will not be included in the economic overview, since, depending on the day of the week they are on, they may vary on the schedules they are on, on those respective days.

5.2.1 Rotational human motion

The investments made into the rotational human motion harvesting systems are based on the existing literature in both scenarios and are located in the following table:

Table 5.5 – Necessary investment in bicycles to install the rotational systems in both scenarios

Rotational system investment - Bicycle				
Scenario 1		**Scenario 2**		
Author	**Investment (€)**	**Author**	**Includes battery?**	**Investment (€)**
Strzelecki et al., 2007	**440**	**Mustafi et al., 2017**	No	187
		K. M. Ullah & Alam, 2017	No	156
		Khan et al., 2015	Yes	123
		Average investment (€)		**155**

Since the rotational system that is going to be used in this study includes a battery, it was determined whether the author of previous literature used a battery in their studies. If that wasn't the case, an additional 100€ was added on top of the reported price of the system that was built to cover these expenses. One of the authors considered for the average electricity production didn't report the costs associated to their system, leading to the exclusion of that system in the economic analysis.

The investment needed for the remaining machines that use rotational motion, e.g. stair stepper, cross trainer and rowing machine, will inherit the investment determined in scenario 2. The reasoning behind this is that the reported output from previous literature is close to the power that a bicycle in that scenario can provide. As such, this harvesting system should be capable of harvesting the energy from the other cardio machines in the same manner.

The avoided costs that these systems can achieve in each individual gym are represented in the table below:

Table 5.6 - Potential avoided cost from rotational motion harvesting in both scenarios

Gym	**Price of electricity (€/kWh)**	**Electricity production (kWh/year)**		**Avoided cost (€/year)**	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2
Feelgood	0.1531	1312	779	201	119
Be Gym Fit		808	238	124	36
Arena Club Oeiras		3042	1473	457	226
Be-Fit Setúbal	0.1649	7953	6345	1311	1046

5.2.1.1 Plug & Play

The results of the Plug & Play model for rotary motion harvesting in each gymnasium are presented in the tables below:

Table 5.7 - Plug & Play model for the rotary motion harvesting in scenario 1

Scenario 1	Feelgood	Be Gym Fit	Arena Club Oeiras	Be-Fit Setúbal
Investment (€)	1500.36	1760.00	2380.36	5301.80
Total Cost (€)	2072.17	2141.21	3142.78	7684.35
Total Avoided Cost (€)	1914.91	1178.93	4439.13	12498.77
NPV_5 (€)	-714.01	-1292.95	-227.73	621.01
NPV_{10} (€)	-157.26	-962.28	1296.36	4814.42
Return Period (years)	NA	NA	5.8	4.3

Small-size gymnasiums do not manage to earn a positive net present value within the technologies' lifetime. In the case of medium-size gymnasiums, a return period of almost six years is observed in *Arena Club Oeiras*, which makes it a compelling investment if the machinery manages to exceed the five-year mark. *Be-Fit Setúbal* could see a considerable profit if they adopt these technologies onto their existing machinery. The initial investment cost could be returned in a little more than four years, which is within the minimum lifetime that was estimated for these technologies.

In the case of scenario 2 the paradigm remains very similar, as can be seen in the next table:

Table 5.8 - Plug & Play model for the rotary motion harvesting in scenario 2

Scenario 2	Feelgood	Be Gym Fit	Arena Club Oeiras	Be-Fit Setúbal
Investment (€)	930.54	620.36	1240.72	3877.25
Total Cost (€)	1502.35	1001.57	2003.14	6259.80
Total Avoided Cost (€)	1136.66	347.15	2149.67	9970.76
NPV_5 (€)	-599.84	-640.30	-428.52	565.47
NPV_{10} (€)	-365.69	-654.42	146.53	3701.96
Return Period (years)	NA	NA	8.7	4.3

Small-size gymnasiums continue to be unable to achieve a profit in the machinery's expected lifetime, while *Be-Fit Setúbal* achieves the same return period of about four years on both scenarios. The only difference lies in the net present value, which is slightly higher in scenario 1. *Arena Club Oeiras* observes a substantial increase in the expected return period, almost reaching 9 years of use needed to turn a profit.

5.2.1.2 Company Ownership

As referenced before, this model will be done in the perspective of the company that may be willing to invest into this type of technology in the considered establishments. This is done due to the fact that the gymnasiums adopting this business proposition only benefit from this model, while the energy company investing accrues all the costs. The results of this model are displayed in the tables below:

Table 5.9 - Company Ownership model for the rotary motion harvesting in scenario 1

Scenario 1				
	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	1500.36	1760.00	2380.36	5302.00
Total Cost (€)	2247.26	2386.33	3755.59	10513.11
Total Benefit (€)	1914.91	1178.93	4439.13	12498.77
NPV_5 (€)	-816.52	-1436.47	-586.52	-1035.16
NPV_{10} (€)	-332.35	-1207.40	683.55	1985.67
Return period (years)	NA	NA	7.3	6.7

From observing the table, we can conclude that this model might not be suited for this type of technologies. Small-scale gymnasiums are running at a loss for the energy company and the remaining, larger gymnasiums, are able to earn a profit, but with a return period that is considered to be excessive for the average consumer according to the observations made in previous literature. Besides the low return period that is needed to deem this technology worth investing in, with the high amount of use these machines will see in the medium and large-scale gymnasiums it is unlikely that the harvesting technology will be able to turn a profit before reaching its life expectancy.

In the time it takes for the energy company investing in *Arena Club Oeiras* and *Be-Fit Setúbal* to earn back their investment, these gyms will have saved 466.18€ and 1978.80€, respectively, on their electric bill. These savings are severely lower than the other models, despite the nullification of the costs, which makes this model not viable for both the company investing and the establishment benefiting from this business model.

A similar situation is observed in scenario 2, which can be seen in the following table:

Table 5.10 - Company Ownership model for the rotary motion harvesting in scenario 2

Scenario 2				
	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	930.54	620.36	1240.72	3877.25
Total Cost (€)	1677.44	1246.69	2615.95	9088.56
Total Benefit (€)	1136.66	347.15	2149.67	9970.76
NPV_5 (€)	-702.35	-783.82	-787.30	-1090.70
NPV_{10} (€)	-540.78	-899.54	-466.28	882.20
Return period (years)	NA	NA	NA	7.8

Be-Fit Setúbal is the only establishment able to payback its initial investment in the expected machinery's lifetime. The remaining gymnasiums are unable to turn a profit, in the case of *Be Gym Fit,* or simply cannot earn back the necessary funds before the expected breakdown of the technology incorporated on their machinery.

During the duration of the Company Ownership, *Be-Fit Setúbal* saves a total of 2300.36€ on their electric expenditure. This again is a considerable downgrade in savings compared to the savings observed in the other models.

5.2.1.3 Leasing

The leasing model presented similar results to the Plug & Play model, due to the similarities of these business schemes. The only difference lies in the spreading of the costs across the leasing period and the slight increase in initial payment due to the luxury of not having to pay for the full system upfront. The results of this model can be observed in the tables below:

Table 5.11 - Leasing model for the rotary motion harvesting in scenario 1

Scenario 1

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	1486.24	1743.44	2357.96	5251.91
Total Cost (€)	2058.05	2124.65	3120.38	7634.46
Total Avoided Cost (€)	1914.91	1178.93	4439.13	12498.77
NPV_5 (€)	-699.89	-1276.39	-205.33	670.89
NPV_{10} (€)	-143.14	-945.72	1318.75	4864.31
Return period (years)	NA	NA	5.7	4.3

Similarly, to the Plug & Play model, small-size gymnasiums are unable to yield enough electricity to make it worthwhile investing in before the expected system breakdown. On the other hand, *Arena Club Oeiras* and *Be-Fit Setúbal* have a very similar RP to the previously mentioned Plug & Play model, which shows that this technology can operate on different models depending on the investor's choice to pay upfront or distribute the costs.

In scenario 2, a similar situation to the previous scenario is observed:

Table 5.12 - Leasing model for the rotary motion harvesting in scenario 2

Scenario 2

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	921.78	614.52	1229.05	3840.77
Total Cost (€)	1493.60	995.73	1991.46	6223.32
Total Avoided Cost (€)	1136.66	347.15	2149.67	9970.76
NPV_5 (€)	-591.08	-783.82	-416.84	601.95
NPV_{10} (€)	-356.94	-899.54	158.21	3747.44
Return period (years)	NA	NA	9.6	4.2

Both *Be Gym Fit* and *Feelgood* aren't able to pay back the investment made into the technology before its expiry. *Arena Club Oeiras* barely manages to receive enough income to benefit from this technology before its life expectancy, while *Be-Fit Setúbal* is the only gymnasium able to apply this technology into their establishment and see a reasonable profit.

From annex XXIX to XL are located the complete data related to these results for a better understanding as to how these results were determined and what they represent in the machinery's lifetime.

5.2.2 Linear human motion

To build the linear motion harvesting prototype, all the pieces listed in Table 5.13 had to be acquired. The investment needed to purchase all these components are listen in the following table:

Table 5.13 - Investment made into the upper body movement harvesting system

Upper body movement harvesting system investment

Component	Quantity	Item price (€)
Three-phase 100W Generator	1	62
Toothed belt	1	10
Gutter	2	10
Reel	3	15
Stainless steel plate	2	25
Plywood	1	15
Bridge rectifier	2	5
Battery	2	80
Total		**222**

Because of the high amount of instantaneous power the lower body machines can produce, an upgraded version with more power capabilities of the current generator has to be adopted, which is reflected in the cost of the system for the lower body version of the linear harvesting system:

Table 5.14 - Investment made into the lower body movement harvesting system

Lower body movement harvesting system investment

Component	Quantity	Item price (€)
Three-phase 300W Generator	1	103
Toothed belt	1	10
Gutter	2	10
Reel	3	15
Stainless steel plate	2	25
Plywood	1	15
Bridge rectifier	2	5
Battery	2	80
Total		**263**

5.2.2.1 Plug & Play

With the Plug & Play model the harvesting of linear human motion to produce electricity yielded the following results in the studied gymnasiums:

Table 5.15 - Plug & Play model for the upper body movement harvesting system

Upper body movement harvesting system

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	888.60	888.60	1332.90	3998.70
Total Cost (€)	1269.81	1269.81	1904.71	5714.14
Total Avoided Cost (€)	90.08	61.89	283.94	4078.18
NPV_5 (€)	-1059.05	-1075.55	-1501.44	-2615.37
NPV_{10} (€)	-1179.72	-1207.91	-1620.78	-1635.95
Return period (years)	NA	NA	NA	NA

Due to the low amount of savings that the upper body motion harvesting system is able to produce, none of the observed gymnasiums are unable to retrieve positive results from this model. The only gym with the potential to use this technology is *Be-Fit Setúbal* which manages to generate a profit, but at a rate that still warrants a too high RP to be considered viable.

In the case of lower body movement, the situation is similar, but with slight improvements in terms of viability, as can be observed in the following table:

Table 5.16 - Plug & Play model for the lower body movement harvesting system

Lower body movement harvesting system

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	1312.80	1312.80	1312.80	3150.72
Total Cost (€)	1789.31	1789.31	1789.31	4294.34
Total Avoided Cost (€)	275.76	218.42	486.75	5569.35
NPV_5 (€)	-1430.33	-1463.90	-1306.81	-559.56
NPV_{10} (€)	-1513.55	-1570.89	-1302.56	1275.00
Return period (years)	NA	NA	NA	6.5

This technology is clearly not made for small-size gyms, which can be seen in the table above. Both the observed small-scale gymnasiums continue to not able to produce a profit, despite the higher electricity production lower body motion creates. *Arena Club Oeiras* manages to earn a slight profit, making the RP an absurdly high amount of years, while *Be-Fit Setúbal* manages a serviceable return period of approximately seven years, which may still prove to be excessive due to the uncertainty of the machinery's lifespan with the heavy use it'll observe.

