Tampere University of Applied Sciences

Energy Harvesting from Human Motion in Smart Cities

An Alternative Renewable Energy Source

Sandhya Thyagaraj Naidu

BACHELOR'S THESIS
June 2021

Energy and Environmental Engineering

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Energy and Environmental Engineering

Sandhya Thyagaraj Naidu
Energy Harvesting from Human Motion in Smart Cities
An Alternative Renewable Energy Source

Bachelor's thesis 45 pages
June 2021

The purpose of the thesis was to study human motion-based energy harvesting through the literature review resulting in integrating as a renewable energy source within a smart city. The study aimed to examine equipment and applications in the market to convert human motion into energy and find locations to install within a smart city. Energy harvesting from human motion is a renewable and sustainable energy source. Human energy harvesting technology converts kinetic energy from human body movements to electricity. The smart city is a concept to define an urban area using information and communication technology as a solution to solve the city's human, social, economic, and environmental issues.

The theoretical framework was to examine energy harvesting from human motion and the smart city concepts. It includes identified everyday common human activities examples and human motion-based energy harvesting types of equipment in the market. It also covers the need for a smart city, the smart city framework program, and smart energy management initiatives. A literature review identified kids playground energy equipment in public parks, fitness energy equipment in gyms, and human walking flooring equipment in crowded areas to incorporate into a smart city. Besides, a modified cost-benefit analysis was designed and applied to assess the proposed energy harvesting solutions from human motions. It includes the evaluation of financial analysis parameters. The Financial analysis was quantitatively evaluated by computing expenditure costs, electricity generated, and revenues.

The empirical study results indicate environmental reduction costs were zero, integrating costs were minimal, implementation and environmental risks are low but lesser revenues, and investment payback durations will be high. Energy harvesting from human energy fits with the concept of smart cities because it uses urban problems with high human populations to tackle energy shortages while still meeting smart energy initiatives. Therefore, deploying a human motion-based energy harvesting source is a feasible option comparable to existing renewable energy alternatives in terms of environmental, indirect social, and economic benefits in the framework of a smart city.

Key words: energy harvesting, human motion, smart city, cost benefit analysis

CONTENTS

ABBREVIATIONS

AI	Artificial Intelligence
AC	alternating current.
CBA	Cost Benefit Analysis
CCTV	Closed Circuit Television
DC	Direct Current
DIY	Do It Yourself
EU	European Union
GDP	Gross Domestic Product
GHG	Green House Gases
TAMK	Tampere University of Applied Sciences
IBM	International Business Machines Corporation
ICT	Information and Communication Technology
IT	Information Technology
ISO	International Organization for Standardization
R&D	Research and Development
RPM	Revolutions Per Minute
STES	Seasonal Thermal Energy Storage
UK	United Kingdom
USA	United States of America
VEH	Vibrational Energy Harvesting

1 INTRODUCTION

Harvesting energy from human motion has been used for decades, and probably the most known application is a bicycle dynamo (Dervojeda,2014). Energy harvesting by human movements is a renewable and sustainable energy source. The thermal energy from the human body and kinetic energy from human body movements can be converted to electricity using the latest human energy harvesting technology. Energy harvesting from human motion is one of the recent innovations under rapid development (Invernizzi 2016,1). Everyday human physical activities which can be used to harvest energy are kids play activities in the park, exercise activities in the gym, walking, biking, and jogging.

The term smart city is one of the rapidly trending topics in modern urban sustainability and urban management. According to Gassmann (2019,25), the smart city is defined based on technology as "A smart city systematically applies digital technologies to reduce resource input, improve its people's quality of life, and increase the competitiveness of the regional economy sustainably. It entails the use of intelligent solutions for infrastructure, energy, housing, mobility, services, and security, based on integrated sensor technology, connectivity, data analytics, and independently functional value-added processes." (Gassmann 2019, 25.) Smart energy is a smart city energy management approach used to transform cities into smart cities in smart city projects.

The thesis's purpose was to study human energy as a renewable energy source in smart cities. In addition, it examined available applications and equipment for harvesting energy from humans in various day-to-day activities and ways to integrate into the smart city using smart energy initiatives.

The research questions of the thesis were:

- Which are the best applications and equipment in the market to harvest energy from human movements?
- Where should the equipment be placed so that residents may utilize it suitably and efficiently?
- What are the financial risks of human energy harvesting?

- How would the harvesting of human energy fit into the concept of smart cities?

The research study of the thesis was to focus on energy harvesting from the kinetic energy of human body movements as an alternative renewable energy in the context of smart cities. Now energy generated by human activities is in the innovation stage can be used as smart energy-generating technology by using the people as a resource available in abundant in cities. The energy harvesting from human body movements was evaluated in this thesis for usage as an alternative renewable energy source in a smart city through a literature study. The scientific articles, academic publications, trusted energy-related, and news websites are sources for the literature review study.

2 THEORETICAL AND CONCEPTUAL FRAMEWORK

2.1 Energy Harvesting from Human Motion

The chapter introduces the human motions, physics principles, systems, equipment, and products in the market used to harvest energy.

2.1.1 Examples of Energy Harvesting Human Motions

Humans perform different body motions during daily activities, namely active motion, and passive motion, that can be converted to energy (Invernizzi 2016,1). Active motions require them to perform voluntary action that generates energy (Invernizzi 2016,1), for example: pressing spring, kids playing, fitness exercise. Passive motion of a human is normal daily activities performed by a person, for example: walking. Examples of Human motions during daily activities used for energy production shown in TABLE 1.

TABLE 1. Examples Energy Harvesting Human activities

Human Activity	Motion Type	Description
Walking	Passive	Humans walk in the public area in multiple locations, which can be converted into energy by installing energy harvest equipment installed at identified Highly crowded locations in cities.
Physical exercise	Active	The energy from humans performing physical exercises in gymnasium regularly to be healthy is harvested and converted into electricity.
Kids Play	Active	Kids are usually very active and spend much time in public and residential area parks, which can be used to harvest energy.

2.1.2 Energy Harvesting System and Conversion principle

FIGURE 1 shows the basic human motion-based energy harvesting system, where basic technical units convert mechanical energy or kinetic energy from human motion to Electrical energy. In FIGURE 1, the human motion creating oscillations, circular motion, or elastic motion is converted to mechanical energy. Next, the energy convertor unit converts the mechanical energy created by human body movements to electricity. Additional power conditioning and energy storage circuits are needed to provide stable power output for various electrical loads usage and requirements. Finally, converted electricity conditioned to required voltage levels and stored with a power control option to provide stable electrical output to electrical loads. (Zhou 2018,3582-3583.)

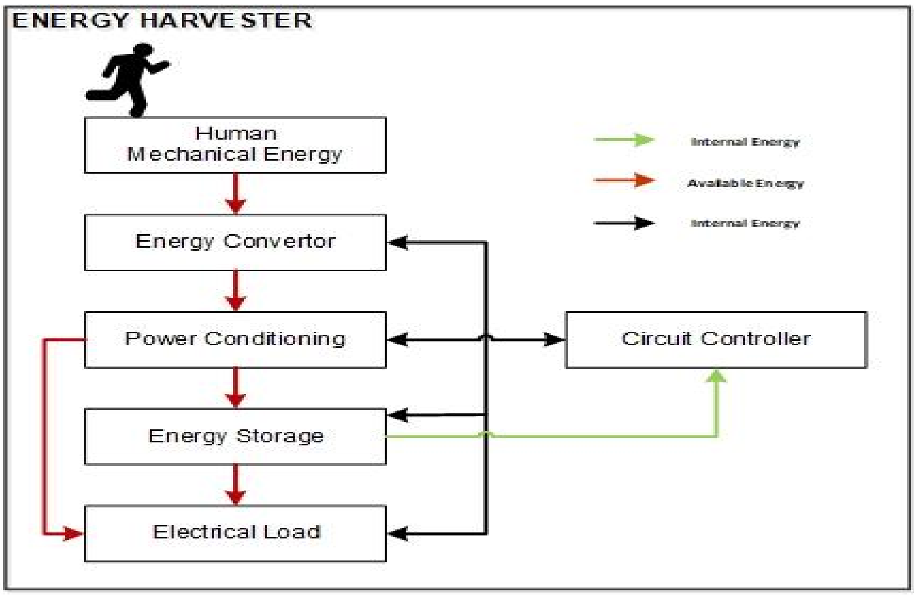

FIGURE 1. Basic System to Harvest Energy from Human Motion (Zhou 2018, modified).

The mechanical energy from human motion is divided into kinetic energy due to human body motion and elastic energy due to elastic deformation created by human motion (Zhou 2018,3590). According to energy conversion mechanisms and basic principles of physics, the energy harvesting devices used to harvest energy from human motion are presented in TABLE 2.

TABLE 2. Different energy harvesters based on conversion principles.

Energy harvester principles	Basic energy harvesting principal details
Electromagnetic	Based on Faraday's law of induction, the electromagnetic harvester generates an electromotive force and thus energy when the permanent magnet relatively moves through the coil. (Jintanawan 2019,2.)
Electrostatic	The electrostatic energy harvesters are based on the current generated due to variable capacitance induced by mechanical vibration due to human motion. (Zhou 2018,3590).
Piezoelectric	The piezoelectric generator produces an electrical charge and energy when given material deformed under mechanical stress (Jintanawan 2019,2)
Triboelectric	Triboelectric energy harvesters based on the electrification of a given material when it comes into frictional contact with a different material (Zhou 2018,3598)

2.2 Human Motion Based Energy Harvesting Applications

The chapter presents the equipment used to harvest energy from motions presented in TABLE 1, kids' playground equipment's fitness equipment, and walking Footstep equipment. The chapter also includes introducing the common types in each classified category.

