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ABSTRACT

This report describes the design and construction of an innovative urban transportation system that uses Metrobuses that are powered entirely by 100% renewable solar energy. Beginning with a review of the literature on global energy and climate challenges, the paper emphasizes the importance of solar energy, including its integration with advanced battery storage systems. The project's aims, motivated by the urgency of combating climate change, include a thorough examination of solar panel design, environmental impact, and economic feasibility. The report also covers risk analysis, project budgeting, and a time scale with a Gantt chart. Innovative 5-dimensional project management is offered, incorporating radar maps, to identify complexity at various project stages. The study finishes with suggestions for future work, conclusion and references that support the project's research and analysis.

Keywords: solar energy, metrobus, urban transportation, urban planning, sustainability, renewable energy, climate change, solar panel, innovation, green peace.

1. INTRODUCTION

1.1 Literature Survey

1.1.1 The Source of Energy in the World

In the past few years, rapid advancements in technology and an increasing worldwide population have led to a higher need for energy. This led to the emergence of two types of energy sources which are renewable energy sources and non-renewable energy sources. As the need for energy increases, there has been a shift towards non-renewable energy sources due to the production of more energy at a cheaper cost. Today there is a big dependence on non-renewable energy sources all around the world. Moreover, a lack of understanding about renewable energy sources has caused various issues such as global warming, the release of CO2 and the greenhouse effect.

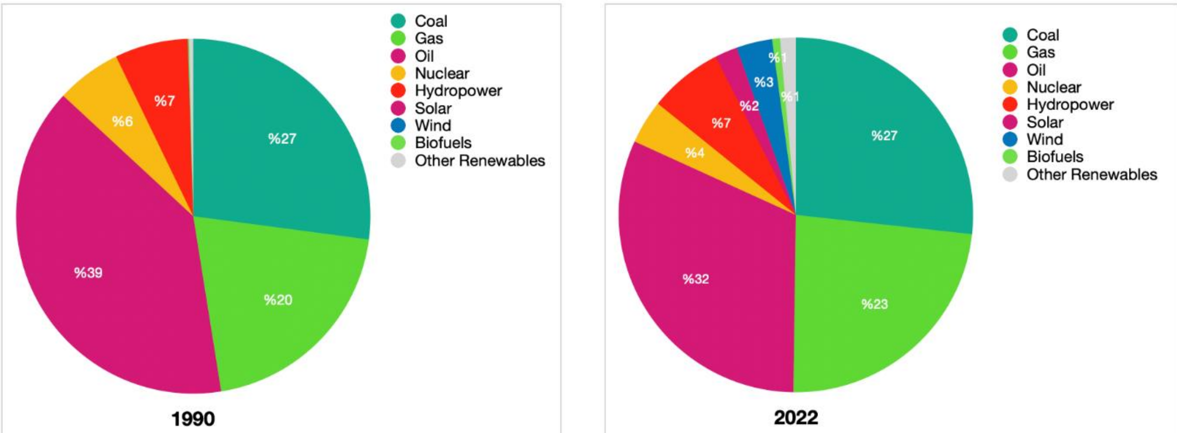

Figure 1 Annual gross world energy consumption

Adapted from [1]

The chart above shows that there is a small change in the energy land space between 1990 and 2022 even if the total annual energy consumption increases over years. This suggests that while overall energy demand has grown, the composition of the energy sources has remained largely consistent.

Moreover, from 1990 to 2022, there was only a small change in the portion of fossil fuels used, decreasing by just about 5%. This slight drop happened even though there was a 54% increase in the total energy used each year during those 30 years. On a more hopeful manner, the percentage of 'low-carbon fuels' saw a minor rise of 10.9% going from 1.07% in 1990 to 11.9% in 2022. These numbers show that progress in reducing the use of fossil fuels has been slow, and it emphasizes how crucial it is to speed up the shift to low-carbon energy sources to effectively tackle climate concerns.

Overall, although we've made some progress in using cleaner energy sources, the speed of this change hasn't been as big as we'd like in relation to reducing carbon emissions. To make efforts to reduce carbon emissions work better, we need a much bigger increase in the role of electricity in our energy use. This will help us move towards using cleaner sources of electricity and lower carbon emissions.

1.1.2 CO2 Emission and Greenhouse Gas

Carbon dioxide (CO2) is a gas found in the Earth's atmosphere in small quantities and helps keep our planet warm like other greenhouse gases. It's a special type of gas called a greenhouse gas, which means it can trap heat and then send it in different directions, including back to the Earth's surface. However, when people add extra carbon dioxide to the air, it's like giving a big boost to this natural warming, and that's why the Earth's temperature is increasing.

Since the 18th century's Industrial Revolution, human activities have significantly raised the amount of CO2 in the atmosphere. In 2022, the global average of carbon dioxide reached a new high: 417.06 parts per million [2]. Carbon dioxide levels are going up mainly because of the fossil fuels that people use for energy. Burning fossil fuels such as coal, oil, and natural gas is the main reason for the worldwide increase in CO2 emissions. According to a report from the International Energy Agency, the CO2 emissions from energy sources around the world increased by 0.9% in 2022. This means an extra 321 million tons of CO2, making the total yearly emissions reach a new record high of over 36.8 billion tons [3].

As seen in the chart below, there is a likely exponential increase in global CO2 emissions from energy combustion and industrial processes between 1850 and 2022. In the year 2022, the six biggest greenhouse gas emitters in the world were China, the United States, India, the European Union (EU27), Russia, and Brazil. These countries released a lot of harmful gases into the atmosphere which is more than the half of the emission.[4]

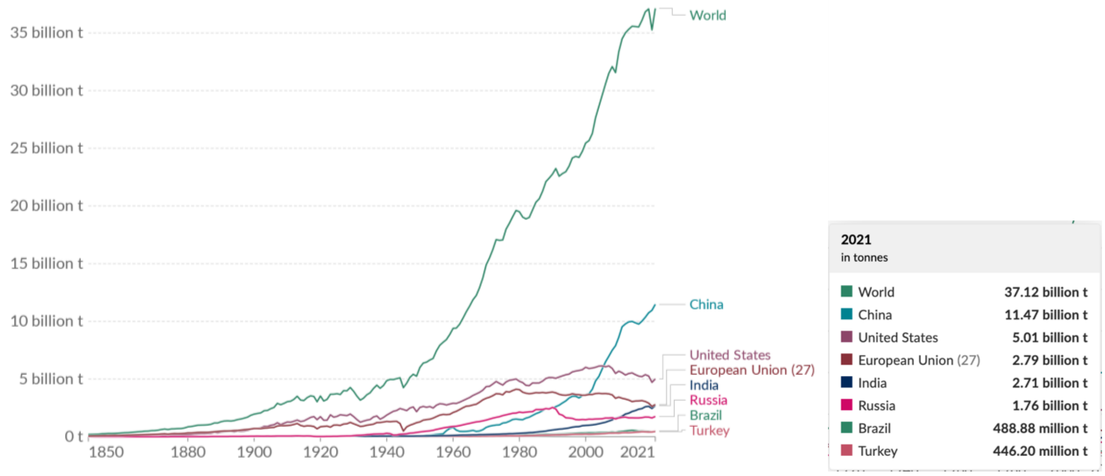

Figure 2 Annual CO2 Emissions from fossil fuels and industry

1.1.3 Climate Change and Global Warming

Global warming is a serious worldwide problem mainly caused by more CO2 and greenhouse gases in the air. The main reasons for global warming are CO2 emissions and greenhouse gases. It happens because we're using non-renewable energy sources like fossil fuels too much, and we're also doing a lot of industrialization and deforestation. These things make the levels of these gases in the air go up. That, in turn, makes the Earth's surface get hotter, which leads to global warming and changes in the climate.

The problem of global warming is our fault because of how we treat the environment. Things like having lots of people, uncontrolled industry, messy cities, regional fights, and using harmful stuff like pesticides and chemicals have made our air, water, and soil dirty. The big use of fossil fuels and cutting down trees, especially since the industrial revolution, makes these problems worse. Since fossil fuels are a big part of the world's energy, the main reason for global warming is greenhouse gases, especially carbon dioxide from industry and transportation.