In the case of the studied gymnasiums implementing both technologies in their machines, they observe the following results:

Table 5.17 - Plug & Play model for the linear movement harvesting system

Linear movement harvesting system				
	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	2201.40	2201.40	2645.70	7149.42
Total Cost (€)	3059.12	3059.12	3694.02	10008.48
Total Avoided Cost (€)	365.85	280.32	770.68	9647.53
NPV_5 (€)	-2489.38	-2539.45	-2808.25	-3174.93
NPV_{10} (€)	-2693.27	-2778.80	-2923.34	-360.95
Return period (years)	NA	NA	NA	NA

None of the gymnasiums that were studied are able to implement both technologies onto their machinery, which means that if this scheme is to be adopted some kind of economic incentive should be applied.

5.2.2.2 Company Ownership

The results for the Company Ownership model in gymnasiums that adopt the linear movement harvesting system in all their machines are presented below:

Table 5.18 - Company Ownership model for the linear movement harvesting system

Linear movement harvesting system				
	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	2201.40	2201.40	2645.70	7149.42
Total Cost (€)	3234.21	3304.24	4306.83	12837.24
Total Benefit (€)	365.85	280.32	770.68	9637.24
NPV_5 (€)	-2591.89	-2682.97	-3167.04	-4831.10
NPV_{10} (€)	-2868.36	-3023.93	-3536.15	-3189.70
Return period (years)	NA	NA	NA	NA

This model is deemed to not be appropriate for this type of technology due to the extremely negative results observed in the simulations shown above. None of the gymnasiums are able to reach an acceptable RP or even turn a profit, which is only the case of *Be-Fit Setúbal*, but at a rate that is unsustainable.

For the establishments considered in this study, this model yields the most savings due to the combination of the low output of the machinery using this type of movement, which translates into low avoided costs, and the high discount on the electric bill offered by the energy company. This means that the establishments would benefit for from receiving a discount on their electricity bill than producing electricity for their establishment. However, due to the extreme return period needed for this technology to become profitable, this model ends up not being able to be implemented in any establishment.

5.2.2.3 Leasing

The studied gymnasiums obtained the following results using the leasing model:

Table 5.19 - Leasing model for the upper body motion harvesting system

Upper body motion harvesting system

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	880.24	880.24	1320.26	3961.07
Total Cost (€)	1261.45	1261.45	1892.17	5676.51
Total Avoided Cost (€)	90.08	61.89	283.94	4078.18
NPV_5 (€)	-1050.69	-1067.19	-1488.90	-2577.74
NPV_{10} (€)	-1171.36	-1199.55	-1608.23	-1598.33
Return period (years)	NA	NA	NA	NA

This model has similar results to the Plug & Play model, since both operate with the same principal with the only difference being the distribution of the investment through a determined period of time in the case of this model. This means that, just like the previously mentioned model, none of the considered gymnasiums are able to sees its investment returned before the expected breakdown of the machinery.

For lower body movement harvesting the situation looks more positive, due to the higher electricity production observed. The economic potential of this technology is still very low, as can be seen in the following tables:

Table 5.20 - Leasing model for the lower body motion harvesting system

Lower body motion harvesting system

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	1300.45	1300.45	1300.45	3121.07
Total Cost (€)	1776.96	1776.96	1776.96	4264.70
Total Avoided Cost (€)	275.76	218.42	486.75	5569.35
NPV_5 (€)	-1417.98	-1451.55	-1294.45	-529.92
NPV_{10} (€)	-1501.19	-1558.53	-1290.21	1304.65
Return period (years)	NA	NA	NA	6.4

Small-size gyms continue to be unable to turn a profit with this scheme, while *Arena Club Oeiras* manages to earn a small sum of a profit, making the return period absurdly high. *Be-Fit Setúbal*, with its very high machine use, can produce enough electricity to see its investment returned in the form of Total Avoided Costs in a little under seven years.

If the gymnasiums decide to incorporate both technologies in the spaces with the leasing model in mind, the following results can be observed:

Table 5.21 - Leasing model for the linear motion harvesting system

Linear motion harvesting system				
	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Investment (€)	2180.69	2180.69	2620.81	7082.15
Total Cost (€)	3038.40	3038.40	3669.13	9941.21
Total Avoided Cost (€)	365.85	280.32	770.68	9647.53
NPV_5 (€)	-2468.66	-2518.74	-2783.36	-3107.66
NPV_{10} (€)	-2672.56	-2758.09	-2989.36	-293.68
Return period (years)	NA	NA	NA	NA

Due to the low electrical output of the upper body movement harvesting system and the somewhat average output of its lower body counterpart, the combination of both these technologies require a large amount of use to make it profitable. This can be observed in the results, which indicate that only large-scale gyms, such as *Be-Fit Setúbal* are able to rake in a profit. However, this profit isn't high enough to warrant interest in investors, since the return period is above the time period that consumers are willing to wait and the expected life expectancy for these technologies.

For better understanding of these results, the tables located in annex XXVIII to XVII are related to the data and calculations used to determine the economic potential of these technologies.

5.3 Environmental benefits

The environmental benefits of adopting these technologies in gymnasiums are plentiful. The most obvious, and relatively simple to quantify, is the amount of greenhouse gas (GHG) emissions that can be saved from producing electricity from this system as opposed to the current electricity production paradigm. To exemplify two distinct types of electricity production, a low scenario, characterized by the current electricity production scheme for small businesses in Portugal was created, alongside a high scenario, which reflects a highly polluting electricity producing involving the use of fossil fuels, mainly coal. The first is representing GHG savings of 200 gCO_2eq/kWh, while the latter shows savings of 900 gCO_2eq/kWh.

The results for each type of movement in this study can be observed in the table below:

Table 5.22 - GHG savings from rotary human motion harvesting – Scenario 1

GHG Savings – Rotary human motion harvesting – Scenario 1				
	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Electricity production (kWh/year)	1312	808	3042	7953
GHG savings - Low scenario ($kgCO_2eq/year$)	262	162	608	1591
GHG savings - High scenario ($kgCO_2eq/year$)	1181	727	2738	7158

Since these savings are directly tied to the amount of electricity these machines produce, it is to be expected that gymnasiums with high amount of machine use have the biggest impact on reducing GHG emissions. This can be observed in the table above, where *Be-Fit Setúbal*, with its immense amount of yearly human motion, has an elevated amount of savings compared to the other establishments. However, the amount of GHG savings that these rotary technologies offer to the gymnasiums that they are installed in is to not be underestimated, despite the relatively low amount when looking at the yearly global amount that is emitted.

The potential GHG savings from rotary human motion harvesting in the second scenario are presented in the table below:

Table 5.23 - GHG savings from rotary human motion harvesting – Scenario 2

GHG Savings – Rotary human motion harvesting – Scenario 2

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Electricity production (kWh/year)	779	238	1473	6345
GHG savings - Low scenario ($kgCO_2eq/year$)	156	48	295	1269
GHG savings - High scenario ($kgCO_2eq/year$)	701	214	1326	5710

The rotational movement harvesting system in this scenario has a lesser electricity production, but at a lower price. This however means that the GHG savings of this system are less than the previous machine, despite the reduced price. Despite this, the GHG savings are still considerably high, with *Be Gym Fit* being the lowest, but still producing a minimum of around 50 $kgCO_2eq/year$ when installed in a location where the pollution related to the electricity production industry is similar to that of Portugal.

In the case of the linear movement harvesting systems, the GHG savings are much lower due to the lower electricity yield from linear movement compared to their rotational counterpart. This is reflected in the tables below:

Table 5.24 - GHG savings from upper body motion harvesting

GHG Savings – Upper body motion harvesting

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Electricity production (kWh/year)	62	42	195	2595
GHG savings - Low scenario ($kgCO_2eq/year$)	12	8	39	519
GHG savings - High scenario ($kgCO_2eq/year$)	56	38	175	2336

Despite the lower electricity production, upper body movement harvesting still manages to impact the GHG emissions in a reasonable way. In an underdeveloped country with a high amount of GHG emissions, due to the use of coal and other damaging fossil fuels, it could still save a huge amount of GHG emissions in a large-size gymnasium such as *Be-Fit Setúbal*. The remaining gymnasiums mitigate a decent amount of emissions, albeit at a much-reduced rate, due to the immense drop in machine use.

Table 5.25 - GHG savings from lower body motion harvesting

GHG Savings – Lower body motion harvesting

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Electricity production (kWh/year)	189	150	334	3544
GHG savings – Low scenario ($kgCO_2eq/year$)	38	30	67	709
GHG savings - High scenario ($kgCO_2eq/year$)	170	135	300	3190

The lower body harvesting machine with its higher electricity production manages to achieve a bigger reduction in GHG emissions compared to its upper body counterpart. This difference is very noticeable in the high scenario, where it adds approximately 850 $kgCO_2eq$/year of savings, while in the low scenario it would only further reduce this amount by approximately 200 $kgCO_2eq$/year when installed *in Be-Fit Setúbal*. The remaining gyms still confer a considerable amount of GHG savings but are completely eclipsed compared to the number that large-scale gymnasiums are able to reach.

If both upper and lower body harvesting technologies are installed on every machine in the studied establishments, the following results are obtained:

Table 5.26 - GHG savings from linear human motion harvesting

GHG Savings – Linear human motion harvesting

	Feelgood	*Be Gym Fit*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Electricity production (kWh/year)	251	192	528	6139
GHG savings - Low scenario ($kgCO_2eq/year$)	50	38	106	1228
GHG savings - High scenario ($kgCO_2eq/year$)	226	173	475	5525

The combination of both types of linear human motion harvesting yields an imposing amount of GHG emissions reduction. This value peaks at approximately 5.5 tCO_2eq/year in the scenario of a large-scale gymnasium, such as *Be-Fit Setúbal*, in the scenario representing electricity production using highly polluting fossil fuels, such as coal.

If the observed gymnasiums were to retrofit every eligible machine in their establishment with the appropriate human motion harvesting machine that would yield the following results:

Table 5.27 - GHG savings from human motion harvesting

GHG Savings - Human motion harvesting

	Rotary motion Scenario	*Feelgood*	*Be Fit Gym*	*Arena Club Oeiras*	*Be-Fit Setúbal*
Electricity production (kWh/year)	1	1563	1000	3571	14092
Electricity production (kWh/year)	2	1030	430	2002	12484
GHG savings - Low scenario (kgCO_2eq/year)	1	313	200	714	2818
GHG savings - Low scenario (kgCO_2eq/year)	2	206	86	400	2497
GHG savings - High scenario (kgCO_2eq/year)	1	1407	900	3214	12683
GHG savings - High scenario (kgCO_2eq/year)	2	927	387	1802	11235

Combining both technologies in these establishments results in a considerable amount of GHG emissions reduction. Due to the superior electricity production of the rotary motion harvesting system in scenario 1 the emission will be further reduced in that scenario, albeit at a heightened price. However, the amount of savings that both these systems would contribute in countries with highly polluting electricity production industry is a very considerable amount, making it an attractive option towards reducing the use of fossil fuels to produce electricity and in turn reduce the emissions in the energy sector.

6 Discussion and future directions

As expected, this study reached a straightforward conclusion related to the electric output of the human motion harvesting systems: The more machine use an establishment has, the more electricity is produced. This means that large-scale gymnasiums, as is the case of *Be-Fit Setúbal*, yield the highest electric output, since it most likely has a high number of users, which in turn means that more time that the machinery is in operation. Mid-size gymnasiums manage to yield a considerable amount of electricity production, despite the lowered user count when compared to large-scale gymnasiums. Small-size gymnasiums are not a good adopter of these technologies for the purpose of yielding considerable savings on their electric bill. This is due to the combination of the low user count these gymnasiums have and the already low amount of electricity these establishments use, making the avoided costs seem almost negligible.

The average coverage of electricity production that these systems can provide to the studied gymnasiums is 7.5% of the total yearly electricity expenditure. In the case of scenario 1 the value is slightly higher (9%) compared to scenario 2 (6%). This is simply due to the higher electricity production the system in the first scenario can achieve compared to the second scenario. The observed gymnasiums showed great interest in these kinds of technologies to be able to produce electricity with the installation of a simple machine onto their existent gymnasium equipment.