2.2.1 Energy Harvesting Kids Playground Toys

Studies show kids are usually very active and have unlimited physical energy spending it in playgrounds by playing with swing, See-Saw, merry-go-round, and other types of equipment. In recent years, there are many innovative developments to convert human power into electricity, particularly in outdoor play activities of children. For example, on many playgrounds, the kinetic energy produced by children spinning merry-go-rounds, oscillating swings, or powering see-saws may be converted to electrical energy using cutting-edge technology. FIGURE 2 presents the most popular types of kid's outdoor toys that can be placed or interfaced with energy harvesters in kid's parks.

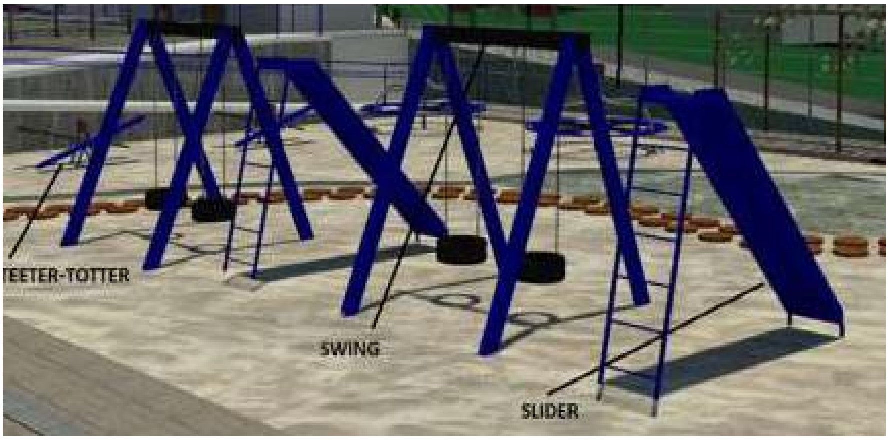

FIGURE 2. Kids Play Park Toys (Carvalho 2013).

Generally, in kids' energy harvesting system, one end of a mechanical system is coupled to the kid's playground toys and another end to electrical generators and electric storage equipment (Carvalho 2013,1028).TABLE 3 explains the mechanisms which allow its movements to be adapted to start electrical generators using mechanical axle by coupling to commonly installed kids' playground equipment.

TABLE 3.Mechanism to harvest energy from kids play equipment.

Playground Toy	Energy Harvesting system and Kids Play Equipment Interface
Swing	The energy harvesting swing shown in FIGURE 3 has a moveable axle that turns with the swing movement is connected to the electrical generator. When kids swing, the moveable axle starts an electric generator (Carvalho 2013,1029).
See-Saw. /Tee-Totter	The energy harvesting Tee-totter in FIGURE 3 shows in the middle of its board, a stuck axle swings movement connects to an electrical converter and drives a generator. (Carvalho 2013,1029.)

Merry-Go-Round	The energy harvesting Merry-Go-Round shown in FIGURE 3 has a middle axle that spins with the rotation is connected to the electrical converter. This axle transfers movement to an electrical generator through a concentric gear. (Carvalho 2013,1029.)
Slider	The slider shown FIGURE 3 has a matting that rolls when a child goes down with it, triggering two internal axles linked up with two electrical generators (Carvalho 2013, 1029).

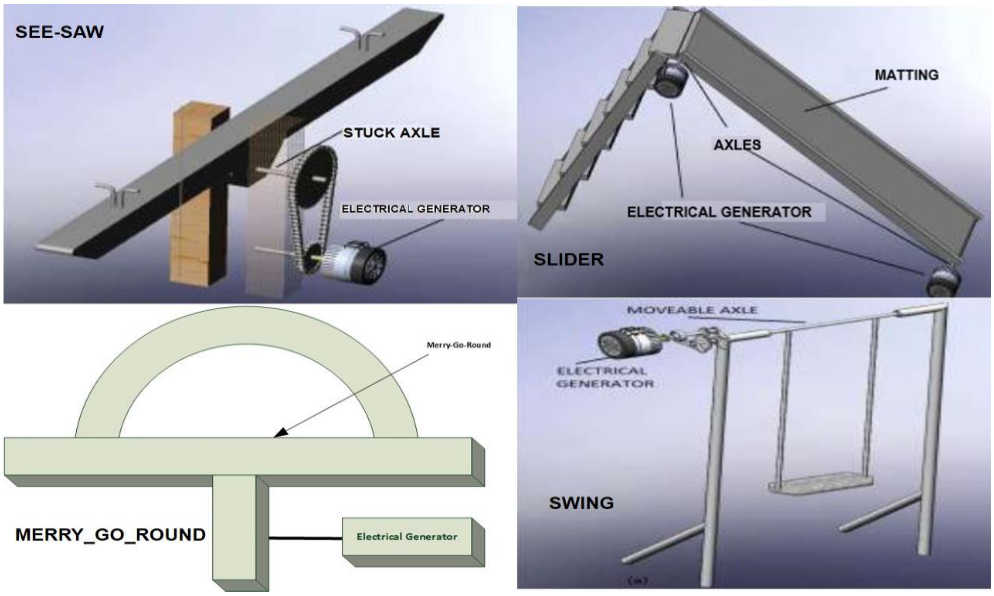

FIGURE 3. Energy harvesting Kids Play Equipment’s (Khan 2017; Carvalho 2013)

The mechanical systems of kid's activity toys drive the connected electrical generator and, in turn, are connected to a voltage-controlled power conditioner and a storage medium with power control options. The stored power can be distributed and utilized by electrical appliances and light.

2.2.2 Energy Harvesting Gym Equipment

Nowadays, physical activity is a vital part of a daily human routine for staying fit and healthy. Humans stay physically fit by using various workout equipment in various places, such as indoor and outdoor gyms. In recent decades, there are several developments of fitness equipment to convert lost human power into electrical energy.

TABLE 4. Energy Harvesting Fitness Equipment

Fitness Equipment	Description
Energy Conversion Kits	The existing gymnasium is converted into the green gym by connecting energy generating equipment's which converts mechanical energy to electrical energy (Chalermthai 2015,1).
Treadmill	A human-powered treadmill converts kinetic energy to potential energy exerted to turn a belt is transferred to an electrical generator into a power booster that is stored in a battery or contributed to the power grid. (Chalermthai 2015,1)
Elliptical machines	Human-powered elliptical machines consist of stair steppers to walk or run. During elliptical machines operations, the kinetic energy from the workout generates DC. ReRev™ technology converts DC into AC and then feeds the current into the power grid of the building electrical system (Chalermthai 2015,1).
Stationary Bike	Energy harvesting stationary bike is a bicycle and belt that connects the flywheel to the generator, spins at something like 1500 RPM (Gibson 2011, 54). The energy generator feeds electricity into a power booster that is stored in the battery or contributed to the power grid.
Rowing Machine	The energy harvesting rowing machine is like a rowing boat where the movement flywheel is connected to the generator to convert to electrical energy. Output electric current (AC) is fed to the power grid or output current (DC) stored to the battery.

Using human energy converting technologies, workouts at fitness centres are generating electricity and contributing to power grids. Additionally, fitness equipment is modified to contribute to generating electricity to a power grid. Most standard fitness equipment's and conversion equipment used to harvest energy from human workout-based research study is discussed in TABLE 4.

2.2.3 Walking Footstep Energy Equipment

Energy harvesting from human walking motion is currently an innovative energy harvester application. Everyday walking is the passive motion of humans. Thousands of people's footsteps kinetic energy transformed into electrical energy for further use using an inexpensive vibration energy harvesting (VEH) device. (Jintanawan 2019,2). There are various methods to harvest energy from people walking, like energy storage shoes and energy flooring (Jintanawan 2019,2). However, the best method to harvest maximum energy installed in the smart city is smart flooring. In smart flooring efficient VEH floor is embedded with an electricity generator.

FIGURE 4. Kinetic energy flooring equipment's (Jintanawan 2019)

Vibrational energy harvesting is the principle that converts the kinetic energy created due to humans walking into electrical energy. There are two techniques explained in TABLE 2, Piezoelectric generator and Electromagnetic generator (Jintanawan 2019,3). By comparing both techniques, piezoelectric generator gives out maximum output at the frequency bandwidth higher than 200Hz, whereas as electromagnetic generator costs less and is effective when frequency bandwidth is 2-20 Hz. The VEH floor, also called Genpath, is capable of converting people's footsteps kinetic energy to electrical energy.

FIGURE 4 illustrates an image of Kinetic energy flooring tiles, made up of two main parts: an EM generator or piezoelectric generator system and power management and storage circuit system. (Jintanawan 2019,3). The human walking flooring equipment is the kinetic energy flooring tiles installed in common crowded areas and used to capture energy generated when people walk on the flooring.

2.3 Human Motion Based Energy Harvesting Products in Market

The chapter presents the most common types of human motion-based energy harvesting products, as described in section 2.2, readily available in the market to install and harvest energy.

2.3.1 Energy Harvesting Kids Playground Products in Market

Some innovative companies are developing in the market and have created kids' playground energy-generating equipment to capture the kinetic energy generated by kid's play.

TABLE 5. Overview of the Kids Playground Energy Equipment Companies

Company	Products	Source
Playground Energy, Sofia, Bulgaria	Lumi seesaw horse, Lumi double seesaw, Lumi Swing, Lumi See-saw	Product Catalogue 2017. https://www.playgroundenergy.com
Empower Playgrounds, Inc. Utah, USA	• Merry-Go Round	https://www.empowerplay-grounds.org/

In TABLE 5, I present a few global creative and innovative companies that manufacture energy-generating kids' playground products available for installation in the market.