You can see the effects of global warming in different weather and environment changes. Higher temperatures make the oceans warm up, ice melt, and more water evaporate. Ocean warming, which happens because the sea takes in too much heat, causes a lot of different problems. Melting ice and snow make the sea level go up, and the data tells us that the ice in Antarctica and Greenland is disappearing fast. Sea levels rising because of water expanding in melting ice sheets and glaciers are a big worry, especially for people living near the coast. It's a big concern for our world and the environment.

In short, too much CO2 and greenhouse gases in the air, mostly because of how we use non-renewable energy and do a lot of industry, have caused global warming. It's making the environment change, like warming up the oceans, melting ice and frozen ground, and making the sea level rise. We need to deal with these problems to take care of our planet and the people in the future.

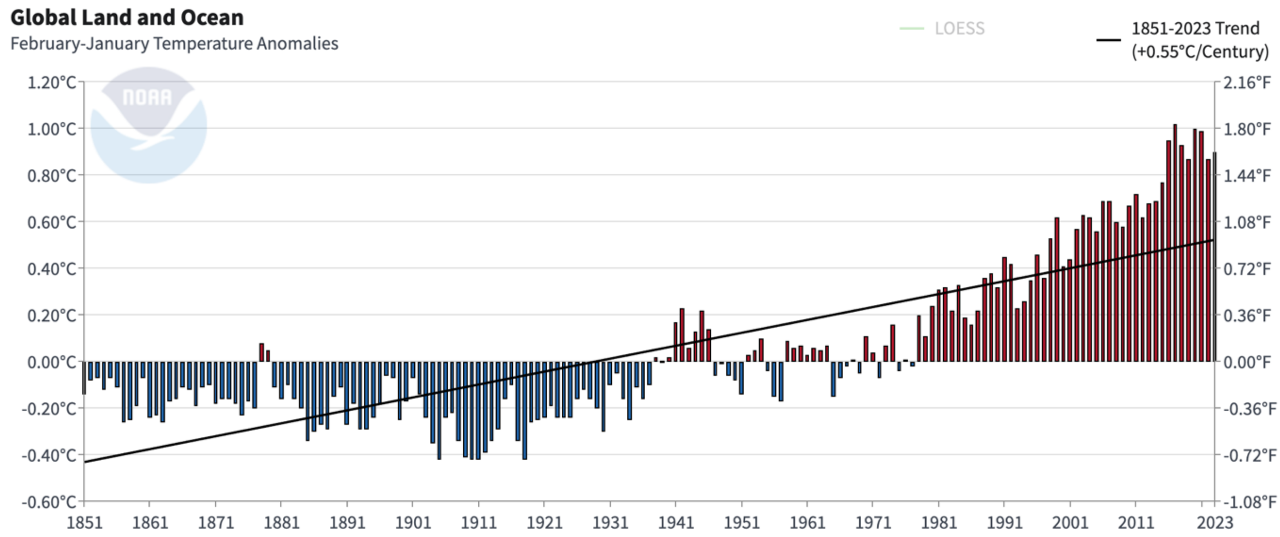

Figure 3 Global Land and Ocean Temperature Anomalies Adapted from [50]

The chart above represents the global average land-sea temperature anomaly between 1850 and 2023. It is obviously seen that the temperature is increasing highly on 73 years, and it is recorded that the last 10 years are the warmest years in the history [31].

1.1.4 Solar Energy

Before renewable energy sources became widespread, harmful gases released by fossil fuels used caused serious problems such as environmental pollution, climate change, global warming, and CO2 emissions, which posed a serious threat to our world [8]. The increase in the energy required over time with the increase in our world population, industrialization, and technological developments has increased the amount of fossil fuel consumed, so increased the damage to our atmosphere, and led to insufficient resources [6].

For all these issues that above, the world turned to search for a new source, and renewable energy sources began to become widespread. Renewable energy is a type of energy obtained from natural resources and can renew itself in nature. According to research, in 2021, the electrical energy obtained from all clean energy sources exceeded coal, which corresponds to 36% of the world's electricity, by providing 38% [8].

The source of solar energy, one of the most important renewable energy sources, is heat and light energy from the sun. Heat and light energy are converted into electrical energy through solar panels. Since it uses its own heat and light source, it is not an external source, making it an abundant and sustainable energy source [7].

Solar Energy in Turkey

Due to its geographical location, Turkey's solar potential is higher than other European countries. In Turkey, every year sunlight is approximately 2600 hours, and this is almost double that of Germany [9]. Turkey can become a very powerful country for global problems with the correct use of solar energy.

The Areas Solar Energy Used widely is the following:

● Agriculture	● Industry
● Power Plants	● Daily materials like watches and calculators
● Transportation	

However, the most researched and widespread area, especially recently, is the transportation area. Solar energy has begun to be used in many transportation vehicles such as cars, trains, metro buses, and buses. With the rapid development of technology, it is predicted that solar-powered transportation vehicles will become a serious part of our lives [10].

1.1.5 Energy Storage Solutions as “Batteries”

Solar energy is a type of energy that comes from the sun. Therefore, we can use this energy if the sun is present, but sometimes we need energy when there is no sun. Therefore, we should save some of the solar energy to use it later when we need it. We can do this by using special technologies that store extra energy and release it when we need it. This means that we can use solar energy even on a day when the sun is not shining. This technology has many benefits. A few of them are as follows:

- It helps balance the energy load: While storage technology stores energy when there is no energy use; When energy is needed, it is used to use the stored energy.
- It is environmentally friendly: It reduces the need for fossil fuels to meet energy, reducing harmful emissions into the air and damage to the environment.

- Saves electricity costs: The stored energy is used when the sun sets, reducing grid consumption. Accordingly, it reduces electricity costs.

These are special batteries that store solar energy while using this technology. These batteries can store energy from the sun and release it when we need it. Using this technology, the United States is getting better at saving and using energy. They predict that by 2025 they will be able to save more energy than ever before [11]. This is because technology has developed and cheaper ways to save energy by using batteries have been found.

1.1.5.1 Classification of Batteries

1.1.5.1.1 Batteries According to Their Chemical Composition

It wouldn't be wrong to compare batteries to different types of sugar. There are six main types of batteries based on whether they are made of lithium-ion, lithium iron phosphate, lead-acid, flow, brine, and nickel-cadmium [12].

Lithium-Ion:

Lithium-ion batteries are special types of batteries that can hold a lot of energy in a small space. They consist of six different chemicals and are known to be good at storing energy.

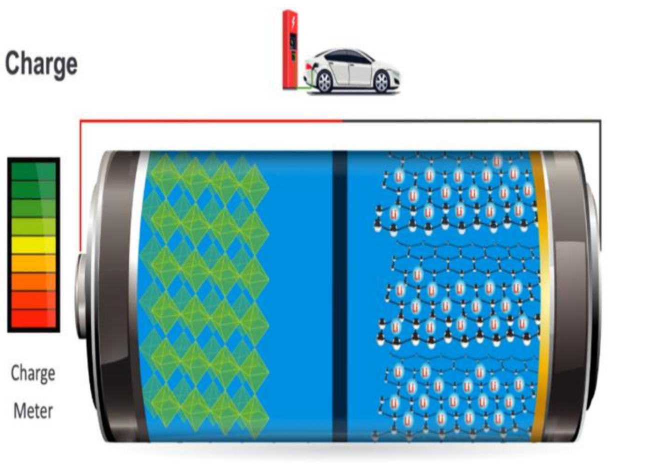

Figure 4 Lithium-Ion Batteries Adapted from [14]

Advantages	**Disadvantages**
• High density	• Expensive
• No need for regular maintenance	• Risk of fire (Overheating as a result of incorrect installation)
• More than 10 years (long) lifetime	• Nickel and cobalt mining practices that cause negative results (environmental pollution, etc.)
• 80% discharge depth	
• Widest range of brand-model options	

LFP (Lithium Iron Phosphate):

LFP (Lithium Iron Phosphate) Batteries: Lithium iron phosphate (LFP) batteries technically fall into the category of lithium-ion batteries, but this battery chemistry has emerged as an ideal choice for energy storage for residential solar power and is therefore considered distinct.