The gymnasium that benefitted the most from the reduction of their electricity dependency on the national electricity grid is *Feelgood*, which saw the highest reduction of 13% in scenario 1 and, a somewhat lower, but still considerably high amount of 9% in scenario 2. The gymnasium that experienced the lowest benefit was *Arena Club Oeiras*, which only saw a reduction of 6 and 3% in scenario 1 and 2 respectively. These discrepancies between gymnasiums is due to the differences in yearly electricity consumption, which is not always accompanied by an increase of the potential electricity production by the machinery, which is the case when observing both small-scale gymnasiums.

Rotary motion harvesting shows a high economic potential for electricity production in mid to large scale gymnasiums, while small-size gymnasiums, such as *Feelgood* and *Be Gym Fit* struggle to justify the installation of these technologies in their establishment, due to the inability of these establishments to reach a positive outcome in the machinery's lifetime. In most cases, these establishment take more than a decade to earn back their initial investment and, in some situations, they do not even manage to avoid more costs than the maintenance necessary to upkeep the systems.

Be-Fit Setúbal can potentially earn back their investment in four years, despite the low number of bicycles compared to other gymnasiums with a similar scale. *Arena Club Oeiras* was able to earn back its investment in six years in scenario 1, which means it has a strong possibility of adopting these technologies in their establishment and become profitable.

In terms of business models, it was concluded that both Plug & Play and leasing are appropriate to be adopted by large and medium-sized gymnasiums, while small-scale gymnasiums are unable to turn a reasonable profit in any business model. The difference between these models lie in the willingness of the owners to invest. If the consumer wants to pay the full investment in the first year, but with less payment in the machinery's lifetime, the Plug & Play model is best suited. If the consumer wants to spread the costs along the years of using these technologies, the leasing model is recommended to dilute the investment needed.

In relation to linear motion, this technology isn't suited for small-size gymnasiums as well, such as *Be Gym Fit* and *Feelgood*. The combination of a high initial investment and low machine use makes these technologies unsustainable in any of the considered business models. The introduction of an economic incentive could change this situation, but it would need to have a high value to support the losses the establishments would incur.

Even medium-size gymnasiums, which are represented by *Arena Club Oeiras*, struggle to maintain a return period which is considered desirable by gymnasiums. None of the considered business models managed to yield a return period worth considering and in the case of the Company Ownership model it would be running at a loss.

The only establishment capable of using linear human motion for electricity production with an acceptable payback period is *Be-Fit Setúbal*, which is representative of large-scale gymnasiums. The only caveat is that the only type of movement that boasts a reasonable return period is lower body movement, which sees a slight increase in price of the machinery but yields considerably more electricity. While installing these technologies onto the machines of this establishment, it sees a potential return period of six and a half years, which can still prove to be too high before the reaches its predicated life expectancy.

For the linear motion harvesting system, none of the observed business models shows much success. The only establishment that could potentially have profit in a reasonable amount of years is *Be-Fit Setúbal* using the Plug & Play model. The Company Ownership model is unable to be used in the current market, due to the high payback period for the electricity producing companies investing in these technologies, and leasing can be used to alleviate the upfront costs, despite the inherit lengthening of the payback period. The use of an economic incentive is needed to promote the adoption of this novelty way of harvesting energy.

From the analysis done in this study we can conclude that rotary human motion harvesting has a solid economic potential across most types of gyms. In the case of linear motion, the situation looks much grimmer due to the high initial investment and the very low electricity output, compared to its rotational counterpart. This technology is viable only in large-scale gymnasiums with a high amount of machine use, such as *Be-Fit Setúbal*. If this technology is to be commercially successful in today's market, it would benefit greatly from some form of financial backing to make it appealing for consumers, such as gymnasiums.

This situation is bound to be improved in the near future with the inevitable decrease in the price of these technologies, which enables some of them, such as solar, to be widely adopted and popular in the current market. This technology sees a payback period of one to four years, depending on the type of solar panels used, when it saw a return period of over a decade a few years ago. [29]

Comparing the three models analysed, Company Ownership was the one that performed the worst, seeing only a few niche cases in which it was possible to turn a profit for both the energy company investing in the establishment and its owners. This model does not work for gymnasiums due to the high energy consumption of these establishments, which means a discount on the electricity bill, even at an insignificant amount of 1%, would still incur a heavy loss for the energy company. This could be solved by reducing the discount further, but this will make the consumers opt to pick the other models, since they would earn more from the avoided costs the machines bring than the discount the energy company offers.

Putting aside the economic side of these technologies, the environmental benefits these systems can bring to their adopters are not to be ignored. The transition from fossil fuels to renewable energy is a change that brings a plethora of benefits, of which the most important one is the GHG savings. The GHG savings that were determined for these systems in each establishment might seem insignificant in the grand scheme of things, but every gymnasium that adopts these technologies will contribute to the reduction of greenhouse gases, which with the potential growth of this technology, can end up being a significant contributor to the abolishment of fossil fuels in the energy sector.

Human motion harvesting can have a tremendous impact on the GHG emissions that are currently plaguing the energy sector, which is reflected in the observed results. In countries which depend on highly polluting facilities, such as coal powered power plants, these systems can reach GHG savings of up to 14 tCO_2eq/kWh, while in Portugal this number is reduced to 2.5 tCO_2eq/kWh, which is still impactful enough to warrant more research and adoption of these technologies by the energy sector. When looking at the grand scheme of the Portuguese emissions, these numbers might seem incredibly insignificant (less than 0.02% of the current Portuguese GHG emissions), but if this technology is to be widely adopted in Portugal, these GHG savings could reach a considerable amount to be a genuine driver towards the reduction of GHG emissions.

However, this study suffers from a few limiting factors which hold back the overall analysis done along this project. The machinery in the current state it is in does not benefit from a scaling economy, which means that the savings it generates are merely generated by the number of machines and the investment. This causes the system to produce the same savings independently of how many machines are installed, so installing ten or ten thousand machines does not increase the individual savings that each machine will confer onto the investing establishment

When comparing these human motion technologies to other, more common and developed renewable technologies, the results that were shown are lacklustre. These renewable technologies that are already implemented in the current market show an all-round much greater potential than the studied systems. This is due to the fact that these technologies are still in their infancy in terms of development, which the other renewable systems have already been through and have been further developed to be widely adopted.

Another limitation was in the number of gymnasiums that were studied, which may make the results vary in terms of results depending on what establishments are used to study these systems. The four gymnasiums that were chosen were used to represent different scales of human motion establishments but can differ widely from other gymnasiums that are technically in the same scale of size. To better understand the economic and environmental implications of adopting these technologies on a larger scale, a national wide survey should be done to have a more concrete idea of how these technologies could impact the national GHG emissions paradigm.

In the future, with the continuous development of renewable energy technologies, which in this case are generators, the economic returns that human motion harvesting can achieve can be improved to a point where it can be viable in any gym setting. The increased use of linear generators and associated development of this these systems in recent years can results in making this counterpart worthy of studying its economic potential in gymnasiums alongside the pre-existing studies. The appearance of new economic incentives can also contribute to augmenting the possibility of using human motion to produce electricity. Exploring these new possibilities could prove vital to the economic potential of recent and future technologies.

The designed system and built prototype can be improved upon for better harvesting or prolonged longevity through the use of better materials or a better way to convert the linear movement into rotational movement. Another option would be to use a linear generator, which would eliminate the need to convert the movement and open up the possibility of directly using the machine to produce electricity. Economically, exploring additional existing business models or creating new scenarios with alternating uses of electricity tied to the price of electricity across the day or additional tax incentives could prove to make this technology more appeasing and make it reach more positive results.

References

[1] International Energy Agency (IEA), “Southeast Asia Energy Outlook 2017,” p. 149, 2017.

[2] R. Strzelecki, M. Jarnut, and G. Benysek, “Exercise bike powered electric generator for fitness club appliances,” *2007 Eur. Conf. Power Electron. Appl. EPE*, 2007.

[3] N. N. Mustafi, M. Mourshed, M. H. Masud, M. S. Hossain, and M. R. Kamal, “Feasibility test on green energy harvesting from physical exercise devices,” *AIP Conf. Proc.*, vol. 1851, 2017.

[4] K. M. Ullah and M. Alam, “Generation of Electrical Power Using Gymnasium Bicycle,” pp. 21–23, 2017.

[5] M. T. Ullah, M. A. Bin Karim, M. H. Uddin, and G. M. Tauseef, “Harvesting green energy from wastage energy of human activities using gymnasium bicycle at Chittagong city,” *2015 Int. Conf. Green Energy Technol. ICGET 2015*, pp. 31–34, 2015.

[6] A. A. S. Khan, T. Alam, M. R. Abir, and M. T. Ullah, “Harvesting Human Exercise Power Using Gymnasium Bicycle,” vol. 2015, no. March, pp. 1–4, 2015.

[7] B. Chalermthai, N. Sada, O. Sarfraz, and B. Radi, “Recovery of useful energy from lost human power in gymnasium,” *2015 IEEE 15th Int. Conf. Environ. Electr. Eng. EEEIC 2015 - Conf. Proc.*, pp. 1700–1705, 2015.

[8] “ReRev . A Renewable Energy Revolution.” [Online]. Available: http://rerev.com/. [Accessed: 23-May-2018].

[9] “Green Micro Gym: Electricity Generating Fitness Equipment.” [Online]. Available: http://www.thegreenmicrogym.com/. [Accessed: 23-May-2018].

[10] U.S. Energy Information Agency (EIA), “International Energy Outlook 2017 Overview,” *U.S. Energy Inf. Adm.*, vol. IEO2017, no. 2017, p. 143, 2017.

[11] International Energy Agency (2018), “Electricity information: Overview 2018.”

[12] Organisation for Economic Co-operation and Development (OECD) / International Energy Agency (IEA), “Global Energy & CO 2 Status Report,” no. March, 2018.

[13] R. Santos, S. Martinho, and P. Antunes, “*Estudo sobre Sector Eléctrico e Ambiente, Relatório-Avaliação Económica dos Impactes Ambientais do Sector Eléctrico*,” *Ecoman, DCEAFCT/UNL, Monte de Caparica*, 2001.

[14] Redes Energéticas Nacionais (REN), “Dados Técnicos 2016 - Technical Data,” *Redes energéticas Nac. SGPS, S.A*, p. 36, 2016.

[15] World Health Organization (WHO), “Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks,” p. 147, 2016.

[16] U.S. Energy Information Administration, *International Energy Outlook 2016*, vol. 0484(2016), no. May 2016. 2016.

[17] International Energy Agency, “Energy and Air Pollution,” *World Energy Outlook - Spec. Rep.*, p. 266, 2016.

[18] International Energy Agency (IEA), “Energy and Climate Change,” *World Energy Outlook Spec. Rep.*, pp. 1–200, 2015.

[19] C. Shearer, R. Fofrich, and S. J. Davis, “Future CO2 emissions and electricity generation from proposed coal-fired power plants in India,” 2017.

[20] A. Moro and L. Lonza, “Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles,” *Transp. Res. Part D Transp. Environ.*, no. July, pp. 0–1, 2017.

[21] “electricityMap | Live CO2 emissions of electricity consumption.” [Online]. Available:

https://www.electricitymap.org/?page=map&solar=false&remote=true&wind=false. [Accessed: 17-Dec-2018].

[22] P. L. Spath, M. K. Mann, and D. R. Kerr, “Life Cycle Assessment of Coal-fired Power Production,” *Other Inf. Supercedes Rep. DE00012100; PBD 1 Sep 1999; PBD 1 Sep 1999*, p. 172, 1999.

[23] Energias de Portugal (EDP), “*Relatório de Sustentabilidade 2017 EDP*,” 2017.

[24] Department of Energy and Climate Change, “Energy Act 2004,” p. 296, 2004.

[25] A. E. Jones, M. Irwin, and A. Izadian, “Incentives for microgeneration development in the U.S. and Europe,” *IECON Proc. (Industrial Electron. Conf.*, pp. 3018–3021, 2010.

[26] D. Infield and F. Li, “Integrating Micro-Generation into Distribution Systems – a review of recent research,” *IEEE Power Energy Soc. Gen. Meet. - Convers. Deliv. Electr. Energy 21st Century*, pp. 1–4, 2008.