2.3.2 Human Energy Harvesting Fitness Products in Market

Fitness equipment is a rapidly expanding industry with widespread use in everyday human activities. Modern technical exercise equipment has developed into a significant and profitable business, with marketing and ubiquitous appearance as human-related devices playing a critical role. Few innovative companies are designing and manufacturing energy harvesting fitness equipment. Some are also working on energy conversion technologies and kits connected to exercise equipment to convert human power into utility-grade electricity.

TABLE 6. Energy Harvesting Fitness Product Companies

Company	Products
The Green Microgym, USA (Human Energy generating exercise equipment designer and installer) https://www.thegreenmicrogym.com **SportsArt, USA** (Exercise equipment manufacturer) https://www.gosportsart.com	• Grid Tied Charging Station • SportsArt electricity generating treadmill. • SportsArt full commercial cross trainer • SportsArt full commercial recumbent • SportsArt Indoor cycle • SportsArt full commercial upright cycle • UpCycle Eco-Charger DIY Kit

In TABLE 6, I present a few global creative and innovative companies that manufacture energy generating fitness products and energy conversion Kits in the market readily available for installation.

2.3.3 Energy Harvesting Flooring Products in Market

Globally after years of research, few researchers started companies to bring energy Harvesting Tiles as a product to the market on a trial basis a few years back. However, a handful of companies listed are manufacturing energy flooring tiles that aim to capture and convert foot power from busy pedestrian areas and street areas. TABLE 7 lists few innovative companies designing and selling energy harvesting footstep equipment in the market.

TABLE 7. Human Energy Flooring Tiles Manufacturers

Company	Products	Website
Pavegen Systems, UK	• Kinetic Tiles	https://pavegen.com
Energy-floor, Netherland	• The walker	https://energy-floors.com/

2.4 Smart Cities

The chapter discusses a general overview of the smart city concepts, including the various definitions, evolution, and need of smart cities. The chapter also briefly discusses energy efficiency and management in smart cities.

2.4.1 Definition of The Smart City

The term smart city is one of the rapidly trending topics in modern urban sustainability and urban management. According to ISO 37122:2019, A smart city is defined based on sustainability as "A city that increases the pace at which it provides social, economic and environmental sustainability outcomes and responds to challenges such as climate change, rapid population growth, and political and economic instability by fundamentally improving how it engages society, applies collaborative leadership methods, works across disciplines and city systems, and uses data information and modern technologies to deliver better services and quality of life to those in the city (residents, businesses, visitors), now and for the foreseeable future, without the unfair disadvantage of others or degradation of the natural environment. " (ISO 37122:2019.)

In general, the definition of a smart city in the simplest form means an urban area that uses information and communication technology to solve its human, social, economic, and environmental issues. Thus, the smart city is a current trend of urban management's strategy to improve the quality of residents living in cities and at leveraging innovation and technologies to solve the challenges and problems generated by high-population density. (Hajduk 2016,35.)

According to Hajduk (2016,36), the smart city concept was used first in 1994. Due to the initiation of the development of smart city projects and its endorsement by the European Union, from 2011 the publication related to this topic has increased. In the 21st Century, the concept “Smart City” is mainly used by Information and Technological companies in combination with IoT (Internet over things) and Artificial Intelligence Technologies. IBM, Cisco, Google, Qualcomm, Schneider Electric, Oracle, Microsoft, Ericsson, Huawei, and Hitachi are market's most relevant and top Information and High Technologies companies working on the development and increasing popularity of smart cities.

2.4.2 Need of Smart Cities

According to United Nations World Urbanization Prospects 2018 report, as shown in
FIGURE 5, in 2018, 55% of the world's population lives in an urban area will have an increase to 7 billion by 2050 and continue to rise. Overall, globally 4.2 billion inhabitants settled in cities compared to 3.4 billion living in rural areas. FIGURE 5 global population projection shows that cities represent the living environment of the future.

The challenges faced by cities vary significantly depending on region, population density, and size of cities. However, based on numerous surveys and data, the issues that cities have identified as most important that arise in the transformation of cities into smart cities are listed in TABLE 8.

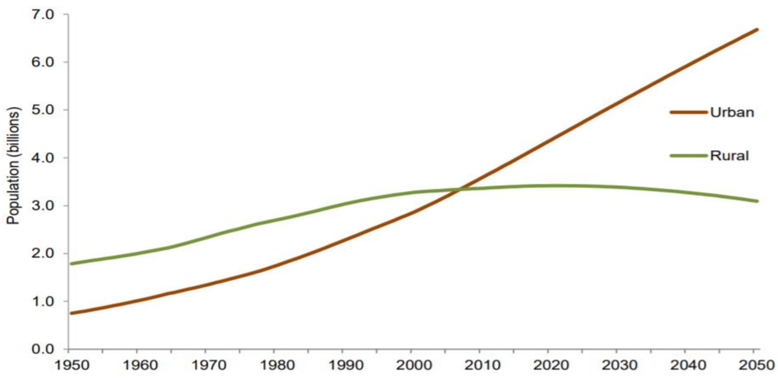

FIGURE 5. World’s Urban and rural populations of the world,1950-2050 (World Urbanization Prospects 2018)

TABLE 8. Urban Problems curbed by transforming to Smart cities.

Urban Problem Type	Problems	
Mobility	Extremely high traffic volumes Transportation congestion Poor Public Transport options	
Security	Crime Poverty	Health issues Unemployment
Facilities	Food Insecurity Homelessness Limited Resources Water Wastewater issues	Poor Infrastructure Residents Connectivity and communication. Energy systems and consumption Solid waste management
Environmental	Poor Air Quality Smog	Water Pollution Climatic Changes

Currently, cities are tasked with finding the mitigations and solutions in solving the urban problems. As a result, the transformation of cities to smart cities by implementing smart city projects to curb urban problems is gaining momentum. Smart cities use information and communication technologies to solve and improve cities' facilities, telecommunication, transportation, waste and wastewater management, energy management, and other urban facilities to create environmentally friendly urban areas. For Example, major cities London, Amsterdam, Barcelona, Munich, Vienna, and Lyon, have experienced notable successes in their transformation into smart cities. (Gassmann 2019,25.)

2.4.3 What constitutes a smart city?

According to Song (2017),” A smart city is first and foremost characterized by the strategic, systematic, and coordinated implementation of modern Information and communication technology applications in a range of urban functional fields” (Song 2017,39). Based on Deloitte Smart Cities (2015) report and other works from several scholars propose the following domains to transform cities by adding “Smart” to Urban Domains and fields that could benefit from enhancement (Song 2017,40) and create smart cities: Smart Mobility, Smart construction, Smart Information, and Communication Infrastructure, Smart Energy, Smart Security, Smart Metabolism, Smart industries, Smart education, Smart Governance, Smart Economy, and Smart Homes (Song 2017,40; Smart Cities 2015,56). TABLE 9 discusses the proposed smart city transformation process domains.

TABLE 9. Smart City Service Areas and Implementation Initiatives

Service Area	Smart City Implementation Initiatives
Smart Mobility	Solutions to reduce traffic congestion and providing faster, sustainable, and cheaper transportation options. Example: Smart Parking, Adaptive connected cars, Sharing services, Smart transport information, and smart traffic control (Smart Cities 2015,56).
Smart Construction	To construct buildings and settlement areas using advanced construction materials and machinery, wirelessly monitoring infrastructure by improving improved construction processes which optimize the supply of amenities, consumption of resources, reducing waste, and improving quality of living (Smart Cities 2015,76; Song 2017,41). Example: Smart Buildings
Smart Information & communication Infrastructure	To set up information communication compatibility and flow between all urban citizens and organizations by establishing faster wireless connectivity based on hardware and software components which improve system efficiency (Song 2017,41).
Smart Energy	Implement green and sustainable energy generation, decentralize energy generation, lower energy consumption, integrate renewable energy production methods, smart grid technologies that control energy consumption, and optimize system coordination.

	(Smart Cities 2015,60-61; Song 2017,41). For example: Smart metering, smart grids, use renewable resources, Electric vehicles
Smart Security	To improve quality of living by preventing various types of crime and provide physical safety and security in an urban area and public spaces, achieved by implementing surveillance equipment that all urban spaces are monitored and controlled. (Smart Cities 2015,59; Song 2017,41). Example: Using Drones for risk assessment, Emergency Apps, Smart Street Lightening
Smart Metabolism	Through functional eco-industrial networks and by applying circular economy ("closing the loop") that reduces the (re)use and recycling of resources which includes Smart water and smart waste management by fulling supply and demand. (Song 2017,41.)
Smart Industries & Logistics	Integrate Smart manufacturing by using robots and related services into urban production and consumption to improve localized industries and job opportunities. (Song 2017,42.)
Smart Education	To educate smart cities with Information and communication technologies to need education institutions with innovation and R&D activities that develop skill complete and qualified people for jobs markets demands and future economic activities (Song 2017,42).
Smart Governance	Using advanced information and communication technologies based on public services to all urban citizens provides Smart government, which includes citizens in the political process (Smart Cities 2015,77-78; Song 2017,42.) For example: Distributed Government, Online Public services
Smart Economy	Integrating, using ICT, and developing related applications for business development and entrepreneurship to build up modem sectors for future economic development (Song 2017,42).
Smart Homes	Homes using technologies, sensors, and electronics for appliance control, home automation, healthcare monitoring services and provide an optimal environment (Smart Cities 2015,77-78; Song 2017,42).