Advantages:	**Disadvantages:**
• They have a longer lifespan than other lithium batteries, making them popular as a long-term storage solution.	• LiFePO4 is a new type of battery chemistry; This means there are fewer producers and less supply; This makes LiFePO4 batteries more expensive.
• Deeper discharge: LFP batteries have a deeper discharge, resulting in greater energy storage capacity and greater battery life. means flexible use.	
• This is a more environmentally friendly option: Since they do not contain nickel or	

cobalt, they are an environmentally friendly option, which is an important advantage in terms of sustainability.	
• Wide temperature range: They operate in a wider temperature range than other batteries. They can work, that is, they are suitable for various climatic conditions.	
• Low risk of heat loss: There is almost no risk of heat loss, which is an important safety advantage.	

Lead-Acid:

Lead-acid batteries are a technology that has been used since before the American Civil War. However, today it is insufficient compared to other batteries.

Advantages:	**Disadvantages:**
• Initial expenses are minimal.	• Requires a low depth of discharge (around 50%).
• Well-established technology.	• Has a shorter lifespan (approximately 5 years).
• Approximately 95% of the material is reusable.	• Increased expenses over the long term due to maintenance and replacements.
• Operates efficiently within a broad temperature range.	• Lower energy density, resulting in a larger spatial footprint.

Flow Batteries

Flow batteries, which substitute a single battery tank (such as a lead-acid or lithium-ion battery), have two distinct tanks, one for positive charge and the other for negative charge. These tanks are divided by a thin membrane. During the charging process, the solution flows from one tank to another and stores energy. As it flows, the solution releases electrons that return to the original reservoir [12].

Advantages:	**Disadvantages:**
• Complete discharge capability (100% depth of discharge).	• Occupies a significant volume because of its low energy density.
• Extended lifespan (approximately 30 years).	• Not currently appropriate for residential applications.
• No risk of thermal runaway.	• Comes with a high cost.
• Requires no maintenance.	
• Fully recyclable.	

Saltwater batteries:

Saltwater batteries are a special type of battery that uses salt water instead of a special liquid called lithium. Salt water is easier to obtain and not as dangerous to use.

Advantages:	**Disadvantages:**
• Long life	• Lower energy density (requires a lot of space)
• Environmentally friendly (does not contain heavy/toxic metals and can be easily recycled)	• Expensive

• 100% depth of discharge	
• No risk of thermal runaway	

Nickel-cadmium (Ni-Cd):

Nickel-cadmium batteries are a type of battery that has been on the market for a long time. They are used to power many different things, such as toys and even large airplanes.

Advantages:	**Disadvantages:**
• Long life	• Cadmium possesses high toxicity.
• Functions effectively in harsh temperatures.	• Memory susceptible to the impact.
• Requires minimal maintenance.	

1.1.5.1.2 Backup vs. consumption-only batteries

Backup and consumption-only batteries represent two different types of solar energy storage systems. Backup batteries typically consist of a battery cabinet, a charge/discharge control box, and a sub-panel that determines which electrical systems will be backed up. Consumption-only batteries, on the other hand, allow homeowners to store and consume their solar energy. These batteries, which are backup-free and more economical, provide the basic functions of traditional backup batteries while allowing for a simpler structure and cost savings [12].

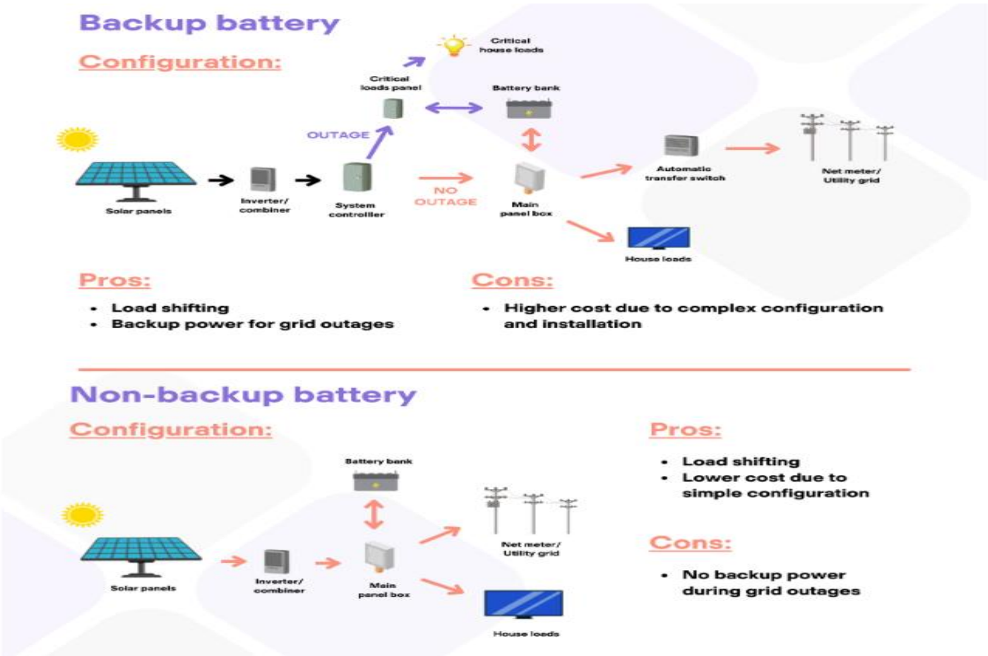

Figure 5 Backup and Non-Backup Battery Adapted from [12]

1.1.5.1.3 AC and DC connected batteries

The key difference between AC and DC coupled batteries is round-trip efficiency. AC-coupled systems require energy conversion multiple times before solar energy is delivered to your home. Each conversion process causes losses, reducing system efficiency and generally providing an efficiency of around 85-90%. On the other hand, DC-coupled systems can achieve a higher efficiency rate of up to 97.5% since only one conversion is required [13].

1.1.5.2 What should we pay attention to when choosing a battery?

Battery Capacity: Think of battery capacity as an energy-storing container. To accommodate the energy generated by solar panels, it must have the proper size. Too little size will prevent it from holding adequate energy. But if it's too big, it might not function.

Connecting Options: It's important to take into account the differences between batteries linked DC and AC. DC batteries are recommended for more recent installations, while AC-coupled batteries are employed as add-ons to systems that already exist. On the other hand, DC batteries might need more expensive and intricate installations.

Depth of Discharge: The maximum amount of battery discharge that is possible is referred to as the depth of discharge. The battery's lifespan might be impacted by this. Lead-acid batteries typically have a discharge depth of about 50%, whereas lithium-ion batteries often have a discharge depth of 80% to 100% [12].

Power Rating: The highest quantity of power that a battery can generate during a specific time frame. Low-capacity batteries with a high-power rating can use up energy more quickly than large-capacity batteries, which can run small gadgets for extended periods of time.

Full Cycle Efficiency: This is the maximum energy that a battery may use following a charge. This rate is often close to 80% and is influenced by the battery's efficiency.

Warranty: The typical solar cell warranty lasts for ten years. Nonetheless, the terms and conditions of the guarantee should be carefully reviewed before selecting a battery. The length of the warranty is crucial for long-term performance and investment protection.

1.1.6 Solar Panel Technology and Its Integration

To prevent environmental harm, the increasing demand for energy caused by population development and economic expansion needs a move toward renewable energy sources. Solar energy is a promising answer, with significant efforts being made to advance its technological development. The conversion of sunlight into electricity is known as solar energy technology. Its technical name is Photovoltaic, which is a combination of the terms "Photo" (light) and "Voltaic" (electrical voltage). [17] Hence, solar energy is obtained with two different technologies, thermal solar technologies, and photovoltaic solar technologies. Photovoltaic PV solar technology is a type of renewable energy that turns sunlight directly into electricity. This method relies on solar cells, which are typically comprised of semiconductor materials like silicon. When sunlight strikes these solar cells, it stimulates electrons, resulting in an electric current.

The term photovoltaic refers to the generation of electricity from a photon of light. As a result, solar cells and panels are referred to as photovoltaics. Photovoltaic (PV) solar energy systems are classified according to their connection status to the power grid and their intended usage. Grid-connected (On-Grid), off-grid (Off-Grid), hybrid photovoltaic energy system, and agricultural pumping applications are the four broad categories. Photovoltaic (PV) solar energy systems also known solar panels technology has seen significant progress over the years, and here are the important aspects of solar panel technology.

Photovoltaic Cells:

Solar panels are made up of numerous individual solar cells, which are commonly constructed of crystalline silicon. These cells serve as the basic building pieces of a solar panel, turning sunlight into electricity.