[27] C. Camus and E. Eusébio, “Micro-generation evaluation of the zero emissions technologies in the Portuguese market,” *2008 5th Int. Conf. Eur. Electr. Mark. EEM*, 2008.

[28] N. Bergman and N. Eyre, “What role for microgeneration in a shift to a low carbon domestic energy sector in the UK?,” *Energy Effic.*, vol. 4, no. 3, pp. 335–353, 2011.

[29] K. P. Bhandari, J. M. Collier, R. J. Ellingson, and D. S. Apul, “Energy payback time (EPBT) and energy return on energy invested (EROI) of solar photovoltaic systems : A systematic review and meta-analysis,” *Renew. Sustain. Energy Rev.*, vol. 47, pp. 133–141, 2015.

[30] I. Zamora, J. I. San Martin, A. J. Mazón, J. J. San Martín, and V. Aperribay, “Emergent Technologies In Electrical Microgeneration.,” *Int. J. Emerg. Electr. Power Syst.*, vol. 3, no. 2, pp. 1–28, 2005.

[31] N. Mithraratne, “Roof-top wind turbines for microgeneration in urban houses in New Zealand,” *Energy Build.*, vol. 41, no. 10, pp. 1013–1018, 2009.

[32] J. Watson, R. Sauter, B. Bahaj, P. James, L. Myers, and R. Wing, “Domestic micro-generation: Economic, regulatory and policy issues for the UK,” *Energy Policy*, vol. 36, no. 8, pp. 3085–3096, 2008.

[33] Ministério do Ambiente Ordenamento do Território e Energia, “Decreto-Lei n.º53/2014,” *Diário da República*, pp. 5298–5311, 2014.

[34] Ministério do Ambiente Ordenamento do Território e Energia, “Portaria n.º 15/2015,” *Diário da República*, pp. 531–532, 2015.

[35] Direcção Geral de Energia e Geologia (DGEG), “Legal Sources on Renewable Energy: Feed-in tariff (Tarifas feed-in),” 2017.

[36] J. Pierce and E. Paulos, “Designing everyday technologies with human-power and interactive microgeneration,” *Proc. Des. Interact. Syst. Conf. DIS 12*, p. 602, 2012.

[37] S. K. Sukumaran, “an Approach in Energy Harvesting From Fitness Equipment” 2014, 978-1-4799-7613-3/14/$31.00 ©2014 IEEE.

[38] V. S. B. B. V Khatake, D. V. Z. V. D. Patel, and G. F. S. G. C. O. E. Jalgaon, “Electric Power Generation from Gym Equipment with Polarity Checker and Changer Circuit,” vol. 5, no. 02, pp. 992–995, 2017.

[39] M. Niroomand and H. R. Foroughi, “A rotary electromagnetic microgenerator for energy harvesting from human motions,” *J. Appl. Res. Technol.*, vol. 14, no. 4, pp. 259–267, 2016.

[40] J. Zhao and Z. You, “A Shoe-Embedded Piezoelectric Energy Harvester for Wearable Sensors,” *Sensors*, vol. 14, no. 7, pp. 12497–12510, 2014.

[41] B. J. Bowers and D. P. Arnold, “Spherical, rolling magnet generators for passive energy harvesting from human motion,” *J. Micromechanics Microengineering*, vol. 19, no. 9, 2009.

[42] J. Granstrom, J. Feenstra, H. A. Sodano, and K. Farinholt, “Energy harvesting from a backpack instrumented with piezoelectric shoulder straps,” *Smart Mater. Struct.*, vol. 16, no. 5, pp. 1810–1820, 2007.

[43] C. R. Saha, T. O’Donnell, N. Wang, and P. McCloskey, “Electromagnetic generator for harvesting energy from human motion,” *Sensors Actuators, A Phys.*, vol. 147, no. 1, pp. 248–253, 2008.

[44] B. Yang and K. S. Yun, “Piezoelectric shell structures as wearable energy harvesters for effective power generation at low-frequency movement,” *Sensors Actuators, A Phys.*, vol. 188, pp. 427–433, 2012.

[45] R. Yang, Y. Qin, C. Li, G. Zhu, and Z. Lin Wang, “Converting Biomechanical Energy into Electricity by a Muscle-Movement-Driven Nanogenerator,” *Nanoletters*, vol. 9, no. 3, pp. 1201–1205, 2009.

[46] Y. Yang, J. Yeo, and S. Priya, “Harvesting energy from the counterbalancing (Weaving) movement in bicycle riding,” *Sensors (Switzerland)*, vol. 12, no. 8, pp. 10248–10258, 2012.

[47] R. Riemer and A. Shapiro, “Biomechanical energy harvesting from human motion: Theory, state of the art, design guidelines, and future directions,” *J. Neuroeng. Rehabil.*, vol. 8, no. 1, pp. 1–13, 2011.

[48] J. Watson, “Co-provision in sustainable energy systems: The case of micro-generation,” *Energy Policy*, vol. 32, no. 17, pp. 1981–1990, 2004.

Annex

Annex I – Linear machine use in *Feelgood*

Name	Quantity	Adaptable	Type	Average amount of time spent on machine during normal schedule (h)
Abductor	1	Yes	Lower body	2
Adductor	1			2
Lower body press	1			2
Lower body curl	1			2
Lower body extension	1			2
Pec fly	1		Upper body	2
Adjustable pulley	1			1
Pulley Row	1			2
Dorsal pulley	1			2
Incline bench	1	No	Cannot be adapted	4
Adjustable bench	1			4
Scott bank	1			1
Total				26

Annex II – Linear machine use in *Be Gym Fit*

Name	Quantity	Adaptable	Type	Average time spent on machine during normal schedule (h)	Average time spent on machine during reduced schedule (h)
Abductor	1	Yes	Lower body	1.00	0.50
Adductor	1			1.00	0.25
Lower body press	1			2.00	1.00
Lower body curl	1			1.50	0.75
Lower body extension	1			1.75	0.75
Pec fly	1		Upper body	1.00	0.25
Adjustable pulley	1			1.50	0.50
Dorsal pulley	1			1.50	0.50
Abs crunch	1			0.50	0.25
Flat bench	1	No	Cannot be adapted	1.00	0.50
Incline bench	1			1.00	0.50
Adjustable bench	1			1.00	0.50
Smith machine	1			0.75	0.25
Straight bench	1			1.50	0.50
Total				17.00	7.00

Annex III – Linear machine use in *Arena Club Oeiras*

Name	Quantity	Adaptable	Type	Average amount of time spent on machine during normal schedule (h)	Average amount of time spent on machine during reduced schedule (h)
Abductor	1	Yes	Lower body	3.00	0.75
Adductor	1			3.00	0.75
Lower body press	1			4.00	1.00
Lower body curl	1			3.00	0.75
Lower body extension	1			3.00	0.75
Pec fly	1		Upper body	3.00	0.75
Abs crunch	1			3.00	0.75
Adjustable pulley	1			3.00	0.75
Pulley Row	1			4.00	1.00
Dorsal pulley	1			4.00	1.00
Gravitron	1			3.00	0.75
Flat Bench	1	No	Cannot be adapted	3.00	0.75
Incline bench	1			3.00	0.75
Adjustable bench	1			3.00	0.75
Smith Machine	1			3.00	0.75
Straight bench	1			3.00	0.75
Scott bank	1			3.00	0.75
Total				54.00	13.50

Annex IV – Linear machine use in *Be-Fit Setúbal*

Name	Quantity	Adaptable	Type	Average time spent on machine during normal schedule (h)	Average time spent on machine during reduced schedule - Saturday (h)	Average time spent on machine during reduced schedule - Sunday (h)
Abductor	2	Yes	Lower body	12	12	8
Adductor	2			12	12	8
Lower body press	1			17	12	10
Lower body curl	2			8	8	5
Lower body extension	2			15	12	8
Declined press	2			12	9	5
Hip machine	1			10	6	4
Chest press	2		Upper body	13	10	7
Pec fly	2			16	10	8
Shoulder press	1			10	6	4
Abs crunch	2			12	8	4
Bicep pulley	2			16	6	4
Lateral pulley	2			17	8	6
Row pulley	2			15	7	5
Dorsal pulley	2			16	6	4
Crossover (weights 2x)	2			10	6	4

Row machine	1			8	5	3
Flat bench	2	No	Cannot be adapted	10	6	4
Incline bench	2			10	6	4
Adjustable bench	6			10	6	4
Declined bench	1			12	6	4
Straight bench	1			10	4	2
Smith machine	1			12	6	4
Hack machine	1			10	6	4
Scott bank	1			10	6	4
Total				547	345	231

Annex V - Electricity production and savings from linear motion harvesting in *Feelgood*

Name	Quantity	Adaptable	Type	Yearly Production of electricity during normal schedule (kWh/year)
Abductor	1	Yes	Lower body	37.80
Adductor	1			37.80
Lower body press	1			37.80
Lower body curl	1			37.80
Lower body extension	1			37.80
Pec fly	1		Upper body	17.64
Adjustable pulley	1			8.82
Pulley Row	1			17.64
Dorsal pulley	1			17.64
Incline bench	1	No	Cannot be adapted	Cannot be adapted
Adjustable bench	1			
Scott bank	1			
Total				250.74
Savings (€)				38.39

Annex VI – Electricity production and savings from linear motion harvesting in *Be Gym Fit*

Name	Quantity	Adaptable	Type	Yearly Production of electricity during normal schedule (kWh/year)	Yearly Production of electricity during reduced schedule (kWh/year)
Abductor	1	Yes	Lower body	18.90	1.95
Adductor	1			18.90	0.98
Lower body press	1			37.80	3.90
Lower body curl	1			28.35	2.93
Lower body extension	1			33.08	2.93
Pec fly	1		Upper body	8.82	0.46
Adjustable pulley	1			13.23	0.91
Dorsal pulley	1			13.23	0.91
Abs crunch	1			4.41	0.46
Flat bench	1	No	Cannot be adapted	Cannot be adapted	
Incline bench	1				
Adjustable bench	1				
Smith machine	1				
Straight bench	1				
Total				176.72	15.41
Savings (€)				27.06	2.36

Annex VII - Electricity production and savings from linear motion harvesting in *Arena Club Oeiras*

Name	Quantity	Adaptable	Type	Yearly Production of electricity during normal schedule (kWh/year)	Yearly Production of electricity during reduced schedule (kWh/year)
Abductor	1	Yes	Lower body	56.70	5.85
Adductor	1			56.70	5.85
Lower body press	1			75.60	7.80
Lower body curl	1			56.70	5.85
Lower body extension	1			56.70	5.85
Pec fly	1		Upper body	26.46	2.73
Abs crunch	1			26.46	2.73
Adjustable pulley	1			26.46	2.73
Pulley Row	1			35.28	3.64
Dorsal pulley	1			35.28	3.64
Gravitron	1			26.46	2.73
Flat Bench	1	No	Cannot be adapted	Cannot be adapted	
Incline bench	1				
Adjustable bench	1				
Smith Machine	1				
Straight bench	1				
Scott bank	1				
Total				478.80	49.40
Savings (€)				73.30	7.56

Annex VIII - Electricity production and savings from linear motion harvesting in *Be-Fit Setúbal*

Name	Quantity	Adaptable	Type	Yearly Production of electricity during normal schedule (kWh/year)	Yearly Production of electricity during reduced schedule - Saturday (kWh/year)	Yearly Production of electricity during reduced schedule - Sunday (kWh/year)
Abductor	2	Yes	Lower body	453.60	93.60	62.40
Adductor	2			453.60	93.60	62.40
Lower body press	1			321.30	46.80	39.00
Lower body curl	2			302.40	62.40	39.00
Lower body extension	2			567.00	93.60	62.40
Declined press	2			453.60	70.20	39.00
Hip machine	1			189.00	23.40	15.60
Chest press	2		Upper body	229.32	36.40	25.48
Pec fly	2			282.24	36.40	29.12
Shoulder press	1			88.20	10.92	7.28
Abs crunch	2			211.68	29.12	14.56
Bicep pulley	2			282.24	21.84	14.56
Lateral pulley	2			299.88	29.12	21.84
Row pulley	2			264.60	25.48	18.20
Dorsal pulley	2			282.24	21.84	14.56