2.4.4 Smart Cities Examples

Globally significant cities have experienced notable success in transforming smart cities by implementing innovative, strategic, and digital initiatives by using modern information and communication technology applications in smart city service areas specified in TABLE 9. Searched Global smart cities and information related to smart cities in the google search engine and obtained the results of globally best 109 smart cities. After analysing obtained 109 smart cities, examples of the latest transformed smart city from each continent globally based on the IMD-SUTD Smart City Index 2020 report and IESE cities in motion index 2020 report are presented in TABLE 10, includes top Initiatives implemented to transform to the smart city.

TABLE 10. Examples of Smart City Initiatives in different world cities

City and Continent	Why Smart city? Top 5 Initiatives
Singapore, Asia	**Smart Mobility and Transportation: -**Shared community experience includes optimizing transport efficiency, utilizing sensor technology, efficient public transport, and encouraging bicycle usage (Smart City Index 2020, IMD-SUTD).
	Smart Health and Safety: - AI-powered smart elderly alert system, Tele-Health video consultations, digitized its healthcare system, Monitoring CCTV cameras for safety and Mobile application to monitor environmental pollution (Smart City Index 2020, IMD-SUTD).
	Smart Education: -Smart learning and educating modern technologies and IT Skills (Smart City Index 2020, IMD-SUTD).
	Smart Governance: - Processing identification Documents and Online Residents Feedback on Governance and proposing ideas (Smart City Index 2020, IMD-SUTD).
	Smart connectivity and Homes: -Connected Life's home monitoring solution provides insights to health providers, the insurance industry and government (Berrone 2020, IESE Cities).

Helsinki, Europe	**Smart Mobility and Transportation: -** Good Public Transport and Buying Tickets and Online scheduling made public transport easier to use (Smart City Index 2020, IMD-SUTD).
	Smart Metabolism: - Applications and websites helps residents to easily give away unwanted items (Smart City Index 2020, IMD-SUTD).
	Smart Education: - Smart learning and Children have access to a good school and Taught IT Skills (Smart City Index 2020, IMD-SUTD).
	Smart Governance: - Processing identification Documents and Online Residents Feedback on Governance and proposing ideas (Smart City Index 2020, IMD-SUTD).
	Smart Environment: - Residents can rent solar units with objective carbon neutral city (Cathelat 2019,88).
Auckland, Australia	**Smart Education: -**Children are taught IT Skills and Life-long learning option available (Smart City Index 2020, IMD-SUTD).
	Smart Environment: - Safeswim is a data analytics which provides an online platform with real-time information on tides, wind, recreational facilities, water-related health risks, location details and image (SCCEI Regional Snapshot 2018).
	Smart Governance: -Processing identification Documents and Online Voting for Participation for Governance (Smart City Index 2020, IMD-SUTD).
	Smart metabolism: - Smart residential water meters reduce manual meter reading costs (SCCEI Regional Snapshot 2018).
	Smart Information and communication Infrastructure: - IoT start-up incubation and smart minds who provide real time location data using Bluetooth technology (SCCEI Regional Snapshot 2018).
New York, North America	**Smart Mobility and Transportation: -** Public Transport more accessible and highly developed system for renting or sharing bicycles (Smart City Index 2020, IMD-SUTD).
	Smart Economy: -High GDP and Number of headquarters of publicly traded companies (Berrone 2020, IESE Cities).

	Smart Health and Safety: -Algorithms that map crime and statistically predict areas at risk of crime (Cathelat 2019,133).
	Smart Governance: -Relevant use of new technologies to serve the daily needs of city residents (Cathelat 2019,242).
	Smart Construction: -Highly developed infrastructures and large number of buildings and skyscrapers (Berrone 2020, IESE Cities).
Medellin, South America	**Smart Environment: -**Using IoTs to measure urban pollution in real time and Early Warning System" (SIATA) performs the same environmental monitoring function (Cathelat 2019,88).
	Smart Governance: -Transformation towards a more equitable, innovative, and participatory urban society (Berrone 2020, IESE Cities).
	Smart mobility: -Smart adaptations of existing transport and Metro Cable: a monocable cable-car system with detachable gondolas equipped with solar (Cathelat 2019,148).
	Smart health & safety: - AI software and face recognition technologies used by crime management system (Cathelat 2019,148).
	Smart Construction: -Construction of smart building

2.4.5 Energy Management in Smart Cities

Cities are major energy consumers, and around 70% of global energy demands are consumed in urban centres (Gassmann 2019,15). Global energy demands need a very high energy density which creates an objective to decentralize energy production and implement smart energy generation technologies. Smart city projects promote renewable energy, smart grids, energy efficiency, and low carbon technologies (Maltese 2016,33). Concerning energy systems for smart cities, companies and organizations are exploring energy generation, supply, and distribution, focusing on innovative systems and technologies accomplishing energy systems using renewable resources.

Cities transforming to smart cities refer energy management approach as smart energy. Smart energy aims at sustainable and green energy production utilizing renewable resources, lower energy consumption, reducing fossil fuel dependency, and implementing smart grid technologies that control energy consumption and smarter distribution of energy (Smart Cities 2015,60; Song 2017,41).

TABLE 11. Smart Energy Initiatives used in Smart cities.

Initiatives	Smart Energy Initiative details
Distributed generation with renewable sources	Non-renewable energy is replaced by distributed generation based on renewable energy production technologies such as solar energy, wind energy, geothermal energy, and biomass fuel energy in smart cities.
Smart Grids	Smart grid is next-generation electricity grids where nodes not only produce and consume energy, but also data enabling end-user energy management (Smart Cities 2015,60)
Microgrids	Microgrids are local grids that can operate on a standalone basis by a local source of energy and local loads and connect /disconnect to national wide grids. Thus, it helps reduces transmission and distribution losses (Smart Cities 2015,60).
Smart metering	A smart meter records energy consumption at regular intervals and uploads data to energy companies, which helps both consumers and companies negotiate energy prices. (Smart Cities 2015,60)
Electric vehicle Charging	More electric vehicle usages, high amount of vehicle batteries in use helps store energy during peak production and provides additional energy during peak usage (Smart Cities 2015,61).
Seasonal thermal energy storage (STES) and excess heat usage	STES helps to store excessive produced in excessive heat summer from building and use in the winter season. Similarly, a city can use excess heat produced at various facilities to warm water used to heat buildings and save energy.

According to Deloitte Smart Cities (2015), important initiatives to implement smart energy as part of smart cities are presented in TABLE 11. Smart cities implementing the smart energy approach first need to migrate to more sustainable and environmentally friendly renewable energy. Renewable energy production technologies used in smart cities are solar energy, wind energy, geothermal energy, and biomass fuel energy. Finally, it is essential to migrate to a completely renewable energy system to be a smart city (Calvillo 2016,273-274).

2.5 Overview of literature review

A theoretical study of the smart city framework using the literature review method was understanding the smart city concept, the need for cities transformation into smart cities, domains to build smart cities, and its implementations and energy management in a smart city. The term smart city refers to a comprehensive variety of approaches designed at solving the urban challenges by improving the quality of life and services of urban.

Currently, populated cities have several challenges such as mobility, safety, infrastructure, energy, water, and environmental issues due to a drastic increase in population. However, the research articles show, the smart city is a different set of solutions to real-world problems that today's heavily populated cities face, and mitigation depends on regional challenges and city services. According to research papers and books by various scholars such as Hajduk (2016) and Reichental (2020), also high technological company's journals, the smart city concept is evolving as information and communication technology advances in every urban domain to serve urban services.

According to Deloitte smart cities (2015) reports, Song (2017) and other several scholars worked on a modular structure and initiatives for each urban domain presented in TABLE 9 to assist in the transforming of a city into a smart city while taking ICT, economic, social, and environmental factors into account. According to Deloitte Smart Cities (2015) reports and Song (2017), the transformation of a smart city is highly dependent on effective energy efficiency initiatives called Smart Energy in the smart city project framework to ensure the electricity supply to all urban consumers. Strategies in smart energy approach campaign to produce energy from renewable resources in a sustainable manner. According to strategies in the smart energy initiatives presented in the TABLE 11 campaign for producing energy from renewable resources in a sustainable manner.

The theoretical study of human motion-based energy harvesting technology shows its growth rate is higher in the future due to the vast availability of needed resources the human activities, and it is still in the innovation phase. Several studies have shown that humans can produce energy from their daily activities and body movements. Research papers by Dai (2012,210), Invernizzi (2016), Zhou (2018), and Jintanawan (2019) have proven that energy harvesting from human motion-based is possible and easy to set up. Zhou (2018) explains the needed technical components to build an energy harvesting system using a human motion which consists of a generator, power conditioning circuit, inverter connected to a storage battery or power grid. Invernizzi (2016), Zhou (2018), and Jintanawan (2019) research papers demonstrate the application of physics principles such as Electromagnetic laws, Electrostatic, Piezoelectric, and Triboelectric to convert human motions mechanical energy to electrical energy. Invernizzi (2016) and Zhou (2018) cited research on the most common energy harvesting human activities. Combining the outcome of studies in this thesis show practically and technical, it is possible to generate energy from human body movements.

In the context of smart cities, the most popular regular activities performed by urban citizens are kids playing outside, physical workouts in gyms, and walking. Examples of equipment are swings, slides, merry-go-round, see-saw, treadmill, indoor cycles, elliptical machines, stationary bike, and kinetic energy flooring tiles. However, based on product research in the market, few technologically innovative companies manufacturing energy harvesting equipment that can be readily installable in a different location in a smart city. According to market research, results about the availability of suitable energy harvesting equipment showed such products are there for businesses but with minimal choices. Thus, installing energy harvesting from human motion in a smart city is a feasible solution. Furthermore, the research study shows it can be easily integrated into smart cities and satisfying smart energy initiatives.