Types of Solar Panels:

Monocrystalline: Single Crystal Structure, Highly Efficient, More Expensive

Polycrystalline: Multiple Crystal Structure, Less Efficient, More Affordable

Thin-Film: Depositing thin layers of photovoltaic material on various substrates, Less Efficient, Flexible and Lighter

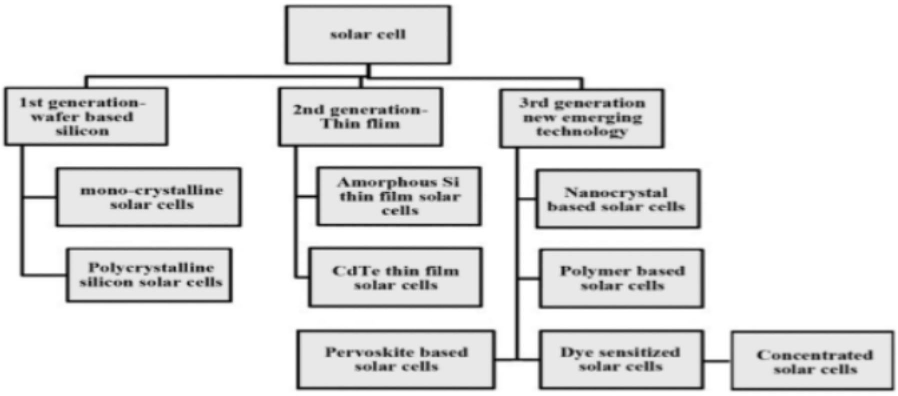

Figure 6 Types of Solar Cells Adapted from [16]

Inverter Technology:

Solar panels generate direct current (DC) electricity, however most household appliances and the power system use alternating current (AC). Inverters are used to transform the direct current (DC) electricity generated by solar panels into alternating current (AC) electricity that may be consumed in residences or put into the grid.

Solar Tracking:

Solar tracking devices are used by some modern solar installations to follow the sun's journey across the sky. These systems tilt and turn the solar panels during the day to maximize their exposure to sunlight and hence increase energy production.

Bifacial Solar Panels:

These panels can absorb sunlight from both the front and back sides, resulting in a higher energy yield. They are frequently employed in niche applications such as ground-mounted systems.

Solar Panel Materials:

While silicon-based panels are the most popular, research into novel materials such as perovskite solar cells, which have the potential to be more efficient and cost-effective, is ongoing.

Energy Storage: By combining solar panels with energy storage options such as lithium-ion batteries, excess energy generated during the day can be stored for use at night or during cloudy times.

Smart Grid Integration: Advanced systems can be linked to the grid, allowing excess energy to be sold back to utility companies, generating revenue for homeowners or businesses.

Maintenance: Solar panels require little care, however they should be cleaned on a regular basis to eliminate dirt and debris. Inverters and other components may need to be cleaned on a regular basis.

Impact on the Environment: Solar panels generate clean, renewable energy, lowering greenhouse gas emissions and reliance on fossil resources. Their manufacturing and disposal, however, can have environmental consequences, and efforts are underway to make the entire lifespan more sustainable.

1.1.7 How Solar Panels Work?

The main purpose of humanity's transition to using solar panels is to provide an environmentally friendly and sustainable energy source by converting sunlight into electrical energy. Investments in solar energy are also increasing regularly, especially to prevent the accelerating global warming and the depletion of the ozone layer. Expanding the use of this clean energy source and becoming one of the main energy sources will help reduce electricity costs and reduce the environmental impacts of non-renewable resources. Therefore, solar panels play an important and flow-changing role in energy production. So, what is the working principle of solar panels, which are of such great importance?

The basic particle that solar panels use to release energy is photons scattered from the sun. And the working principle of the system is designed entirely on how the kinetic energy of these photons can be converted. The processes a solar panel goes through when converting the rays from the sun into electrical energy are listed as follows.

1. Capturing Sunlight:

To convert the rays coming from the sun to our world into electrical energy, they must first be captured and stored by a system. For this reason, the photovoltaic (PV) cells on solar panels are made of semiconductor materials specially designed to capture sunlight. Thanks to its surface covered with these cells, the solar panel captures the sunlight falling on it and makes it ready for operation.

2. Absorption of Captured Light:

After sunlight is captured by the semiconductor surface of the solar panel, it is absorbed by the PV cells. As it is known, sunlight contains energy particles called photons, and these photons excite the atoms of PV cells. In this way, the separation of these parts is ensured and the absorption of photons, which are the energetic units of sunlight, is achieved.

3. Electron Release:

Excited atoms perceive this warning as an alarm system and release electrons, and these released electrons move inside the PV cell and act as a current generator.

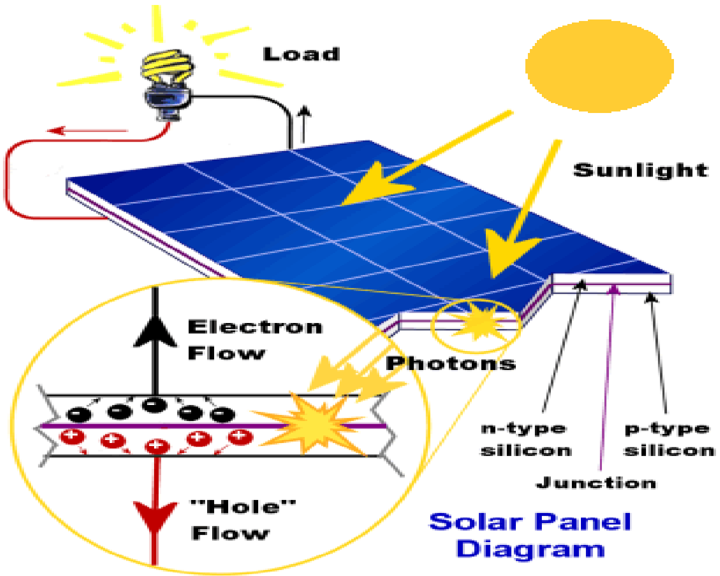

Figure 7 Solar Panel Diagram Adapted from [23]

4. Electricity Production:

In the last step in the electricity production process, the released electrons are collected in one direction using a steering mechanism to create an electric current. Thanks to this directing mechanism, the electric current created is directed to the terminals of the solar panel.

5. Electricity Use or Storage:

Finally, the generated electric current can be directed to energy storage systems (e.g., batteries) or to the area needed for direct use in case it cannot be used immediately. This electricity can be used in homes, workplaces, vehicles or other applications and can help humanity prevent many problems such as environmental pollution or global warming. [21]

1.1.8 Global Initiatives and Policies for Carbon Reduction

Paris Agreement (2015)

The United Nations Framework Convention on Climate Change (UNFCCC) signed the Paris Agreement in 2015. The agreement basically aims to reduce the impact of concepts such as climate change, global warming, and greenhouse gases worldwide. Although the agreement was signed in 2015, it came into force in 2016. [26] This agreement developed the framework set by the Kyoto Protocol and became one of the important steps taken by the world in cooperation on climate issues. Although this agreement has been accepted by many countries around the world, a few countries have not signed this agreement. Although they are members of the UNMFCC, Eritrea, Iran, Iraq, Libya, and Yemen are countries that have not signed the agreement.