Crossover (weights 2x)	2			176.40	21.84	14.56
Row machine	1			70.56	9.10	5.46
Flat bench	2	No	Cannot be adapted	Cannot be adapted		
Incline bench	2					
Adjustable bench	6					
Declined bench	1					
Straight bench	1					
Smith machine	1					
Hack machine	1					
Scott bank	1					
Total				4927.86	725.66	485.42
Savings (€)				812.60	119.66	80.05

Annex IX – Rotary machine use in *Feelgood*

Name	Quantity	Adaptable	Average amount of time spent on machine during normal schedule (h)
Bicycle	2	Yes	6
Cross Trainer	2		6
Rowing Machine	1		6
Stair Stepper	1		6
Treadmill	3	No	6
Total			54

Annex X – Rotary machine use in *Be Gym Fit*

Name	Quantity	Adaptable	Average time spent on machine during normal schedule (h)	Average time spent on machine during reduced schedule (h)
Bicycle	2	Yes	3.00	1.00
Spinning Bicycle	2		3.00	1.00
Treadmill	2	No	2.50	0.75
Total			17.00	5.50

Annex XI - Rotary machine use in *Arena Club Oeiras*

Name	Quantity	Adaptable	Average amount of time spent on machine during normal schedule (h)	Average amount of time spent on machine during reduced schedule (h)
Bicycle	3	Yes	8	2
Cross Trainer	2		8	2
Rowing Machine	1		8	2
Stair Stepper	1		8	2
Cardio Bicycle	1		8	2
Treadmill	3	No	8	2
Total			88	22

Annex XII – Rotary machine use in *Be-Fit Setúbal*

Name	Quantity	Adaptable	Average amount of time spent on machine during normal schedule (h)	Average amount of time spent on machine during reduced schedule - Saturday (h)	Average amount of time spent on machine during reduced schedule - Sunday (h)
Bicycle	2	Yes	6	4	2
Cross trainer	10		12	6	3
Rowing machine	4		10	5	2
Stair stepper	6		8	4	2
Reclined bicycle	2		6	4	2
Cardio bicycle	1		6	4	2
Treadmill	15	No	17	8	8
Total			493	244	180

Annex XIII - Electricity production and avoided costs from rotary motion harvesting in *Feelgood*

Name	Quantity	Adaptable	Yearly Production of electricity during normal schedule - scenario 1 (kWh/year)	Yearly Production of electricity during normal schedule - scenario 2 (kWh/year)
Bicycle	2	Yes	756.00	222.61
Cross Trainer	2		302.40	302.40
Rowing Machine	1		102.82	102.82
Stair Stepper	1		151.20	151.20
Treadmill	3	No	Cannot be adapted	
Total			1312.42	779.03
Avoided costs (€)			200.93	119.27

Annex XIV - Electricity production and avoided costs from rotary motion harvesting in *Be Gym Fit*

Name	Quantity	Adaptable	Yearly Production of electricity during normal schedule - scenario 1 (kWh/year)	Yearly Production of electricity during reduced schedule - scenario 1 (kWh/year)	Yearly Production of electricity during normal schedule - scenario 2 (kWh/year)	Yearly Production of electricity during reduced schedule - scenario 2 (kWh/year)
Bicycle	2	Yes	378.00	26.00	111.31	7.66
Spinning Bicycle	2		378.00	26.00	111.31	7.66
Treadmill	2	No	Cannot be adapted			
Total			756.00	52.00	222.61	15.31
Avoided costs (€)			115.74	7.96	34.08	2.34

Annex XV - Electricity production and avoided costs from rotary motion harvesting in *Arena Club Oeiras*

Name	Quantity	Adaptable	Yearly Production of electricity during normal schedule - scenario 1 (kWh/year)	Yearly Production of electricity during reduced schedule - scenario 1 (kWh/year)	Yearly Production of electricity during normal schedule - scenario 2 (kWh/year)	Yearly Production of electricity during reduced schedule - scenario 2 (kWh/year)
Bicycle	3	Yes	1512.00	156.00	445.22	45.94
Cross Trainer	2		403.20	41.60	403.20	41.60
Rowing Machine	1		137.09	14.14	137.09	14.14
Stair Stepper	1		201.60	20.80	201.60	20.80
Cardio Bicycle	1		504.00	52.00	148.41	15.31
Treadmill	3	No	Cannot be adapted			
Total			2757.89	284.54	1335.52	137.79
Avoided costs (€)			422.23	43.56	204.47	21.10

Annex XVI – Electricity production and avoided costs from rotary motion harvesting in *Be-Fit Setúbal*

Name	Quantity	Adaptable	Yearly Production of electricity during normal schedule - scenario 1 (kWh/year)	Yearly Production of electricity during reduced schedule - Saturday - scenario 1 (kWh/year)	Yearly Production of electricity during reduced schedule - Sunday - scenario 1 (kWh/year)	Yearly Production of electricity during normal schedule - scenario 2 (kWh/year)	Yearly Production of electricity during reduced schedule - Saturday - scenario 2 (kWh/year)	Yearly Production of electricity during reduced schedule - Sunday - scenario 2 (kWh/year)
Bicycle	2	Yes	756.00	104.00	52.00	222.61	30.62	15.31
Cross trainer	10		3024.00	312.00	156.00	3024.00	312.00	156.00
Rowing machine	4		685.44	70.72	28.29	685.44	70.72	28.29
Stair stepper	6		1209.60	124.80	62.40	1209.60	124.80	62.40
Reclined bicycle	2		756.00	104.00	52.00	222.61	30.62	15.31
Cardio bicycle	1		378.00	52.00	26.00	111.31	15.31	7.66
Treadmill	15	No	Cannot be adapted					
Total			6809.04	767.52	376.69	5475.57	584.08	284.97
Avoided costs (€)			1122.81	126.56	62.12	902.92	96.31	46.99

Annex XVII – Plug & Play model for linear motion harvesting in *Feelgood*

Linear motion - Lower body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1312.80	0.00									
O&M Cost (€)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Total Cost (€)	1362.80	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Avoided Cost (€)	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94
Total Avoided Cost (€)	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94
Updated Investment (€)	1312.80	0.00									
Updated Total Cost (€)	1362.80	48.54	47.13	45.76	44.42	43.13	41.87	40.65	39.47	38.32	37.20
Updated Total Avoided Cost (€)	28.94	28.09	27.27	26.48	25.71	24.96	24.23	23.53	22.84	22.18	21.53
Net Present Value (€)	-1333.86	-1354.31	-1374.17	-1393.45	-1412.16	-1430.33	-1447.97	-1465.10	-1481.73	-1497.87	-1513.55

Linear motion - Upper body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	888.60	0.00									
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Total Cost (€)	928.60	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Avoided Cost (€)	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45
Total Avoided Cost (€)	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45
Updated Investment (€)	888.60	0.00									
Updated Total Cost (€)	928.60	38.83	37.70	36.61	35.54	34.50	33.50	32.52	31.58	30.66	29.76
Updated Total Avoided Cost (€)	9.45	9.18	8.91	8.65	8.40	8.15	7.92	7.69	7.46	7.24	7.03
Net Present Value (€)	-919.15	-948.81	-977.60	-1005.55	-1032.70	-1059.05	-1084.63	-1109.47	-1133.58	-1156.99	-1179.72

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	2201.40	0.00									
O&M Cost (€)	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Total Cost (€)	2291.40	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Avoided Cost (€)	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39
Total Avoided Cost (€)	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39
Updated Investment (€)	2201.40	0.00									
Updated Total Cost (€)	2291.40	87.38	84.83	82.36	79.96	77.63	75.37	73.18	71.05	68.98	66.97
Updated Total Avoided Cost (€)	38.39	37.27	36.18	35.13	34.11	33.11	32.15	31.21	30.30	29.42	28.56
Net Present Value (€)	-2253.01	-2303.12	-2351.77	-2399.00	-2444.86	-2489.38	-2532.60	-2574.57	-2615.31	-2654.87	-2693.27

Annex XVIII – Company Ownership model for linear motion harvesting in *Feelgood*

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	2201.40	0.00									
O&M Cost (€)	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Discount of 1% for gym (€)	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37
Total Cost (€)	2309.77	108.37	108.37	108.37	108.37	108.37	108.37	108.37	108.37	108.37	108.37
Earnings from gym (€)	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39
Total Benefit (€)	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39
Updated Investment (€)	2201.4	0.00									
Updated Total Cost (€)	2309.77	105.22	102.15	99.18	96.29	93.48	90.76	88.12	85.55	83.06	80.64
Updated Total Benefit (€)	38.39	37.27	36.18	35.13	34.11	33.11	32.15	31.21	30.30	29.42	28.56
Net Present Value (€)	-2271.38	-2339.33	-2405.30	-2469.34	-2531.52	-2591.89	-2650.50	-2707.40	-2762.65	-2816.28	-2868.36

Annex XIX – Leasing model for linear motion harvesting in *Feelgood*

Linear motion - Lower body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	275.69	275.69	275.69	275.69	275.69	0.00					
O&M Cost (€)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Total Cost (€)	325.69	325.69	325.69	325.69	325.69	50.00	50.00	50.00	50.00	50.00	50.00
Avoided Cost (€)	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94
Total Avoided Cost (€)	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94	28.94
Updated Investment (€)	275.69	267.66	259.86	252.29	244.95	0.00					
Updated Total Cost (€)	325.69	316.20	306.99	298.05	289.37	43.13	41.87	40.65	39.47	38.32	37.20
Updated Total Avoided Cost (€)	28.94	28.09	27.27	26.48	25.71	24.96	24.23	23.53	22.84	22.18	21.53
Net Present Value (€)	-296.75	-584.86	-864.58	-1136.15	-1399.81	-1417.98	-1435.62	-1452.75	-1469.38	-1485.52	-1501.19

Linear motion - Upper body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	186.61	186.61	186.61	186.61	186.61	0.00					
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Total Cost (€)	226.61	226.61	226.61	226.61	226.61	40.00	40.00	40.00	40.00	40.00	40.00
Avoided Cost (€)	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45
Total Avoided Cost (€)	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45	9.45
Updated Investment (€)	186.61	181.17	175.89	170.77	165.80	0.00					
Updated Total Cost (€)	226.61	220.01	213.60	207.38	201.34	34.50	33.50	32.52	31.58	30.66	29.76
Updated Total Avoided Cost (€)	9.45	9.18	8.91	8.65	8.40	8.15	7.92	7.69	7.46	7.24	7.03
Net Present Value (€)	-217.15	-427.98	-632.67	-831.40	-1024.33	-1050.69	-1076.27	-1101.11	-1125.22	-1148.63	-1171.36

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	462.29	462.29	462.29	462.29	462.29	0.00					
O&M Cost (€)	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Total Cost (€)	552.29	552.29	552.29	552.29	552.29	90.00	90.00	90.00	90.00	90.00	90.00
Avoided Cost (€)	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39
Total Avoided Cost (€)	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39
Updated Investment (€)	462.29	448.83	435.76	423.06	410.74	0.00					
Updated Total Cost (€)	552.29	536.21	520.59	505.43	490.71	77.63	75.37	73.18	71.05	68.98	66.97
Updated Total Avoided Cost (€)	38.39	37.27	36.18	35.13	34.11	33.11	32.15	31.21	30.30	29.42	28.56
Net Present Value (€)	-513.91	-1012.84	-1497.25	-1967.55	-2424.14	-2468.66	-2511.89	-2553.85	-2594.60	-2634.15	-2672.56

Annex XX – Plug & Play model for linear motion harvesting in *Be Gym Fit*

Linear motion - Lower body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1312.80	0.00									
O&M Cost (€)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Total Cost (€)	1362.80	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Avoided Cost (€)	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92
Total Avoided Cost (€)	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92
Updated Investment (€)	1312.80	0.00									
Updated Total Cost (€)	1362.80	48.54	47.13	45.76	44.42	43.13	41.87	40.65	39.47	38.32	37.20
Updated Total Avoided Cost (€)	22.92	22.25	21.60	20.97	20.36	19.77	19.19	18.64	18.09	17.57	17.05
Net Present Value (€)	-1339.88	-1366.17	-1391.70	-1416.48	-1440.54	-1463.90	-1486.58	-1508.60	-1529.98	-1550.74	-1570.89