3 HUMAN MOTION BASED ENERGY HARVESTING EQUIPMENT INTEGRATION IN SMART CITY

The chapter suggests the ways to integrate identified energy harvesting equipment: kids playground energy equipment, fitness energy equipment, and human walking flooring equipment in the context of smart cities in practice.

3.1 Energy Generating Kids Playground

Smart cities have several parks and playgrounds for kids to play in. Children's energy-harvesting toys, such as see-saws, swings, merry-go-round sliders, and other toys, are installed in school play areas and public parks in a smart city where many children play. Children's play energy would generate a significant amount of energy, stored, or fed into the power grid for distribution if needed. Even though the energy produced by children's activities is minimal comparing to other renewable energy sources such as solar or wind, it may significantly increase energy harvesting efficiency through new advanced technologies.

To state few use cases, the Amsterdam Smart City project has established a system of harvesting kinetic energy from playgrounds and redistributing it to children in the form of light or sound to motivate them to play more (Smart Energy Playground for the Whole Family 2017). Also, a project for interactive playgrounds is in Milton Keynes, UK, as a part of the smart city project.

3.2 Human powered Eco-Gyms

Gymnasiums and Fitness centres in most cities are some of the most inefficient locations in terms of energy consumptions (Chalermthai 2015,1). Gym equipment consumes electricity and needs to provide comfort to users by providing adequate lighting and temperature for exercise, which consumes a significant amount of energy. It is critical to convert gymnasiums and fitness centres to Eco-Gyms, also known as Green Gyms, to transform into smart cities. The solution for energy management and improving energy consumption in smart cities is to establish a Sustainable gymnasium and remodel existing gym equipment where human workout contributes to generating electricity. The places and equipment's which can be installed in smart cities to harvest energy and contribute to smart city energy generation presented in TABLE 12.

TABLE 12. Location to establish Fitness Equipment's in Smart City

Implementation Method	Smart City Installation Location
Energy Conversion Kits are interfaces to existing fitness equipment's in the gymnasium to generate energy.	✓ Indoor Gymnasiums ✓ Outdoor Gymnasiums
Install fitness equipment's with energy generator and ReRev™ technology which converts DC to AC and then feed the current into the power grid of the gymnasium electrical system or building or university of companies	✓ Private Residential Building ✓ Apartments and shopping malls ✓ Universities Campus ✓ Industrial and Companies Campus

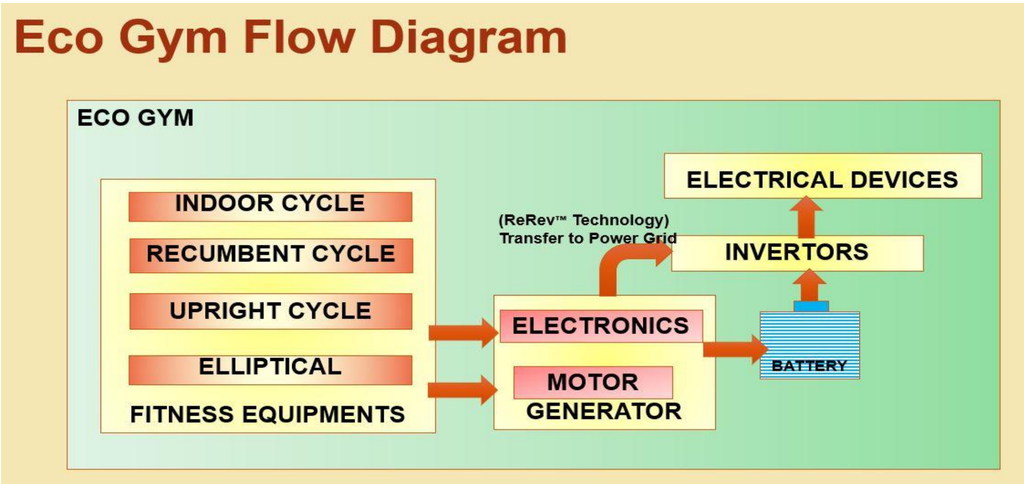

FIGURE 6. Energy Harvesting in Gymnasium (Author 2021)

A typical setup diagram of an energy harvesting gym from Human exercise shown in FIGURE 6. As shown in FIGURE 6, the first existing gymnasium installs human workouts to electric energy converters to harvest electric power from exercises through gym equipment. Gym equipment installed to harvest energy are mostly. treadmills, elliptical machines, rowing machines, and encouraged by displaying contributed generated power by individuals, and micro-invert technology used to turn human energy into electricity. Energy harvested by human energy in kilowatts transmitted to building electricity systems by plugging equipment into an outlet using ReRev™ technology or stored in a battery for local use.

3.3 Kinetic Energy Tiles Flooring in crowded area

In smart cities, numerous crowded areas exist, such as airports, commercial building areas, railway stations, and city centre shopping areas. Installing energy-generating floors in such crowded areas can produce ample electricity from their footsteps. Therefore, energy harvesting flooring can be a crucial component in smart city concepts.

Kinetic energy flooring tiles generate energy when people walk on them, and then tiles transformed electricity can power everything from street lighting to interactive adverts (Energy Harvesting 2021). For example, Pavegen, a kinetic energy flooring tile manufacturer-installed tiles on the lap of the Paris marathon, where 40,000 runners were generating 7 kwh as they raced to the finish line (Energy Harvesting 2021). Electricity-generating smart flooring can be used along with other renewable resources such as solar and wind by compensating for their vulnerability to use due to changing weather (Energy Harvesting: Pavegen and the Rise of Kinetic Tile Tech 2021). Installer can get the most electric energy out of kinetic energy flooring tiles in smart cities by using them in specific high traffic areas to nearby power equipment based on demand (Energy Harvesting 2021).

Typically identified locations in a smart city where kinetic energy flooring tile can be installed are railway stations, bus stations, crowded city centres, shopping centres, and airports. A brief synopsis of the corporate case studied in this case study, According to Dervojeda (2014,5), Pavegen already had a large customer base. Several nations in schools, retail malls, and other public places have implemented the system. In addition, massive blue-chip corporations like Shell, Schneider Electric, and Siemens have expressed interest in a test installation (Dervojeda 2014,5). For example, Pavegen collaborated with Broadgate to contribute to London's bustle electricity to lighting and donations to a local homelessness charity.

4 EMPIRICAL STUDY

The chapter presents the cost-benefit analysis of energy harvesting applications such as energy-generating kids' playground, human-powered eco-gyms, and kinetic energy flooring tiles in context smart cities installed with corresponding equipment at defined locations.

4.1 Cost-Benefit Analysis

Cost-benefit analysis (CBA) is one of the analysis tools commonly applied in assessing the efficiency of planned activities. The cost-benefit analysis evaluates the difference between gain and harm in a given situation (Karam 1976,379). For planning and implementation analysis, the actual effects can choose benefit (B) as the mathematical expectation of good and detriment (D) as the mathematical expectation of harm (Karam 1976,379). Both B and D have easily quantifiable components (cost and gain) and components that represent intangible good and harm (Karam 1976,380).

The aim of cost-benefit analysis is planning an operation and practice is then evaluating whether (Karam 1976,379) the net benefit is related to evaluating the decision of an operation and a practice (Karam 1976, 382). Therefore, it is convenient to relate to the unit price of operation to analyse the continued operation. Example: -in case of energy production per MW and year are units. The net benefit is the change in the net benefit of the proposed solution compared to alternative solutions caused by operation and practice.

4.1.1 The Cost-Benefit Analysis Implementation Method

Cost-benefit analysis is used to access proposed smart solutions. In this thesis, energy harvesting from human motion is evaluated as the smart solution, meaning it the most suitable method for developing a ratio approach in the decision-making processes (Turečková 2020,1). Furthermore, it is implemented based on the analysis of all indirect and direct costs and benefits, which also measures society's investments' impacts (Turečková 2020,2).

In CBA method: On one hand, it measures the harms such as negative effects arising from investment, all negative impacts on society expressed in finances, and on the other side, it measures the benefits such as positive effects of investment, all positive impacts on society contributing to individual and societal prosperity. (Turečková 2020,2). By the aggregation of both forms of impacts, benefits, and harm, and by comparison of individual components of other renewable energy generation, select a choice that maximizes the difference between the evaluated activity's costs and benefits, or the activity implemented if the ostensible benefits outweigh the ostensible costs. (Turečková 2020,3; Karma 1976,382).

Adapting European Union’s guide to cost-benefit analysis of investment projects procedure, the key component of the cost-benefit analysis considered for this thesis for analysis are financial. In TABLE 13, Here introduces key component, the simplified measured parameters and purpose of analysis to conduct cost-benefit analysis.

TABLE 13. Cost Benefit Analysis key components

Component	Measured Parameters	Purpose
Financial Analysis	**Investment costs** ✓ Land or space cost ✓ Equipment cost ✓ Start-up technical cost	To assess the financial efficiency of energy harvesting from human motion applications in the context of smart cities. The financial costs and benefits must be stated explicitly in the evaluation. (Tureková 2020,3).
	Operation and maintenance cost ✓ Operation cost ✓ Safety Cost	
	Revenues ✓ Profitability for 5 years	

In this section of the thesis, the generic methodology for conducting a cost-benefit analysis of energy generation sources using components described in TABLE 13
.