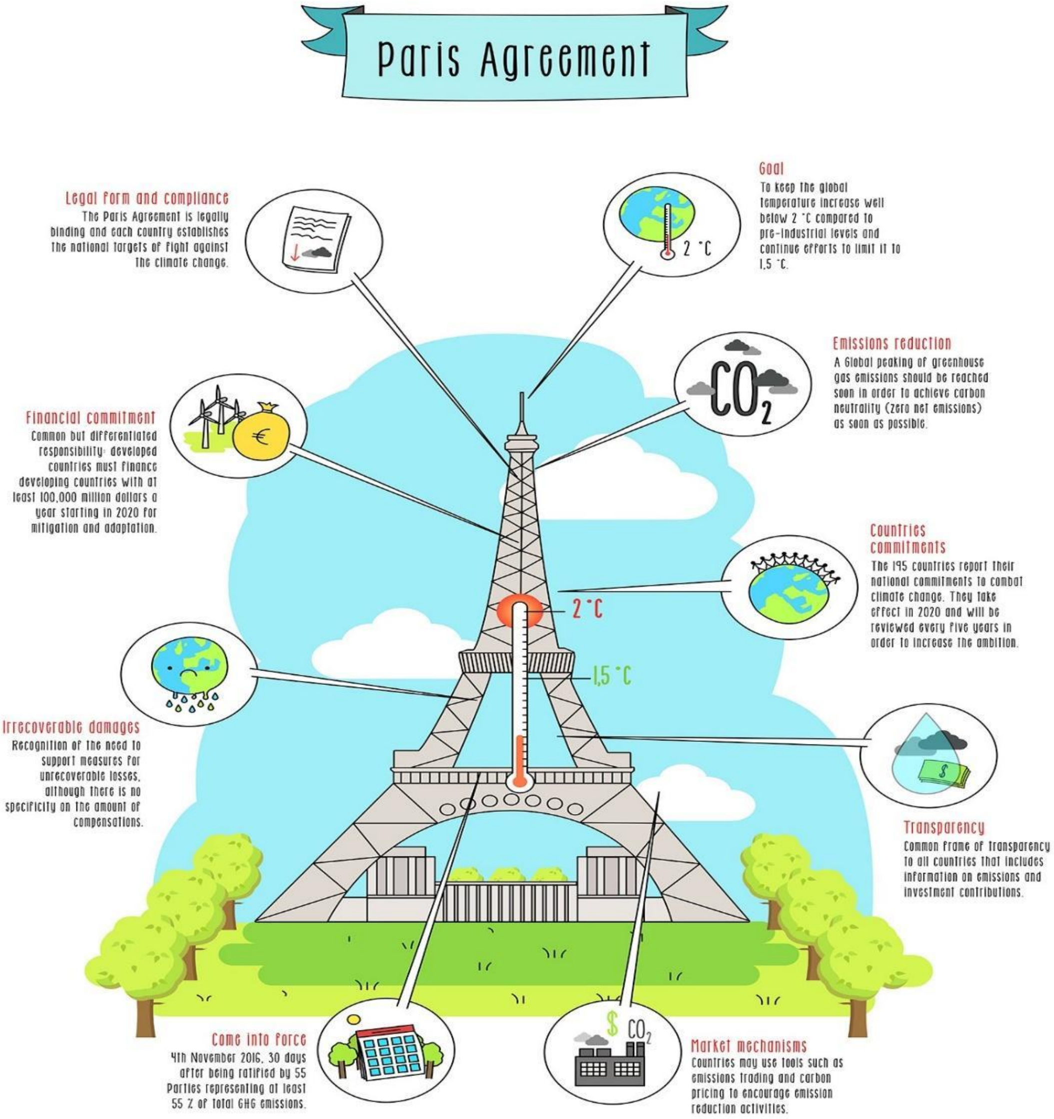

Figure 8 Paris Agreement

Solar Energy

One of the most important sustainable energy sources is solar energy. It is the process of converting the light coming from the sun into electrical and heat energy. This light is usually collected in solar panels and converted into energy there. [27]

Solar Energy usage types

- Photovoltaic (PV) Systems
- Thermal Solar Energy Systems

- Concentrated Solar Power

Advantages of Solar Energy

- Clean and Renewable Energy
- Limited Land Use and Environmental Impact
- Decreased Utility Bills
- Energy Autonomy
- Employment Opportunities

The Usage Areas of Solar Energy

- Solar-Powered Roofs
- Solar Power Plants
- Solar Farms
- Solar Water Heating Systems
- Solar Traffic Signal Systems
- Solar Lighthouses
- Solar-Powered Satellites
- Solar-Powered Airports
- Solar-Powered Vehicles

Electric Cars

Cars that allow the engine to run thanks to the electricity stored in the battery and thus enable the car to move are called electric cars. Unlike other types of cars, they are vehicles that do not use fuels such as gasoline or diesel, so they do not produce substances that harm the environment. [30]

Environmental Advantages

Since electric vehicles do not produce substances that harm the environment, they reduce greenhouse gases and emissions. In this way, electric cars make a significant contribution to the fight against climate change. [25]

Cost Savings

Recently, gasoline and diesel fuel prices have increased significantly due to the increase in inflation around the world. Since electric cars use electrical energy, they are considered budget-friendly vehicles.

Encouragement and Fiscal Advantages

Since electric cars and vehicles do not emit substances that harm the environment, many countries have incentive laws to increase their use.

Carbon Pricing

Carbon pricing is an application where the state assigns costs to reduce the greenhouse gas production emitted in factories, businesses and production areas across the country and encourages reducing the impact on the environment. Thanks to this application, businesses and factories reduce the amount of CO_2 and greenhouse gases they emit into the environment because they pay an amount of penalty to the state in direct proportion to the amount of CO_2 and greenhouse gases they emit.

Transportation policies

Transportation industry is one of the important factors affecting carbon emissions and environmental pollution. Thanks to transportation policies aimed at carbon reduction, this carbon emission and environmental pollution are significantly reduced. Thanks to the support of vehicles that are environmentally friendly and run on renewable energies, gases released in the field of transportation are prevented. [29] Some of the policies carried out in this field:

Fuel Economy Standards: Some basic fuel efficiency processes are carried out in the production of new generation automobiles. Thanks to these processes, it is aimed to produce a minimum level of carbon emissions by consuming a certain amount of performance per certain kilometer. [28]

Public Transportation Investment: Transportation channels and diversity are being increased in many cities, especially in metropolises. Thanks to this diversity of transportation, the use of individual vehicles is reduced and less amount of greenhouse gases and CO_2 gases are released into the environment.

Global Green New Deal

The concept of the "Global Green New" agreement was created to deal with problems such as economic inequality and sustainable development, especially climate change. [52] The basic elements that make up this concept are the policies and plans of the countries. The main goals and objectives of this agreement are:

Climate Action: It is to combat climate change by emphasizing the support of renewable energy sources to reduce carbon emissions and greenhouse gas emissions.

Sustainable Development: The Global Green New Deal advocates for economic growth that prioritizes environmental sustainability and social fairness while considering the well-being of future generations.

Job Generation: It provides employment creation in sectors covering the concepts of renewable energy, energy efficiency and environmental pollution prevention.

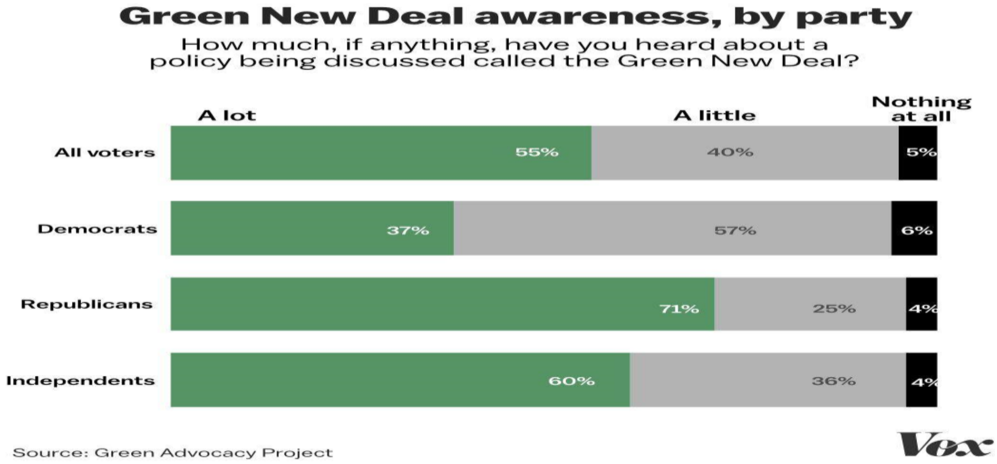

Figure 9 Green New Deal Awareness Statistics

1.2 Objective of the Project

The transportation sector is a major contributor to environmental pollution and global warming, accounting for approximately 25% of global greenhouse gas emissions [32]. To prevent climate change and protect the environment, it is essential to transition to a more sustainable transportation system. One promising solution is to use only renewable energy sources to power transportation vehicles such as solar-powered vehicles. This would eliminate the emissions from fossil fuels and help to protect the environment. This project is aims to show that using 100% renewable energy in transportation system reduce the carbon emission, prevents climate change and global warming on a large scale, and leads to positive economic and social impacts.