Linear motion - Upper body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	888.60	0.00									
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Total Cost (€)	928.60	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Avoided Cost (€)	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49
Total Avoided Cost (€)	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49
Updated Investment (€)	888.60	0.00									
Updated Total Cost (€)	928.60	38.83	37.70	36.61	35.54	34.50	33.50	32.52	31.58	30.66	29.76
Updated Total Avoided Cost (€)	6.49	6.31	6.12	5.94	5.77	5.60	5.44	5.28	5.13	4.98	4.83
Net Present Value (€)	-922.11	-954.64	-986.22	-1016.88	-1046.65	-1075.55	-1103.61	-1130.85	-1157.30	-1182.98	-1207.91

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	2201.40	0.00									
O&M Cost (€)	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Total Cost (€)	2291.40	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Avoided Cost (€)	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41
Total Avoided Cost (€)	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41
Updated Investment (€)	2201.40	0.00									
Updated Total Cost (€)	2291.40	87.38	84.83	82.36	79.96	77.63	75.37	73.18	71.05	68.98	66.97
Updated Total Avoided Cost (€)	29.41	28.56	27.73	26.92	26.13	25.37	24.63	23.92	23.22	22.54	21.89
Net Present Value (€)	-2261.99	-2320.81	-2377.92	-2433.36	-2487.19	-2539.45	-2590.19	-2639.46	-2687.28	-2733.72	-2778.80

Annex XXI – Company Ownership model for linear motion harvesting in *Be Gym Fit*

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	2201.40	0.00									
O&M Cost (€)	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Discount of 1% for gym (€)	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72
Total Cost (€)	2317.12	115.72	115.72	115.72	115.72	115.72	115.72	115.72	115.72	115.72	115.72
Earnings from gym (€)	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41
Total Benefit (€)	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41
Updated Investment (€)	2201.40	0.00									
Updated Total Cost (€)	2317.12	112.35	109.08	105.90	102.82	99.82	96.91	94.09	91.35	88.69	86.11
Updated Total Benefit (€)	29.41	28.56	27.73	26.92	26.13	25.37	24.63	23.92	23.22	22.54	21.89
Net Present Value (€)	-2287.71	-2371.50	-2452.85	-2531.84	-2608.52	-2682.97	-2755.25	-2825.43	-2893.56	-2959.70	-3023.93

Annex XXII – Leasing model for linear motion harvesting in *Be Gym Fit*

Linear motion - Lower body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	275.69	275.69	275.69	275.69	275.69	0.00					
O&M Cost (€)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Total Cost (€)	325.69	325.69	325.69	325.69	325.69	50.00	50.00	50.00	50.00	50.00	50.00
Avoided Cost (€)	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92
Total Avoided Cost (€)	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.92
Updated Investment (€)	275.69	267.66	259.86	252.29	244.95	0.00					
Updated Total Cost (€)	325.69	316.20	306.99	298.05	289.37	43.13	41.87	40.65	39.47	38.32	37.20
Updated Total Avoided Cost (€)	22.92	22.25	21.60	20.97	20.36	19.77	19.19	18.64	18.09	17.57	17.05
Net Present Value (€)	-302.77	-596.72	-882.11	-1159.18	-1428.19	-1451.55	-1474.23	-1496.25	-1517.63	-1538.38	-1558.53

Linear motion - Upper body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	186.61	186.61	186.61	186.61	186.61	0.00					
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Total Cost (€)	226.61	226.61	226.61	226.61	226.61	40.00	40.00	40.00	40.00	40.00	40.00
Avoided Cost (€)	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49
Total Avoided Cost (€)	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49
Updated Investment (€)	186.61	181.17	175.89	170.77	165.80	0.00					
Updated Total Cost (€)	226.61	220.01	213.60	207.38	201.34	34.50	33.50	32.52	31.58	30.66	29.76
Updated Total Avoided Cost (€)	6.49	6.31	6.12	5.94	5.77	5.60	5.44	5.28	5.13	4.98	4.83
Net Present Value (€)	-220.11	-433.81	-641.29	-842.72	-1038.29	-1067.19	-1095.25	-1122.49	-1148.94	-1174.62	-1199.55

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	462.29	462.29	462.29	462.29	462.29	0.00					
O&M Cost (€)	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Total Cost (€)	552.29	552.29	552.29	552.29	552.29	90.00	90.00	90.00	90.00	90.00	90.00
Avoided Cost (€)	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41
Total Avoided Cost (€)	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41
Updated Investment (€)	462.29	448.83	435.76	423.06	410.74	0.00					
Updated Total Cost (€)	552.29	536.21	520.59	505.43	490.71	77.63	75.37	73.18	71.05	68.98	66.97
Updated Total Avoided Cost (€)	29.41	28.56	27.73	26.92	26.13	25.37	24.63	23.92	23.22	22.54	21.89
Net Present Value (€)	-522.88	-1030.53	-1523.40	-2001.91	-2466.48	-2518.74	-2569.48	-2618.74	-2666.57	-2713.01	-2758.09

Annex XXIII – Plug & Play model for linear motion harvesting in *Arena Club Oeiras*

Linear motion - Lower body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1312.80	0.00									
O&M Cost (€)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Total Cost (€)	1362.80	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Avoided Cost (€)	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07
Total Avoided Cost (€)	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07
Updated Investment (€)	1312.80	0.00									
Updated Total Cost (€)	1362.80	48.54	47.13	45.76	44.42	43.13	41.87	40.65	39.47	38.32	37.20
Updated Total Avoided Cost (€)	51.07	49.59	48.14	46.74	45.38	44.06	42.77	41.53	40.32	39.14	38.00
Net Present Value (€)	-1311.73	-1310.68	-1309.67	-1308.69	-1307.73	-1306.81	-1305.91	-1305.03	-1304.19	-1303.36	-1302.56

Linear motion - Upper body

Year	0	1	2	3	4	5	6	7	8	9
Investment (€)	1332.90	0.00								
O&M Cost (€)	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Total Cost (€)	1392.90	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Avoided Cost (€)	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79
Total Avoided Cost (€)	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79
Updated Investment (€)	1332.90	0.00								
Updated Total Cost (€)	1392.90	58.25	56.56	54.91	53.31	51.76	50.25	48.79	47.36	45.99
Updated Total Avoided Cost (€)	29.79	28.93	28.08	27.27	26.47	25.70	24.95	24.22	23.52	22.83
Net Present Value (€)	-1363.11	-1392.43	-1420.91	-1448.55	-1475.39	-1501.44	-1526.74	-1551.30	-1575.15	-1598.30

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	2645.70	0.00									
O&M Cost (€)	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Total Cost (€)	2755.70	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Avoided Cost (€)	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87
Total Avoided Cost (€)	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87
Updated Investment (€)	2645.70	0.00									
Updated Total Cost (€)	2755.70	106.80	103.69	100.67	97.73	94.89	92.12	89.44	86.84	84.31	81.85
Updated Total Avoided Cost (€)	80.87	78.51	76.23	74.01	71.85	69.76	67.73	65.75	63.84	61.98	60.17
Net Present Value (€)	-2674.83	-2703.12	-2730.58	-2757.24	-2783.12	-2808.25	-2832.65	-2856.34	-2879.33	-2901.66	-2923.34

Annex XXIV – Company Ownership model for linear motion harvesting in *Arena Club Oeiras*

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	2645.70	0.00									
O&M Cost (€)	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Discount of 1% for gym (€)	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30
Total Cost (€)	2820.00	174.30	174.30	174.30	174.30	174.30	174.30	174.30	174.30	174.30	174.30
Earnings from gym (€)	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87
Total Benefit (€)	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87
Updated Investment (€)	2645.70	0.00									
Updated Total Cost (€)	2820	169.23	164.30	159.51	154.87	150.35	145.98	141.72	137.60	133.59	129.70
Updated Total Benefit (€)	80.87	78.51	76.23	74.01	71.85	69.76	67.73	65.75	63.84	61.98	60.17
Net Present Value (€)	-2739.13	-2829.85	-2917.92	-3003.42	-3086.44	-3167.04	-3245.29	-3321.26	-3395.02	-3466.63	-3536.15

Annex XXV – Leasing model for linear motion harvesting in *Arena Club Oeiras*

Linear motion - Lower body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	275.69	275.69	275.69	275.69	275.69	0.00					
O&M Cost (€)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Total Cost (€)	325.69	325.69	325.69	325.69	325.69	50.00	50.00	50.00	50.00	50.00	50.00
Avoided Cost (€)	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07
Total Avoided Cost (€)	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07	51.07
Updated Investment (€)	275.69	267.66	259.86	252.29	244.95	0.00					
Updated Total Cost (€)	325.69	316.20	306.99	298.05	289.37	43.13	41.87	40.65	39.47	38.32	37.20
Updated Total Avoided Cost (€)	51.07	49.59	48.14	46.74	45.38	44.06	42.77	41.53	40.32	39.14	38.00
Net Present Value (€)	-274.61	-541.23	-800.08	-1051.39	-1295.38	-1294.45	-1293.55	-1292.68	-1291.83	-1291.01	-1290.21

Linear motion - Upper body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	279.91	279.91	279.91	279.91	279.91	0.00					
O&M Cost (€)	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Total Cost (€)	339.91	339.91	339.91	339.91	339.91	60.00	60.00	60.00	60.00	60.00	60.00
Avoided Cost (€)	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79
Total Avoided Cost (€)	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79	29.79
Updated Investment (€)	279.91	271.76	263.84	256.16	248.70	0.00					
Updated Total Cost (€)	339.91	330.01	320.40	311.06	302.00	51.76	50.25	48.79	47.36	45.99	44.65
Updated Total Avoided Cost (€)	29.79	28.93	28.08	27.27	26.47	25.70	24.95	24.22	23.52	22.83	22.17
Net Present Value (€)	-310.12	-611.20	-903.51	-1187.31	-1462.85	-1488.90	-1514.20	-1538.76	-1562.61	-1585.76	-1608.23

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	555.60	555.60	555.60	555.60	555.60	0.00					
O&M Cost (€)	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Total Cost (€)	665.60	665.60	665.60	665.60	665.60	110.00	110.00	110.00	110.00	110.00	110.00
Avoided Cost (€)	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87
Total Avoided Cost (€)	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87	80.87
Updated Investment (€)	555.60	539.41	523.70	508.45	493.64	0.00					
Updated Total Cost (€)	665.60	646.21	627.39	609.12	591.37	94.89	92.12	89.44	86.84	84.31	81.85
Updated Total Avoided Cost (€)	80.87	78.51	76.23	74.01	71.85	69.76	67.73	65.75	63.84	61.98	60.17
Net Present Value (€)	-584.73	-1152.43	-1703.59	-2238.70	-2758.23	-2783.36	-2807.76	-2831.44	-2854.44	-2876.77	-2898.45

Annex XXVI – Plug & Play model for linear motion harvesting in *Be-Fit Setúbal*

Linear motion - Lower body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	3150.72	0.00									
O&M Cost (€)	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
Total Cost (€)	3270.72	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
Avoided Cost (€)	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39
Total Avoided Cost (€)	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39
Updated Investment (€)	3150.72	0.00									
Updated Total Cost (€)	3270.72	116.50	113.11	109.82	106.62	103.51	100.50	97.57	94.73	91.97	89.29
Updated Total Avoided Cost (€)	584.39	567.37	550.84	534.80	519.22	504.10	489.42	475.16	461.32	447.89	434.84
Net Present Value (€)	-2686.33	-2235.47	-1797.74	-1372.75	-960.15	-559.56	-170.65	206.94	573.54	929.45	1275.00

Linear motion - Upper body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	3998.70	0.00									
O&M Cost (€)	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00
Total Cost (€)	4178.70	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00
Avoided Cost (€)	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92
Total Avoided Cost (€)	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92
Updated Investment (€)	3998.70	0.00									
Updated Total Cost (€)	4178.70	174.76	169.67	164.73	159.93	155.27	150.75	146.36	142.09	137.96	133.94
Updated Total Avoided Cost (€)	427.92	415.46	403.36	391.61	380.20	369.13	358.38	347.94	337.81	327.97	318.41
Net Present Value (€)	-3750.78	-3510.08	-3276.39	-3049.50	-2829.23	-2615.37	-2407.74	-2206.15	-2010.44	-1820.43	-1635.95