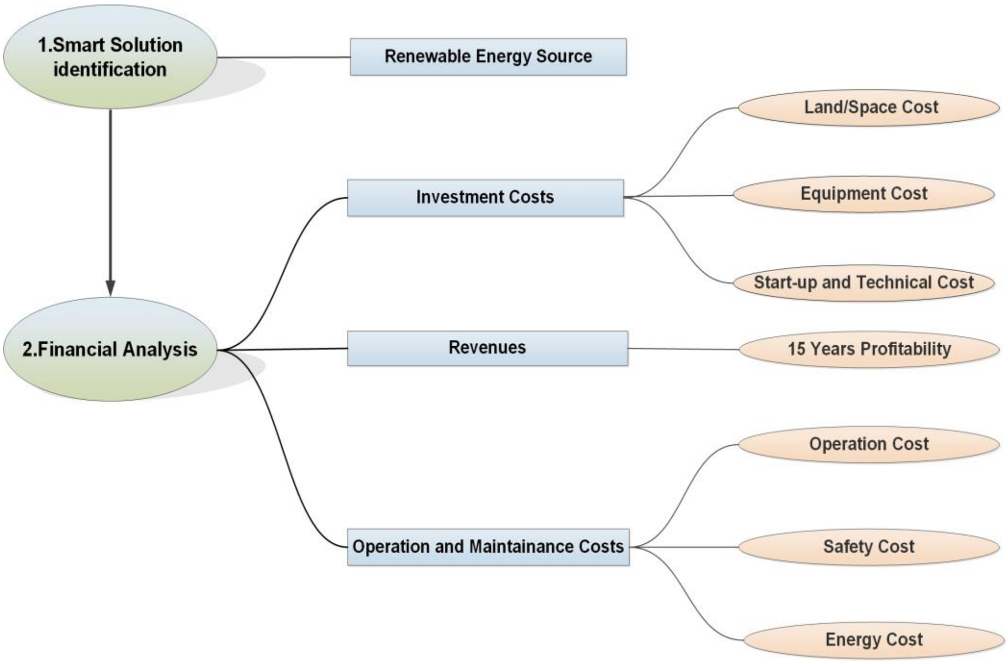

FIGURE 7. The Cost-Benefit analysis simplified procedure for energy generation adapted from EU's guide 2015 (Author 2021)

TABLE 14. Defined procedure for energy generation cost benefit analysis guide to EU's cost-benefit analysis of investment projects 2015.

CBA analysis step	Analysis component	Details
Smart solution Identification	Identify renewable energy source	This identifies the renewable energy generation method, including the technology and equipment used. For example: - solar and energy harvesting from human motion. For example: - solar and energy harvesting from human motion.
Financial Analysis	Investment cost	This phase calculates the investments qualitatively and quantitatively. The calculation mainly covers space costs, energy generation equipment costs, start-up

		costs, technical costs, legal compliance costs, installation costs, and labour costs.
	Operation and maintenance cost (O&M)	(O&M) Costs of energy generation are analysed using the quantity of energy produced/distributed or not, safety costs, and operation cost to maintain equipment (EU guide to cost-benefit analysis of investment projects,2015).
	Revenues	According to the EU's guide to cost-benefit analysis of investment projects, revenues connected with Energy sales: a tariff or a unit price paid by consumers or saved.

Combining the proposed CBA procedure by the EU and renewable energy generation source parameters, steps are defined to conduct a cost-benefit analysis of any renewable energy generation method is presented in
FIGURE 7. A brief explanation of the steps of cost-benefit analysis of energy generation is shown in TABLE 14. In cost-benefit analysis, parameters measured in quantitative method.

4.2 Cost Benefit Analysis of Energy Harvesting from Human Motion

As a first step, the renewable energy source is Energy harvesting from human motion identified as a smart solution. Next, cost-benefit analysis is executed for human motion-based energy harvesting sources by following the procedures outlined in TABLE 14 by applying defined cost-benefit analysis steps to human motion-based energy harvesting sources shown in FIGURE 8.

Here the financial analysis of all three identified energy harvesting equipment implementation in a defined space in the smart city is carried out. Later, the results of the cost-benefit analysis of the energy harvesting from human motion equipment in the context of a smart city were reviewed to discuss the advantages and disadvantages of energy generation.

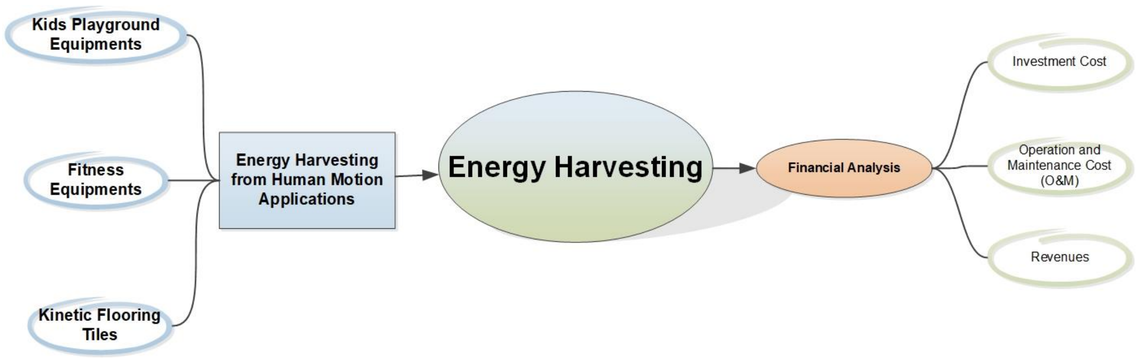

FIGURE 8. Applying CBA Procedure to Evaluate Energy Harvesting from Human Motion Adapted from EU's Guide 2015 (Author 2021)

The second step financial analysis of all three identified energy generating equipment from human motion is performed by calculating revenues using investment cost of equipment, operation cost, and maintenance cost of equipment. The measurement and calculation are using quantitative values for financial analysis.

The Green Microgym (www.thegreenmicrogym.com) and the SportsArt shops' webpage (https://www.gosportsart.com/eco-calculator/) have been referred to as a source to collect fitness equipment prices and associated values needed to conduct a cost-benefit analysis of human-powered Eco-Gyms at an imaginary university, and the results summarised in chapter 5 . The approximate prices from the global market's web pages were referred to gather costs of kids' playground toys prices, related electronic components, and associated values needed to conduct a cost-benefit analysis of an energy harvesting kids playground, and the results presented in chapter 5.

The Pavegen webpage (www.pavegen.com) and the article "Energy Harvesting: Pavegen and the Rise of Kinetic Tile Tech" are referred to as sources to collect the energy specification of energy tiles, tiles prices, and associated values used for calculation needed to conduct a financial analysis of an energy harvesting floor in the railway station, and the results presented in the chapter 5.

5 RESULTS AND DISCUSSION

5.1 Financial Analysis

TABLE 15 shows the results of a financial analysis of an imaginary Eco-Gym set up on a university campus and the outcomes of related measuring parameters.

TABLE 15. Financial Analysis of Human Powered Eco-Gyms

Eco-Gym Location	University Campus		
Equipment's Installed	One Treadmill, One Elliptical, One Upright cycle and Two Indoor cycle		
INVESTMENT COST			
Equipment Costs (Includes Invertor cost using ReRev™ technology)	Tread Mill	=	10000 €
	Indoor **c**ycle (3000 € .2)	=	6000 €
	Upright cycle	=	4500 €
	Elliptical	=	8000 €
	Total Equipment cost	**=**	**28500 €**
Installation, transportation, and Labour costs			500 €
Land and Space Cost			0 €
	Total Investment		**29000 €**
Operation and maintenance Costs			
Minimal Costs			
Revenues			
Total Hours in Use	15 Hours per day		
Total Days in Use	30 Days per month		
Watts Generated	160 W/hour (Output per user)		
Watt-hours Generated per year	$equipments * use\ hours/day * use\ days/month * 15 * 160\ W = 4320000W$ = 4320 kW/year		
Finland Cost of Electricity in per kilowatt hour (kWh)	18,00c/kWh (Environmental electricity cost + Transmission cost) (https://www.helen.fi/en/electricity/electricity-products-and-prices)		
Savings per year	777,6 €		
Savings after 15 years	**11664 €**		

TABLE 16 shows the results of financial analysis of an energy-generating kids. playground park built in a smart city and the outcome of related measuring parameters.

TABLE 16. Financial analysis of energy harvesting Kid's playground toys

Location	Smart City Kids Park		
Equipment's Installed	One Merry-Go-Round and One Swing		
INVESTMENT COST			
Playground toys costs	Swing	=	500 €
	Merry-Go-Round	=	800 €
	Total Toys Cost	**=**	**1300 €**
Labour costs	Installing in Park (1-2 days) =		1000 €
Transportation cost			200 €
Generator cost (Low RPM High Torque DC Motor)	Energy Generators (2.500 €)		1000 €
DC convertor			100 €
Invertor and other components	Two sets (2 .1000€) =		2000 €
	Total Investment		**5600 €**
Operation and maintenance Costs			
Minimal Costs			
Revenues			
Total Hours in Use	12 Hours per day		
Total Days in Use	30 Days per month		
Watts Generated	150 W/hour (Output per equipment)		
Watt-hours Generated per year	$equipments * use\ hours/day * use\ days/month * 12 * 150\ W = 108000W$ = 108 kW/year		
Finland Cost of Electricity in per kilowatt hour (kWh)	18,00c/kWh (Environmental electricity cost + Transmission cost) (https://www.helen.fi/en/electricity/electricity-products-and-prices)		
Savings per year	19,44 €		
Savings after 15 years	**291,6 €**		

The financial analysis of Pavegen energy-generating flooring tiles installed at the city central railway terminal entrance platform and related measuring parameters results presented in TABLE 17.