1.3 Current Global Problem and Motivation

Today, Urban transportation is a major contributor to CO2 emissions, accounting for about 23% of global energy-related CO2 emissions. In cities, transportation accounts for an even higher share of CO2 emissions, often exceeding 50% [33].

A study found that the top 15% of cities in the world accounted for 52% of all greenhouse gas (GHG) emissions. Most of these cities were in Asia and Europe, such as Handan, Shanghai, and Suzhou in China; Tokyo in Japan; Moscow in Russia; and Istanbul in Turkey.

The study also found that both developed and developing countries have cities with high GHG emissions. Some cities in developed countries, such as cities in Japan, the USA, Korea, Germany, and Singapore, also generated a great deal of emissions [38].

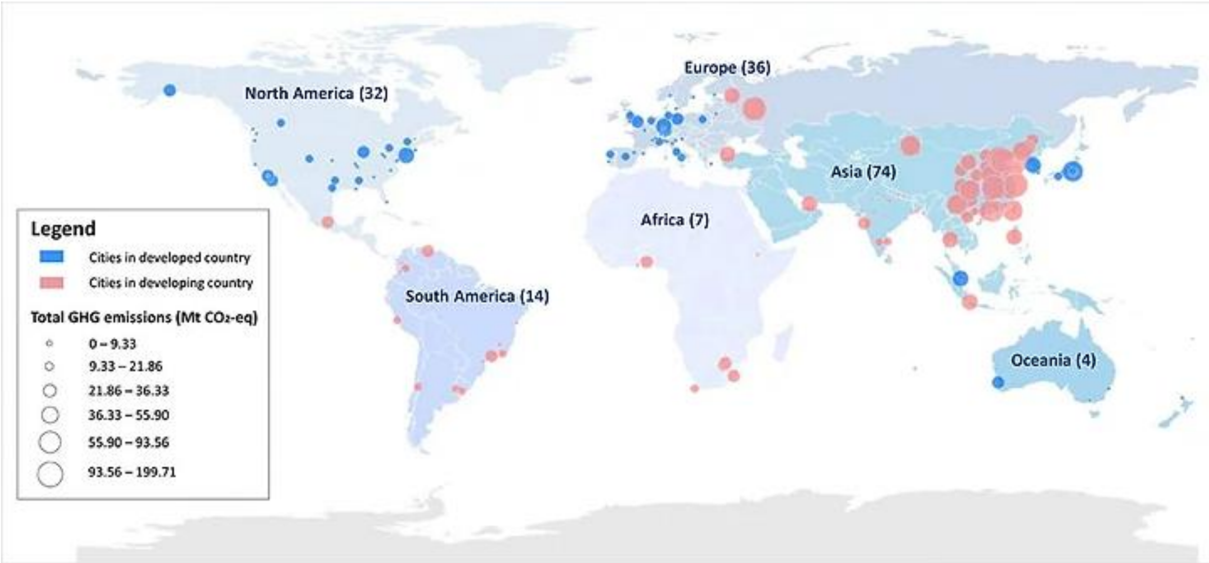

Figure 10 Total GHG Emissions Source: Adapted from [38]

There are several factors that contribute to the high CO2 emissions from urban transportation. One factor is the reliance on fossil fuels, such as gasoline and diesel, to power vehicles. Another factor is the high volume of traffic in cities. Finally, the design of many cities, with their dispersed development patterns and lack of public transportation options, encourages driving [34].

The high CO2 emissions from urban transportation have several negative consequences. They contribute to climate change, which can lead to more extreme weather events, such as heatwaves, droughts, floods, and storms. CO2 emissions also contribute to air pollution, which can cause respiratory problems, heart disease and cancer [35].

The motivation of this project is to design a Metrobus system in Istanbul that uses solar panels as an energy source to reduce CO2 emissions from urban transportation. To achieve this, we investigate an intensive literature survey and examine some studies conducted before. Then, we design our system based on our examinations by following the project management procedures.

1.4 Case Studies

Solar-powered vehicles are a game changer in sustainable mobility, harnessing the sun's energy to reshape the automotive industry. These vehicles have evolved from a once-futuristic concept to a driving force in the green revolution. Solar-powered vehicles transform sunshine into electric energy by combining cutting-edge technology and renewable energy, reducing reliance on traditional fuels and the environmental impact of transportation. The history of solar-powered vehicles can be traced back to pioneering attempts in the mid-20th century, such as the Sun mobile in 1955. [43] Subsequent advances in solar technology, energy storage, and electric propulsion have catapulted these vehicles to popularity, paving the way for a more sustainable and environmentally friendly future.

Australia / Byron Bay (2017)

In Byron Bay, Australia, the world's first 100% solar-powered train will make its debut. The Byron Bay Railways Company has transformed a 1949 model train into an eco-friendly electric train, complete with 6.5 kW solar panels and a battery capacity like that of a Tesla Model S. The two-car train, which can carry 100 passengers, requires only 4 kW of energy per trip and can go 12-15 miles on a single charge. [39] In keeping with its dedication to sustainable and ecologically friendly renewable energy methods, the company explored a diesel train but ultimately chose a solar-powered solution.

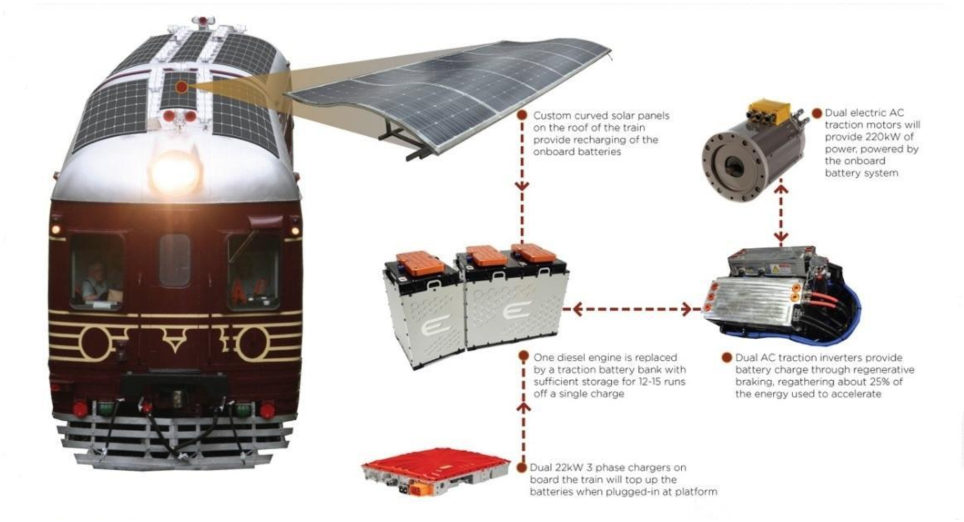

Figure 11 Byron Bay

India / DEMU (2017)

The world's first solar-powered DEMU (diesel electrical multiple unit) train took off from Delhi's Safdarjung railway station. The train, which runs from Sarai Rohilla to Farukh Nagar, is outfitted with 16 solar panels, each of which generates 300 Wp and costs Rs 54 lakh. The solar panels are part of the 'Make in India' project, and they are the world's first use of solar panels as a grid in railways. [40] The train has a battery backup and can run for 72 hours. The solar-powered DEMU trains contribute to Indian Railways' target of generating 1,000 MW of solar energy in five years. Solar power is being planned for both urban and long-distance trains, with perhaps 50 more coaches on the way. [40] The project is estimated to save Rs 700 crore per year, with a potential savings of 5.25 lakh liters of diesel per train over 25 years, resulting in a reduction of 1,350 tons of carbon dioxide emissions. [40]

Figure 12 DEMU

Tindo /Australia (2007)

Adelaide's Tindo electric bus is a trailblazing example of green technology integration into municipal infrastructure. It operates as part of the Adelaide Connector Bus service, offering free transportation to passengers as the world's first 100% solar-powered electric bus. Tindo, unlike other solar-powered cars, does not have solar panels on the vehicle; instead, it is powered by solar panels at the city's major bus station. This novel solution allows the bus to freely travel between the city center and North Adelaide while providing amenities such as air conditioning and WiFi to its 40 passengers.[41] The Tindo, commissioned from New Zealand's Designline International as part of a larger green project, is a zero-emissions car featuring a regenerative braking system that saves an additional 30% of energy use. It saved about 70,000 kg of CO2 emissions and 14,000 gallons of diesel in its first year. [41] Notably, the bus's innovative solar photovoltaic charging mechanism and capacity to go over 200 kilometers between recharges have piqued the interest of the green community at large.