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	7149.42	0.00									
O&M Cost (€)	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00
Total Cost (€)	7449.42	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00
Avoided Cost (€)	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31
Total Avoided Cost (€)	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31
Updated Investment (€)	7149.42	0.00									
Updated Total Cost (€)	7449.42	291.26	282.78	274.54	266.55	258.78	251.25	243.93	236.82	229.93	223.23
Updated Total Avoided Cost (€)	1012.31	982.83	954.20	926.41	899.43	873.23	847.79	823.10	799.13	775.85	753.25
Net Present Value (€)	-6437.11	-5745.54	-5074.12	-4422.26	-3789.38	-3174.93	-2578.38	-1999.21	-1436.90	-890.98	-360.95

Annex XXVII – Company Ownership model for linear motion harvesting in *Be-Fit Setúbal*

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	7149.42	0.00									
O&M Cost (€)	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00
Discount of 1% for gym (€)	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82
Total Cost (€)	7746.24	596.82	596.82	596.82	596.82	596.82	596.82	596.82	596.82	596.82	596.82
Earnings from gym (€)	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31
Total Benefit (€)	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31
Updated Investment (€)	7149.42	0.00									
Updated Total Cost (€)	7746.00	579.44	562.56	546.17	530.27	514.82	499.83	485.27	471.14	457.41	444.09
Updated Total Benefit (€)	1012.31	982.83	954.20	926.41	899.43	873.23	847.79	823.10	799.13	775.85	753.25
Net Present Value (€)	-6733.93	-6330.54	-5938.90	-5558.67	-5189.51	-4831.10	-4483.13	-4145.30	-3817.31	-3498.87	-3189.70

Annex XXVIII – Leasing model for linear motion harvesting in *Be-Fit Setúbal*

Linear motion - Lower body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	661.65	661.65	661.65	661.65	661.65	0.00					
O&M Cost (€)	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
Total Cost (€)	781.65	781.65	781.65	781.65	781.65	120.00	120.00	120.00	120.00	120.00	120.00
Avoided Cost (€)	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39
Total Avoided Cost (€)	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39	584.39
Updated Investment (€)	661.65	642.38	623.67	605.50	587.87	0.00					
Updated Total Cost (€)	781.65	758.88	736.78	715.32	694.49	103.51	100.50	97.57	94.73	91.97	89.29
Updated Total Avoided Cost (€)	584.39	567.37	550.84	534.80	519.22	504.10	489.42	475.16	461.32	447.89	434.84
Net Present Value (€)	-197.26	-388.78	-574.72	-755.24	-930.50	-529.92	-141.00	236.59	603.18	959.10	1304.65

Linear motion - Upper body

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	839.73	839.73	839.73	839.73	839.73	0.00					
O&M Cost (€)	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00
Total Cost (€)	1019.73	1019.73	1019.73	1019.73	1019.73	180.00	180.00	180.00	180.00	180.00	180.00
Avoided Cost (€)	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92
Total Avoided Cost (€)	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92	427.92
Updated Investment (€)	839.73	815.27	791.52	768.47	746.09	0.00					
Updated Total Cost (€)	1019.73	990.03	961.19	933.19	906.01	155.27	150.75	146.36	142.09	137.96	133.94
Updated Total Avoided Cost (€)	427.92	415.46	403.36	391.61	380.20	369.13	358.38	347.94	337.81	327.97	318.41
Net Present Value (€)	-591.80	-1166.37	-1724.21	-2265.79	-2791.60	-2577.74	-2370.11	-2168.53	-1972.82	-1782.80	-1598.33

Linear motion - Total

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1501.38	1501.38	1501.38	1501.38	1501.38	0.00					
O&M Cost (€)	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00
Total Cost (€)	1801.38	1801.38	1801.38	1801.38	1801.38	300.00	300.00	300.00	300.00	300.00	300.00
Avoided Cost (€)	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31
Total Avoided Cost (€)	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31	1012.31
Updated Investment (€)	1501.38	1457.65	1415.19	1373.97	1333.96	0.00					
Updated Total Cost (€)	1801.38	1748.91	1697.97	1648.52	1600.50	258.78	251.25	243.93	236.82	229.93	223.23
Updated Total Avoided Cost (€)	1012.31	982.83	954.20	926.41	899.43	873.23	847.79	823.10	799.13	775.85	753.25
Net Present Value (€)	-789.07	-1555.15	-2298.92	-3021.03	-3722.11	-3107.66	-2511.11	-1931.94	-1369.63	-823.70	-293.68

Annex XXIX – Plug & Play model for rotary motion harvesting in *Feelgood*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1500.36	0.00									
O&M Cost (€)	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Total Cost (€)	1560.36	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Avoided Cost (€)	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93
Total Avoided Cost (€)	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93
Updated Investment (€)	1500.36	0.00									
Updated Total Cost (€)	1560.36	58.25	56.56	54.91	53.31	51.76	50.25	48.79	47.36	45.99	44.65
Updated Total Avoided Cost (€)	200.93	195.08	189.40	183.88	178.52	173.32	168.28	163.38	158.62	154.00	149.51
Net Present Value (€)	-1359.43	-1222.60	-1089.76	-960.79	-835.58	-714.01	-595.98	-481.39	-370.14	-262.13	-157.26

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	930.54	0.00									
O&M Cost (€)	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Total Cost (€)	990.54	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Avoided Cost (€)	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27
Total Avoided Cost (€)	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27
Updated Investment (€)	930.54	0.00									
Updated Total Cost (€)	990.54	58.25	56.56	54.91	53.31	51.76	50.25	48.79	47.36	45.99	44.65
Updated Total Avoided Cost (€)	119.27	115.80	112.42	109.15	105.97	102.88	99.89	96.98	94.15	91.41	88.75
Net Present Value (€)	-871.27	-813.73	-757.86	-703.62	-650.96	-599.84	-550.20	-502.01	-455.22	-409.79	-365.69

Annex XXX – Company Ownership model for rotary motion harvesting in *Feelgood*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1500.36	0.00									
O&M Cost (€)	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Discount of 1% for gym (€)	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37
Total Cost (€)	1578.732	78.372	78.372	78.372	78.372	78.372	78.372	78.372	78.372	78.372	78.372
Earnings from gym (€)	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93
Total Benefit (€)	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93
Updated Investment (€)	1500.36	0.00									
Updated Total Cost (€)	1578.73	76.09	73.87	71.72	69.63	67.60	65.64	63.72	61.87	60.07	58.32
Updated Total Benefit (€)	200.93	195.08	189.40	183.88	178.52	173.32	168.28	163.38	158.62	154.00	149.51
Net Present Value (€)	-1377.80	-1258.81	-1143.29	-1031.13	-922.24	-816.52	-713.88	-614.22	-517.48	-423.54	-332.35

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	930.54	0.00									
O&M Cost (€)	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Discount of 1% for gym (€)	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37	18.37
Total Cost (€)	1008.91	78.37	78.37	78.37	78.37	78.37	78.37	78.37	78.37	78.37	78.37
Earnings from gym (€)	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27
Total Benefit (€)	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27
Updated Investment (€)	930.54	0.00									
Updated Total Cost (€)	1008.91	76.09	73.87	71.72	69.63	67.60	65.64	63.72	61.87	60.07	58.32
Updated Total Benefit (€)	119.27	115.80	112.42	109.15	105.97	102.88	99.89	96.98	94.15	91.41	88.75
Net Present Value (€)	-889.64	-849.94	-811.39	-773.96	-737.62	-702.35	-668.10	-634.84	-602.56	-571.21	-540.78

Annex XXXI – Leasing model for rotary motion harvesting in *Feelgood*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	315.08	315.08	315.08	315.08	315.08	0.00					
O&M Cost (€)	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Total Cost (€)	375.08	375.08	375.08	375.08	375.08	60.00	60.00	60.00	60.00	60.00	60.00
Avoided Cost (€)	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93
Total Avoided Cost (€)	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93	200.93
Updated Investment (€)	315.08	305.90	296.99	288.34	279.94	0.00					
Updated Total Cost (€)	375.08	364.15	353.54	343.25	333.25	51.76	50.25	48.79	47.36	45.99	44.65
Updated Total Avoided Cost (€)	200.93	195.08	189.40	183.88	178.52	173.32	168.28	163.38	158.62	154.00	149.51
Net Present Value (€)	-174.14	-343.22	-507.37	-666.73	-821.46	-699.89	-581.86	-467.27	-356.02	-248.01	-143.14

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	195.41	195.41	195.41	195.41	195.41	0.00					
O&M Cost (€)	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Total Cost (€)	255.41	255.41	255.41	255.41	255.41	60.00	60.00	60.00	60.00	60.00	60.00
Avoided Cost (€)	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27
Total Avoided Cost (€)	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27	119.27
Updated Investment (€)	195.41	189.72	184.20	178.83	173.62	0.00					
Updated Total Cost (€)	255.41	247.97	240.75	233.74	226.93	51.76	50.25	48.79	47.36	45.99	44.65
Updated Total Avoided Cost (€)	119.27	115.80	112.42	109.15	105.97	102.88	99.89	96.98	94.15	91.41	88.75
Net Present Value (€)	-136.14	-268.32	-396.65	-521.24	-642.21	-591.08	-541.44	-493.25	-446.46	-401.04	-356.94

Annex XXXII – Plug & Play model for rotary motion harvesting in *Be Gym Fit*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1760.00	0.00									
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Total Cost (€)	1800.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Avoided Cost (€)	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70
Total Avoided Cost (€)	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70
Updated Investment (€)	1760.00	0.00									
Updated Total Cost (€)	1800.00	38.83	37.70	36.61	35.54	34.50	33.50	32.52	31.58	30.66	29.76
Updated Total Avoided Cost (€)	123.70	120.10	116.60	113.21	109.91	106.71	103.60	100.58	97.65	94.81	92.05
Net Present Value (€)	-1676.30	-1595.03	-1516.13	-1439.53	-1365.16	-1292.95	-1222.85	-1154.79	-1088.71	-1024.56	-962.28

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	620.36	0.00									
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Total Cost (€)	660.36	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Avoided Cost (€)	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43
Total Avoided Cost (€)	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43
Updated Investment (€)	620.36	0.00									
Updated Total Cost (€)	660.36	38.83	37.70	36.61	35.54	34.50	33.50	32.52	31.58	30.66	29.76
Updated Total Avoided Cost (€)	36.43	35.37	34.34	33.34	32.36	31.42	30.51	29.62	28.76	27.92	27.10
Net Present Value (€)	-623.93	-627.40	-630.77	-634.04	-637.22	-640.30	-643.29	-646.20	-649.02	-651.76	-654.42

Annex XXXIII – Company Ownership model for rotary motion harvesting in *Be Gym Fit*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1760.00	0.00									
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Discount of 1% for gym (€)	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72
Total Cost (€)	1825.72	65.72	65.72	65.72	65.72	65.72	65.72	65.72	65.72	65.72	65.72
Earnings from gym (€)	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70
Total Benefit (€)	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70
Updated Investment (€)	1760.00	0.00									
Updated Total Cost (€)	1825.72	63.81	61.95	60.14	58.39	56.69	55.04	53.44	51.88	50.37	48.90
Updated Total Benefit (€)	123.70	120.10	116.60	113.21	109.91	106.71	103.60	100.58	97.65	94.81	92.05
Net Present Value (€)	-1702.02	-1645.72	-1591.07	-1538.00	-1486.48	-1436.47	-1387.91	-1340.76	-1294.99	-1250.55	-1207.40

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	620.36	0.00									
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Discount of 1% for gym (€)	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72	25.72
Total Cost (€)	686.08	65.72	65.72	65.72	65.72	65.72	65.72	65.72	65.72	65.72	65.72
Earnings from gym (€)	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43
Total Benefit (€)	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43
Updated Investment (€)	620.36	0.00									
Updated Total Cost (€)	686.08	63.81	61.95	60.14	58.39	56.69	55.04	53.44	51.88	50.37	48.90
Updated Total Benefit (€)	36.43	35.37	34.34	33.34	32.36	31.42	30.51	29.62	28.76	27.92	27.10
Net Present Value (€)	-649.65	-678.10	-705.71	-732.52	-758.55	-783.82	-808.35	-832.17	-855.29	-877.75	-899.54