TABLE 17. Financial Analysis of Footsteps Kinetic Energy Flooring Tiles

Location	Smart City Railway Terminal Entrance Flooring	
Equipment's Installed	100 Triangular Energy Generating Flooring Tiles with all sides of dimension 500mm and area 1.2 square feet covering 12 square feet	
INVESTMENT COST		
Tiles Costs	100 Energy Tiles (175 €/square feet.12) =	2100 €
Installation and Labour cost	20 € / square foot. 12 square feet	300 €
Shipping cost		200 €
	Total Investment	**2600 €**
Operation and maintenance Costs		
Average Lifetime is 10-15 years now and covered under warranty for 5 years		
Revenues		
Person walking Distance	12 feet and 1 feet/step	
Watts Generated	8 W/step	
Watt-hours Generated per person walking 12 feet	$12\ feet\ .1\ \text{feet/step}\ \ 5\ W/step\ = 60\ W$ = 60 W	
Total number of per-sons/days	10000 persons/day	
Watt-hours Generated per year	$10000\ persons/day\ .60W\ .365\ day = 219000000\ W$ = 21900 kW/year	
Finland Cost of Elec-tricity in per kilowatt hour (kWh)	18,00c/kWh (Environmental electricity cost + Transmission cost) (https://www.helen.fi/en/electricity/electricity-prod-ucts-and-prices)	
Savings per year	3942 €	
Savings after 15 years	**59130 €**	

5.2 Results Summary and Discussion

As a result, this study developed a simplified Cost-Benefit analysis procedure adapting the cohesion policy and components defined by the European Union's Cost-Benefit Analysis framework in Guide to Cost-Benefit Analysis of Investment

Projects methods. TABLE 21 shows the amount of energy generated per year from each type of identified energy harvesting from human motion equipment used for financial analysis in the Cost-Benefit analysis process.

TABLE 18. Energy generated per year (Financial Analysis)

Type of Energy harvesting	Energy generated per year)
Fitness equipment (Eco-Gym in University)	4320 kW/year
Kid's playground toys (City Park)	108 kW/year
Kinetic Energy Flooring Tiles (Railway Terminal Entrance)	21900 kW/year

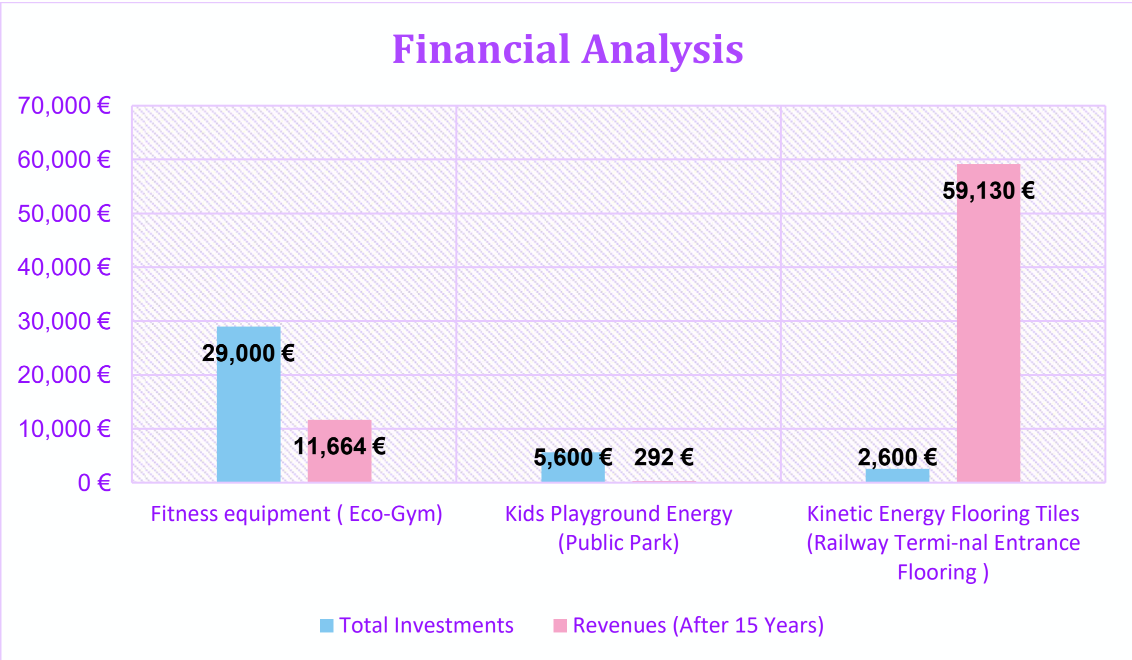

FIGURE 9. Energy harvesting equipment's financial analysis results

The cost-benefit analysis results comprise a financial analysis of installing energy harvesting equipment from human movements in smart city, presented in FIGURE 9 and TABLE 18, respectively. Financial analysis results consist of total investments and revenues.

Financial analysis results show total investment to set up energy-harvesting kids playground equipment in a public park is 5600€ and expensive after compared to savings of energy expenses is only 292€ for 15 years with a loss of over 95%. Next, the total investment to set up energy-harvesting fitness equipment is

29000€ and very expensive after comparing savings of energy expenses is 11664€ for 15 years with a loss of over 50%. Finally, the total investment to install kinetic energy-harvesting flooring is 2600€, and the benefit after comparing energy consumption is 59130€ for 15 years, for a yield of more than 22 times the investment.

The Cost-Benefit analysis results demonstrate the benefits and drawbacks of all three chosen human motion-based energy harvesting equipment. According to Financial Results, even though Operation cost, installation cost, and maintenance cost are minimal, energy generated is lesser per year energy-harvesting kids playground and fitness equipment. Also, humans cannot work for 24 hours which is the max limit that directly affects the revenue generated, so payback time is very high.

Based on the research results, the densely populated areas in a smart city are ideal locations to install Kinetic energy flooring tiles and kid’s playground energy parks and meet local energy demands. Individuals and organizations can install energy harvesting fitness equipment to endorse themselves as environmentally friendly while also reducing their electric bills. The fact, however, is that the financial revenues face significant challenges before human motion energy harvesting types of equipment can become the mainstream energy producer. So, energy harvesting fitness equipment and kids’ playground energy parks might have to wait decades to recover the money spent converting and installing machines to generate electricity.

From a Smart cities’ perspective, it is demanding to consider the cost-benefit analysis of human power eco-gyms compared to other renewable energy sources due it is higher contributions to the energy requirements of a smart city. The cost-benefit analyses showed that deploying footstep kinetic energy flooring tiles as a human motion-based energy harvesting source is a feasible option comparable to energy harvesting fitness equipment and kids’ playground energy parks for now. But financial revenues might improve in the future if companies selling equipment would increase volume while lowering prices of equipment and advancement in technologies to harvest more energy.

6 CONCLUSION

The thesis aims to study the utilization of human motion as an energy harvest source by first finding market applications and equipment to convert human movements into energy. Later to locate in a smart city where urban people can use it conveniently and efficiently.

According to Invernizzi (2016,1), different research articles, and observations, the most common human daily activities identified in cities are walking, fitness exercise, and kids playing. The urban residents spend an average couple of hours performing identified motions activities every day. According to studies on human movements in smart cities, residents perform fitness exercises in gymnasiums, kids playing in public playgrounds and parks, and walking in crowded areas like city centres, airports, railways, and bus terminals. Accordingly, the corresponding best suitable human motion-based energy harvesting applications are fitness equipment in gyms, Kid's playground toys as equipment, and flooring of crowded areas.

According to the study, the fitness equipment can generate electricity by integrating energy harvesting kits like the upcycle eco-charger and installing energy-producing treadmills, indoor cycles, elliptical machines, and stationary bikes. Thus, energy harvesting would not require buying land or constructing vast buildings unless planned to build new gyms. In the current market, the innovative companies Green Microgym and SportsArt manufacture energy harvesting fitness and energy conversion kit products for the application.

Next, about energy-generating kid's playground toys, many kids in urban areas spend an average couple of hours every day in city public parks playing in swing, slider, see-saw, and merry-go-round, respectively. As a result, electrical energy generated converting kid's play activities by upgrading energy harvesting toys in existing parks or building new parks with energy harvesting types of equipment. Later, the power grid transmits the converted electrical energy or battery stores the converted energy for local use. Latest innovative companies like Playground

Energy and Empower Playgrounds are designing and manufacturing energy harvesting playground toys for usage in the current market.

During the last few years, innovation companies are designing and manufacturing energy harvesting flooring tiles converting human walking kinetic energy into electrical energy called kinetic energy flooring tiles. This application installs flooring tiles in crowded areas to harvest energy. In the market, Pavegen kinetic flooring tiles and Energy-floor tiles are available for application. Hence, the most fitting energy harvesting applications for urban residents are energy-generating kids' playground toys, human-powered eco-gyms, and kinetic energy flooring tiles.

In smart cities, fitness exercise equipment is commonly available in indoor and outdoor gyms, private buildings, apartments, and commercial buildings. Therefore, fitness exercise equipment users can generate more electricity by converting existing gyms into eco-gyms by interfacing energy conversion kits and building more eco-gyms by installing energy harvesting exercise equipment. Similarly, kids spend most of their time playing with toys in school gardens, city parks, and theme parks in smart cities. Consequently, installing energy harvesting playground equipment in such parks helps city administration and schools conserving energy consumption of renewable source electricity. Now about energy flooring tiles application in smart cities, the most popular crowded areas are railway terminals, bus terminals, city centres, airports, and shopping malls. In these urban locations, people walking footsteps count is very high, and installing kinetic energy flooring tiles generates energy. Therefore, the most suitable location to install equipment based on its usage in smart cities are gymnasiums, Kid's playground parks, and crowded places.