Figure 13 Tindo

Sion / Germany (2022)

Pepper Motion and Sono Motors, both based in Germany, are working together to develop a solar retrofit option for commercial vehicles. The first vehicle to be outfitted with Sono's "Solar Bus Kit" is a modified Mercedes Citaro. While the PV system on the bus's roof does not directly power the bus's electric drive, it does contribute to the low-voltage electrical system by giving energy to the air conditioning system and other ancillary equipment. This reduces the strain on the high-voltage battery and the DC/DC converter, which may result in longer operating hours, fewer charging cycles, and reduced overall operating costs. The Solar Bus Kit will be tested on public roadways for two years, capturing real-world data on energy yield and consumption. For best energy utilization, the 1.3 kWp PV system connects with Sono Motors' MCU. [42]

Figure 14 Sion

Sunmobile / USA (1955)

William G. Cobb debuted the "Sunmobile," the world's first solar-powered automobile, during the General Motors Powerama auto show in Chicago on August 31, 1955. [43] The Sunmobile, a 15-inch-long vehicle, was the first to introduce photovoltaics to the automotive industry. It employed 12 selenium photoelectric cells to turn sunlight into electricity, which powered a tiny engine connected to the driveshaft [43]. Despite early demonstrations of solar power in automobiles, mass-produced solar automobiles have yet to hit the market. Solar car races, like as the 2008 North American Solar Challenge, continue to demonstrate photovoltaic automobile concepts in road races across the world [43].

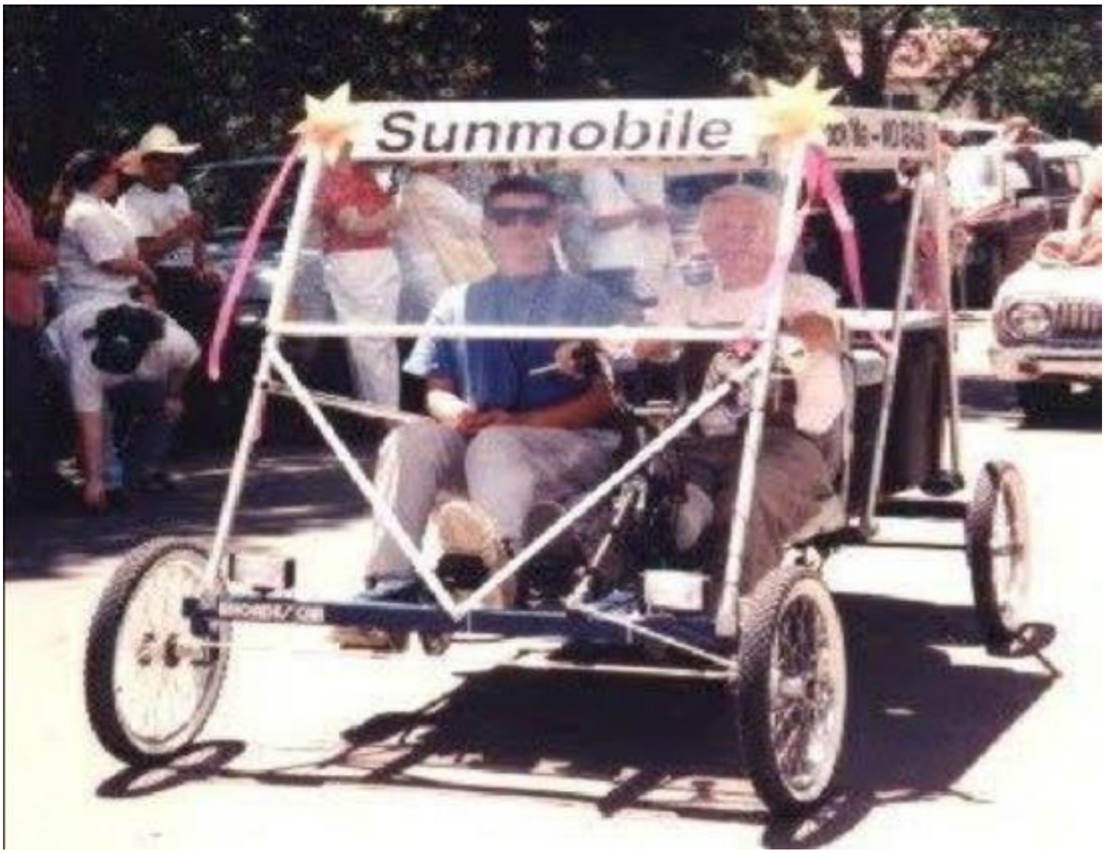

Figure 15 SunMobile

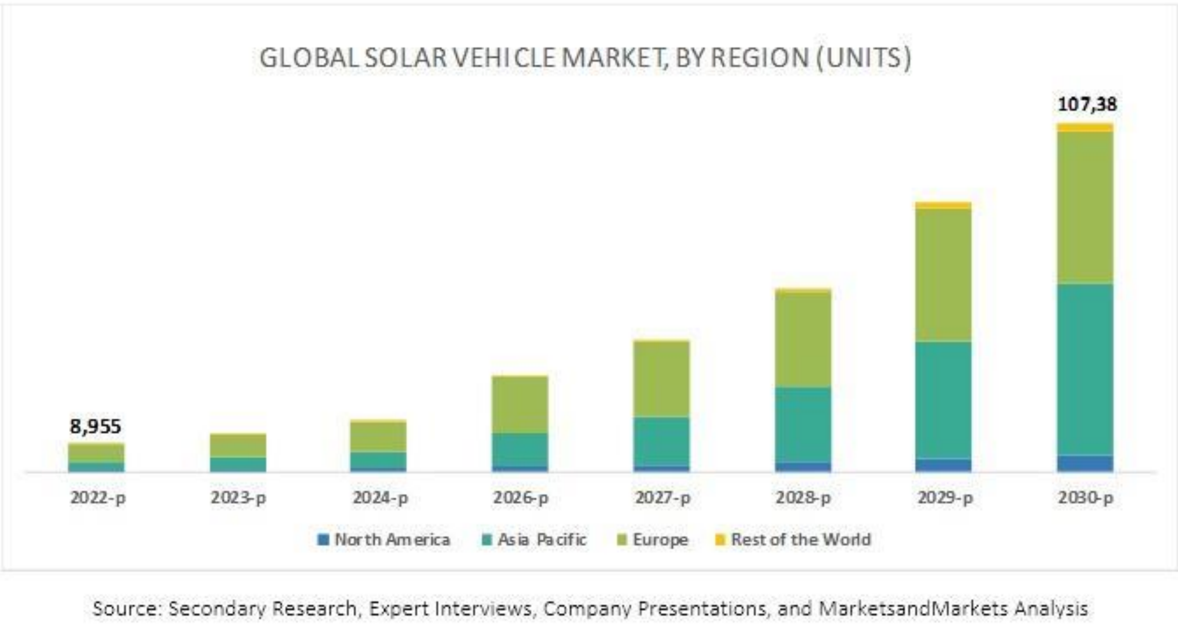

Figure 16 Global Solar Vehicle Market Adapted from [44]

The graph represents the dynamic trajectory of the global solar vehicle market from 2022 to 2030, focusing on the regions of North America, Asia Pacific, and Europe. Each year, the market data demonstrates a constant and encouraging growth trend in car marketing across all regions.

North America:

The solar vehicle industry in North America is experiencing a significant boom, reflecting an increasing acceptance of sustainable mobility alternatives. From 2022 to 2030, market share increases steadily, demonstrating the region's commitment to solar-powered vehicles. This expansion can be ascribed to a mix of technology improvements, advantageous legislative frameworks, and rising consumer environmental consciousness.

Asia Pacific:

The Asia Pacific region appears as a significant driver in the worldwide solar vehicle market, with substantial expansion anticipated throughout the projected period. Countries in this region, particularly technical behemoths like China and Japan, make important contributions to the upward trend. Government incentives, combined with increased consumer interest in environmentally friendly options, are driving a significant growth in solar car use.