Annex XXXIV – Leasing model for rotary motion harvesting in *Be Gym Fit*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	369.60	369.60	369.60	369.60	369.60	0.00					
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Total Cost (€)	409.60	409.60	409.60	409.60	409.60	40.00	40.00	40.00	40.00	40.00	40.00
Avoided Cost (€)	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70
Total Avoided Cost (€)	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70	123.70
Updated Investment (€)	369.60	358.83	348.38	338.24	328.38	0.00					
Updated Total Cost (€)	409.60	397.67	386.09	374.84	363.92	34.50	33.50	32.52	31.58	30.66	29.76
Updated Total Avoided Cost (€)	123.70	120.10	116.60	113.21	109.91	106.71	103.60	100.58	97.65	94.81	92.05
Net Present Value (€)	-285.90	-563.46	-832.95	-1094.58	-1348.60	-1276.39	-1206.29	-1138.23	-1072.15	-1008.00	-945.72

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	130.28	130.28	130.28	130.28	130.28	0.00					
O&M Cost (€)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Total Cost (€)	170.28	170.28	170.28	170.28	170.28	40.00	40.00	40.00	40.00	40.00	40.00
Avoided Cost (€)	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43
Total Avoided Cost (€)	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43	36.43
Updated Investment (€)	130.28	126.48	122.80	119.22	115.75	0.00					
Updated Total Cost (€)	170.28	165.32	160.50	155.83	151.29	34.50	33.50	32.52	31.58	30.66	29.76
Updated Total Avoided Cost (€)	36.43	35.37	34.34	33.34	32.36	31.42	30.51	29.62	28.76	27.92	27.10
Net Present Value (€)	-133.85	-263.80	-389.97	-512.46	-631.38	-634.46	-637.46	-640.36	-643.18	-645.92	-648.58

Annex XXXV – Plug & Play model for rotary motion harvesting for *Arena Club Oeiras*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	2380.36	0.00									
O&M Cost (€)	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Total Cost (€)	2460.36	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Avoided Cost (€)	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80
Total Avoided Cost (€)	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80
Updated Investment (€)	2380.36	0.00									
Updated Total Cost (€)	2460.36	77.67	75.41	73.21	71.08	69.01	67.00	65.05	63.15	61.31	59.53
Updated Total Avoided Cost (€)	465.80	452.23	439.06	426.27	413.85	401.80	390.10	378.74	367.70	356.99	346.60
Net Present Value (€)	-1994.56	-1620.00	-1256.35	-903.30	-560.52	-227.73	95.37	409.06	713.61	1009.29	1296.36

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1240.72	0.00									
O&M Cost (€)	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Total Cost (€)	1320.72	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Avoided Cost (€)	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56
Total Avoided Cost (€)	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56
Updated Investment (€)	1240.72	0.00									
Updated Total Cost (€)	1320.72	77.67	75.41	73.21	71.08	69.01	67.00	65.05	63.15	61.31	59.53
Updated Total Avoided Cost (€)	225.56	218.99	212.62	206.42	200.41	194.57	188.91	183.40	178.06	172.88	167.84
Net Present Value (€)	-1095.16	-953.83	-816.62	-683.41	-554.08	-428.52	-306.61	-188.25	-73.34	38.22	146.53

Annex XXXVI – Company Ownership model for rotary motion harvesting in *Arena Club Oeiras*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	2380.36	0.00									
O&M Cost (€)	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Discount of 1% for gym (€)	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30
Total Cost (€)	2524.662	144.302	144.302	144.302	144.302	144.302	144.302	144.302	144.302	144.302	144.302
Earnings from gym (€)	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80
Total Benefit (€)	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80
Updated Investment (€)	2380.36	0.00									
Updated Total Cost (€)	2524.66	140.10	136.02	132.06	128.21	124.48	120.85	117.33	113.91	110.60	107.37
Updated Total Benefit (€)	465.80	452.23	439.06	426.27	413.85	401.80	390.10	378.74	367.70	356.99	346.60
Net Present Value (€)	-2058.87	-1746.74	-1443.70	-1149.48	-863.84	-586.52	-317.27	-55.86	197.93	444.32	683.55

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1240.72	0.00									
O&M Cost (€)	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Discount of 1% for gym (€)	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30	64.30
Total Cost (€)	1385.02	144.30	144.30	144.30	144.30	144.30	144.30	144.30	144.30	144.30	144.30
Earnings from gym (€)	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56
Total Benefit (€)	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56
Updated Investment (€)	1240.72	0.00									
Updated Total Cost (€)	1385.02	140.10	136.02	132.06	128.21	124.48	120.85	117.33	113.91	110.60	107.37
Updated Total Benefit (€)	225.56	218.99	212.62	206.42	200.41	194.57	188.91	183.40	178.06	172.88	167.84
Net Present Value (€)	-1159.46	-1080.56	-1003.97	-929.60	-857.40	-787.30	-719.25	-653.17	-589.02	-526.74	-466.28

Annex XXXVII – Leasing model for rotary motion harvesting in *Arena Club Oeiras*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	499.88	499.88	499.88	499.88	499.88	0.00					
O&M Cost (€)	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Total Cost (€)	579.88	579.88	579.88	579.88	579.88	80.00	80.00	80.00	80.00	80.00	80.00
Avoided Cost (€)	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80
Total Avoided Cost (€)	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80	465.80
Updated Investment (€)	499.88	485.32	471.18	457.46	444.13	0.00					
Updated Total Cost (€)	579.88	562.99	546.59	530.67	515.21	69.01	67.00	65.05	63.15	61.31	59.53
Updated Total Avoided Cost (€)	465.80	452.23	439.06	426.27	413.85	401.80	390.10	378.74	367.70	356.99	346.60
Net Present Value (€)	-114.08	-224.84	-332.37	-436.77	-538.12	-205.33	117.77	431.45	736.01	1031.69	1318.75

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	260.55	260.55	260.55	260.55	260.55	0.00					
O&M Cost (€)	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Total Cost (€)	340.55	340.55	340.55	340.55	340.55	80.00	80.00	80.00	80.00	80.00	80.00
Avoided Cost (€)	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56
Total Avoided Cost (€)	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56	225.56
Updated Investment (€)	260.55	252.96	245.59	238.44	231.50	0.00					
Updated Total Cost (€)	340.55	330.63	321.00	311.65	302.58	69.01	67.00	65.05	63.15	61.31	59.53
Updated Total Avoided Cost (€)	225.56	218.99	212.62	206.42	200.41	194.57	188.91	183.40	178.06	172.88	167.84
Net Present Value (€)	-114.99	-226.63	-335.01	-440.24	-542.41	-416.84	-294.93	-176.58	-61.67	49.89	158.21

Annex XXXVIII – Plug & Play model for rotary motion harvesting in *Be-Fit Setúbal*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	5301.80	0.00									
O&M Cost (€)	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Total Cost (€)	5551.80	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Avoided Cost (€)	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49
Total Avoided Cost (€)	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49
Updated Investment (€)	5301.80	0.00									
Updated Total Cost (€)	5551.80	242.72	235.65	228.79	222.12	215.65	209.37	203.27	197.35	191.60	186.02
Updated Total Avoided Cost (€)	1311.49	1273.29	1236.21	1200.20	1165.24	1131.30	1098.35	1066.36	1035.30	1005.15	975.87
Net Present Value (€)	-4240.31	-3209.74	-2209.18	-1237.77	-294.64	621.01	1509.99	2373.08	3211.03	4024.57	4814.42

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	3877.25	0.00									
O&M Cost (€)	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Total Cost (€)	4127.25	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Avoided Cost (€)	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23
Total Avoided Cost (€)	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23
Updated Investment (€)	3877.25	0.00									
Updated Total Cost (€)	4127.25	242.72	235.65	228.79	222.12	215.65	209.37	203.27	197.35	191.60	186.02
Updated Total Avoided Cost (€)	1046.23	1015.75	986.17	957.45	929.56	902.48	876.20	850.68	825.90	801.85	778.49
Net Present Value (€)	-3081.02	-2307.99	-1557.47	-828.81	-121.37	565.47	1232.29	1879.70	2508.25	3118.49	3710.96

Annex XXXIX – Company Ownership model for rotary motion harvesting in *Be-Fit Setúbal*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	5301.80	0.00									
O&M Cost (€)	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Discount of 1% for gym (€)	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82
Total Cost (€)	5848.62	546.82	546.82	546.82	546.82	546.82	546.82	546.82	546.82	546.82	546.82
Earnings from gym (€)	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49
Total Benefit (€)	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49
Updated Investment (€)	5301.80	0.00									
Updated Total Cost (€)	5848.62	530.89	515.43	500.42	485.84	471.69	457.95	444.61	431.66	419.09	406.89
Updated Total Benefit (€)	1311.49	1273.29	1236.21	1200.20	1165.24	1131.30	1098.35	1066.36	1035.30	1005.15	975.87
Net Present Value (€)	-4537.13	-3794.73	-3073.96	-2374.17	-1694.77	-1035.16	-394.76	226.98	830.62	1416.68	1985.67

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	3877.25	0.00									
O&M Cost (€)	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Discount of 1% for gym (€)	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82	296.82
Total Cost (€)	4424.07	546.82	546.82	546.82	546.82	546.82	546.82	546.82	546.82	546.82	546.82
Earnings from gym (€)	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23
Total Benefit (€)	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23
Updated Investment (€)	3877.25	0.00									
Updated Total Cost (€)	4424.07	530.89	515.43	500.42	485.84	471.69	457.95	444.61	431.66	419.09	406.89
Updated Total Benefit (€)	1046.23	1015.75	986.17	957.45	929.56	902.48	876.20	850.68	825.90	801.85	778.49
Net Present Value (€)	-3377.84	-2892.98	-2422.24	-1965.21	-1521.50	-1090.70	-672.46	-266.39	127.84	510.60	882.20

Annex XL – Leasing model for rotary motion harvesting in *Be-Fit Setúbal*

Scenario 1

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	1113.38	1113.38	1113.38	1113.38	1113.38	0.00					
O&M Cost (€)	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Total Cost (€)	1363.38	1363.38	1363.38	1363.38	1363.38	250.00	250.00	250.00	250.00	250.00	250.00
Avoided Cost (€)	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49
Total Avoided Cost (€)	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49	1311.49
Updated Investment (€)	1113.38	1080.95	1049.47	1018.90	989.22	0.00					
Updated Total Cost (€)	1363.38	1323.67	1285.11	1247.68	1211.34	215.65	209.37	203.27	197.35	191.60	186.02
Updated Total Avoided Cost (€)	1311.49	1273.29	1236.21	1200.20	1165.24	1131.30	1098.35	1066.36	1035.30	1005.15	975.87
Net Present Value (€)	-51.89	-102.26	-151.17	-198.66	-244.76	670.89	1559.87	2422.96	3260.91	4074.46	4864.31

Scenario 2

Year	0	1	2	3	4	5	6	7	8	9	10
Investment (€)	814.22	814.22	814.22	814.22	814.22	0.00					
O&M Cost (€)	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Total Cost (€)	1064.22	1064.22	1064.22	1064.22	1064.22	250.00	250.00	250.00	250.00	250.00	250.00
Avoided Cost (€)	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23
Total Avoided Cost (€)	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23	1046.23
Updated Investment (€)	814.22	790.51	767.48	745.13	723.43	0.00					
Updated Total Cost (€)	1064.22	1033.23	1003.13	973.91	945.55	215.65	209.37	203.27	197.35	191.60	186.02
Updated Total Avoided Cost (€)	1046.23	1015.75	986.17	957.45	929.56	902.48	876.20	850.68	825.90	801.85	778.49
Net Present Value (€)	-18.00	-35.47	-52.43	-68.90	-84.89	601.95	1268.78	1916.18	2544.73	3154.97	3747.44