After finding smart city-fitting energy harvesting applications, I do a cost-benefit analysis to determine the practicality of employing human motion-based energy harvesting applications as an alternative renewable energy source. According to cost-benefit analysis, the financial analysis results show higher investment cost, lower revenues, and payback duration is longer in general. In day-to-day activities, humans work for only 12-15 hours and need rest for 9-12 hours which directly reduces energy produced by the equipment. In addition, increasing energy generation requires to build of many more human-power-based harvesting equipment. Therefore, the results show that the financial benefit is minimal. However, the environmental impacts such as No GHG emissions and a reduced carbon footprint suggest considering energy harvesting from human movements as an energy solution.

According to the literature Smart Cities (2015,60), the Smart energy initiative of the smart city framework specifies the need for more microgrids that can operate independently from a local source of energy and local loads by using the distributed generation of renewable sources. Human motion-based energy harvesting technology can play a vital role and fit into smart energy strategy by satisfying both stated criteria. Locally built energy generating stations by installing selected energy harvesting equipment is similar to microgrids and helps to save distribution and transmission energy losses.

Furthermore, one of the problems confronting Smart cities is the scarcity of vast lands required by other renewable energy sources such as solar and wind to fulfil regulatory environment permits. However, the land or space requirements for human motion-based energy harvesting equipment are minimal and easy to set up in any building or park. Also, human power-based energy generators do not require any environmental permits to set up. By installing human motion-based energy harvesting devices can generate electricity from their daily activities and movements. Hence, human activities generating energy will play a vital role in future smart city initiatives for serving the energy needs of individual and small energy demands.

In conclusion, the study shows that the kinetic energy flooring application takes advantage of densely populated people as an energy source to tackle energy shortages while meeting smart energy initiatives of smart city projects. Financial analysis suggests installing footstep kinetic energy flooring tiles as energy harvesting from human energy equipment in smart cities compared to types of energy harvesting equipment. In the future, integrating energy harvesting fitness equipment and kid playground toys into smart cities considered if financial benefits improve lowering equipment prices, improving energy harvesting system efficiency, and increasing revenue.

REFERENCES

Airaksinen, M., Ailisto, H. & Nylund N. 2015. Smart City - Research Highlights. Read on 26.02.2021. http://www.vtt.fi/inf/pdf/researchhighlights/2015/R12.pdf.

Berrone, P. & Ricart, J, E. 2020. IESE Cities in Motion Index. IESE Business School, University of Navarra. Read on 15.03.2021.

Calvillo, C.F., Sánchez-Miralles, A. & Villar, J. 2016. Energy management and planning in smart cities, Renewable and Sustainable Energy Reviews, Volume 55, p. 273–287. Read on 10.03.2021. https://www.sciencedirect.com/science/article/abs/pii/S1364032115012125

Carvalho, F. C., Galhardo, M. A. B., Aguilar, H. C., Farias, G. M. & Pinho, J. T. 2013. Use of alternative energy generation in playgrounds as a means of knowledge spreading. ScienceDirect, Energy Procedia Volume 57, 2014, p1024-1033. Read on 10.04.2021. https://doi.org/10.1016/j.egypro.2014.10.068

Cathelat, B. 2019. Smart Cities, Shaping Society of 2030, United Nations Educational, Scientific and Cultural Organization (UNESCO) & Netexplo. Read on 23.04.2021.

Chalermthai, B., Sada, N., Sarfraz, O. & Radi, B. July 2015. Recovery of useful energy from lost human power in gymnasium. IEEE ,15th International Conference on Environment and Electrical Engineering (EEEI). DOI:10.1109/ EEEIC.2015.7165428. Read on 12.03.2021. https://ieeexplore.ieee.org/document/7165428

Dai, D. & Liu, J. 2012. Tackling global electricity shortage through human power: Technical opportunities from direct or indirect utilizations of the pervasive and green human energy. Frontiers in Energy volume 6, p. 210–226, Higher Education Press and Springer-Verlag Berlin Heidelberg. Read on 15.03.2021.

Dervojeda, K., Verzijl, D., Rouwmaat, E., Probst, L. & Frideres, L. 2014.Clean Technologies, Energy harvesting. Business Innovation Observatory, European Commission. Read on 15.05.2021.

Energy Harvesting: Pavegen and the Rise of Kinetic Tile Tech. 2021. Read on 11.04.2021. https://theswitch.co.uk/energy/guides/technology/energy-harvesting-tiles#kinetic-tile-uses

Fujimoto, A. 2014. Energy Harvesting Flooring, Stanford University, Fall 2014. Read on 11.05.2021. http://large.stanford.edu/courses/2014/ph240/fujimoto1/

Gassmann, O., Böhm, J. & Palmié, M. 2019. Smart Cities: Introducing Digital Innovation to Cities. 1st Edition. Emerald Publishing Limited. Read on 10.03.2021.

Gibson, T. 2011. Turning Sweat into Watt. IEEE Spectrum, v. 48, Issue 7. Read on 10.04.2021. https://ieeexplore.ieee.org/document/5910449

Guide to Cost-Benefit Analysis of Investment Projects. 2015. Economic Appraisal Tool for Cohesion Policy 2014-2020, European Commission, European Union. Read on 10.05.2021.

Hajduk, S. 2016. The Concept of a Smart City in Urban Management. Business, Management and Education, v. 14, n. 1, p. 39-49. Read on 01.03.2021.

Invernizzi, F., Dulio, S., Patrini, M., Guizzettic, G. & Mustarelli, P. 2016. Energy harvesting from human motion: materials and techniques. Royal Society of Chemistry, 45, 5455. Read on 03.03.2021. https://doi.org/10.1039/C5CS00812C

ISO 37122:2019. 2019. Sustainable cities and communities - Indicators for smart cities, 1st Edition. Read on 01.03.2021.
https://www.iso.org/standard/69050.html.

Jintanawan, T., Phanomchoeng, G., Suwankawin, S., Kreepoke, P., Chetchatree P. & U-viengchai, C. 2019. Design of Kinetic-Energy Harvesting Floors. Energies 2020, 13(20), 5419. Read on 25.03.2021. https://doi.org/10.3390/en13205419

Karam, R, A. & Morgan, K, Z. 1976. Energy and the environment Cost-benefit Analysis. Pergamon Press, Inc. Read on 12.05.2021

Khan, A, H. & Saeed, A. 2017. Self-energy sustainable playgrounds for children. Read on 10.04.2021. https://ieeexplore.ieee.org/document/8324167

Maltese, L., Mariotti, L. & Boscacci, F. 2016. Smart City, Urban Performance and Energy, Springer International Publishing, Switzerland, p. 25-42. Read on 02.03.2021. https://link.springer.com/chapter/10.1007/978-3-319-31157-9_2

Product Catalogue 2017, Playground Energy. Read on 24.04.2021.
https://elverdal.dk/media/uploads/Playground-energy-katalog-Elverdal.pdf

Reichental, J. 2020. Smart Cities for Dummies, John Wiley & Sons, Inc. Read on 10.03.2021

SCCEI Regional Snapshot, Auckland, New Zealand. 2018. Read on 05.05.2021
https://anz.smartcitiescouncil.com/resources/smart-cities-regional-snapshot-auckland-new-zealand

Seow, Z, L., Chen, T, S. & Khairudin, N, B. 2011. An Investigation into Energy Generating Tiles -Pavegen, University of British Columbia Social Ecological Economic Development Studies (SEEDS) Student Report. Read on 12.05.2021.

Sisó, R.2016. The Energetic Playground, A feasibility study applying energy sources on a Playground: Green Energy alternatives. Degree Thesis for Bachelor of Engineering, Degree Programme in Energy and Environmental Engineering, Novia University of Applied Science, Vaasa, Finland. Read on 20.04.2021.

Smart Cities How rapid advances in technology are reshaping our economy and society. Version 1.0, November 2015. Govlab, Deloitte, Read on 10.03.2021. https://www2.deloitte.com/tr/en/pages/public-sector/articles/smart-cities.html

Smart City Index 2020. Institute for Management Development in collaboration with Singapore University for Technology and Design (SUTD). Read on 25.03.2021. https://www.imd.org/smart-city-observatory/smart-city-index/

Smart Cities Inspire Citizens. How do cities & buildings of the future inspire people? Case Studies. Read on 25.05.2021.https://pavegen.com/smart-cities/

Smart Energy Playground for the Whole Family. 2017. Read on 24.05.2021. https://amsterdamsmartcity.com/updates/project/green-energy-playground-for-the-whole-family

Song, H., Srinivasan, R., Sookoor, T. & Jeschke, S. (ed) 2017. Smart Cities Foundations, Principles, and Applications. John Wiley & Sons, Inc. Read on 14.04.2021.

Transport Hubs. How can transport hubs become destinations people want to visit? Case Studies. Read on 25.05.2021. https://pavegen.com/transport-hubs/

Turečková, K. & Nevima, J. 2020. The Cost Benefit Analysis for the Concept of a Smart City: How to Measure the Efficiency of Smart Solutions? Sustainability 2020, 12(7), 2663. Read on 15.03.2021. https://doi.org/10.3390/su12072663

World Urbanization Prospects 2018. 2019. United Nations, New York. Read on 02.03.2021. https://population.un.org/wup/Publications/Files/WUP2018-Higlights.pdf

Zhou, M., Al-Furjan, M.S.H., Zou, J. & Liu, W. February 2018. A review on heat and mechanical energy harvesting from human –Principles, prototypes, and perspectives, Renewable and Sustainable Energy Reviews, v. 82, p. 3582–3609. Read on 10.03.2021. https://www.sciencedirect.com/science/article/abs/pii/S1364032117314776