Europe:

Europe, known for its proactive approach to environmental sustainability, is experiencing rapid growth in the solar vehicle market. From 2022 to 2030, the graph shows constant development, underscoring the region's significant investments in clean energy efforts. Stringent emission laws, along with a rising infrastructure for electric and solar charging, help Europe maintain its leadership in solar car adoption.

Global Outlook:

The global solar vehicle business is experiencing promising growth, highlighting a collective shift toward greener mobility alternatives. The years 2022 to 2030 will see a steady gain in market share, spurred by technical advancements, increased consumer awareness of climate change, and a rising consumer desire for sustainable transportation solutions.

Finally, the graph emphasizes the worldwide solar vehicle market's upward trajectory, demonstrating steady growth in North America, Asia Pacific, and Europe. As these regions continue to invest in solar technology and develop a favorable legislative environment, the solar car market will expand significantly, contributing to a more sustainable and environmentally conscious future in the automobile sector.

1.5 Hypothesis

Our hypothesis that the integration of solar panels for renewable energy can mitigate environmental concerns associated with traditional non-renewable fuels, thereby suggesting a paradigm shift in urban transportation. We believe that solar-powered solutions for metro buses will not only satisfy the needs of urban transportation but also offer a more affordable and environmentally friendly option. This presents solar-powered metro buses as a cutting-edge and environmentally friendly way to adapt urban mobility.

1.6 Novelty of the Project

Our project aims to bring about a revolutionary change in urban transit by introducing a novel approach to the pressing problem of carbon emissions. The project is notable for its exclusive use of solar-powered Metrobuses, which are implemented along the Söğütlüçeşme-Pendik route, which was carefully chosen based on various factors. Because there are areas with higher population densities than transportation densities and transportation issues, we particularly choose this route. Covering a vast area with solar panels on terminals, the initiative strives to reduce the entire city's transportation-related carbon footprint to zero.

This creative and environmentally responsible solution not only improves the quality of the air and water while transforming urban transit, but it also adds to the ecosystem of sustainable and environmentally friendly urban transportation.

2. DESIGN AND SOLUTION

2.1 Area Planning

While planning the area, we examined in detail the factors affecting the metrobus line we will choose. These factors:

1. By looking at the population distribution data of Istanbul in 2022 [54], the densely populated areas were determined, and these results showed which metrobus line was more logical to build.

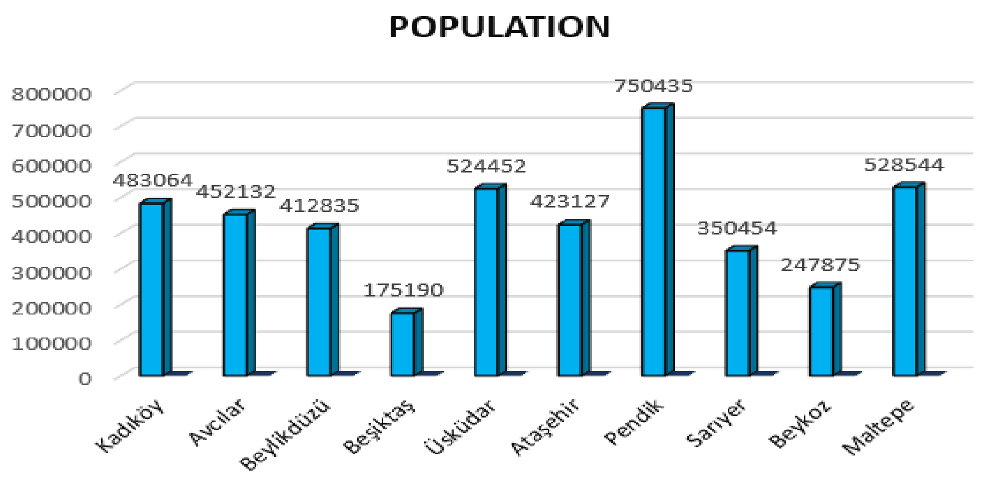

Figure 17 Population Distribution among districts

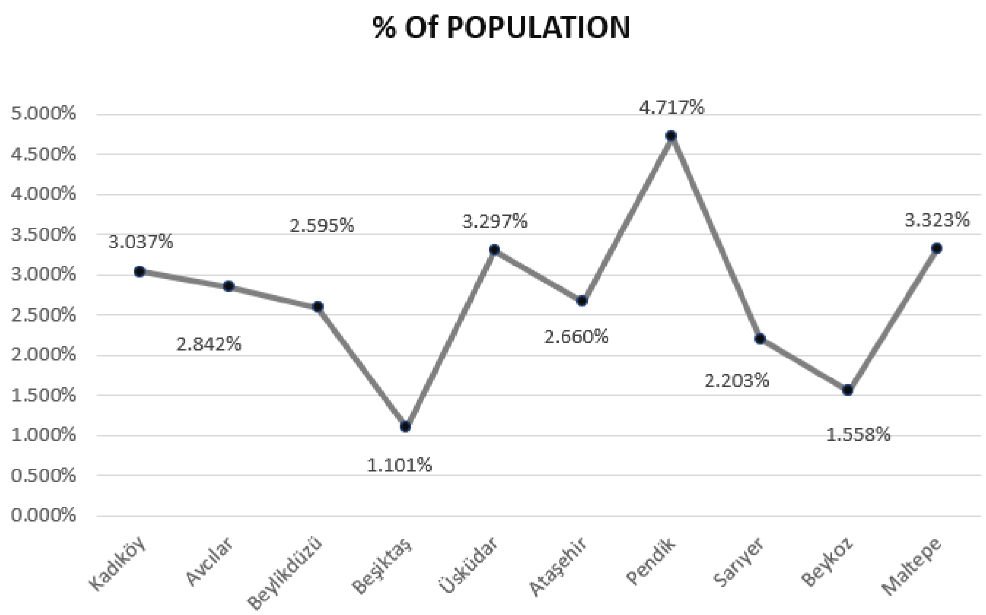

Figure 18 Population Distribution among districts (%)

We obtained the populations of the districts located on the current and alternative metrobus line from official sources. According to this sample data, Pendik, Maltepe, Kadıköy, Avcılar and Üsküdar are currently among the districts with the highest population.

2. By taking a 16-day sample of the weather data in 2022 [53], the temperature and weather conditions of each district were observed. Based on these observations, it was determined in which district or districts a charging station should be installed. When choosing the area

for the charging station, two important issues were taken into consideration. The first of these is the average temperature of the districts, covering the hours of sunshine throughout the year, and the number of fair-weather conditions these districts have during the year. (Fair weather conditions: Sunny and Partly Cloudy weather conditions)

We arranged the data we took from the internet as follows and made it ready to be used in the necessary graphs and tables. For example, Pendik and Kadıköy data:

Table 1 Pendik Seasonal Temperature Averages

Pendik 2022 Winter Temperature Average (°C)		
Rainy	8	1
Partly Cloudy	7	0
Cloudy	9	2
Rainy	7	-1
Partly Cloudy	6	-1
Cloudy	8	6
Snowy	7	2
Snowy	5	1
Snowy	5	2
Cloudy	6	2
Cloudy	7	3
Partly Cloudy	8	4
Rainy	9	3
Heavy Rain	5	2
Rainy	12	7
Rainy	11	7

Pendik 2022 Spring Temperature Average (°C)		
Sunny	22	6
Rainy	9	5
Sunny	13	5
Heavy Rain	14	5
Cloudy	16	5
Partly Cloudy	17	8
Sunny	18	9
Sunny	15	8
Rainy	14	8
Heavy Rain	14	8
Partly Cloudy	15	9
Cloudy	16	9
Sunny	17	10
Cloudy	14	8
Sunny	16	10
Rainy	17	11

Pendik 2022 Summer Temperature Average (°C)		
Sunny	29	20
Partly Cloudy	30	20
Sunny	31	20
Partly Cloudy	30	22
Sunny	29	20
Sunny	30	20
Sunny	30	21
Partly Cloudy	29	21
Sunny	30	22
Sunny	30	21
Sunny	30	20
Cloudy	29	20
Sunny	29	21
Partly Cloudy	27	22
Cloudy	28	22
Sunny	28	22

Pendik 2022 Autumn Temperature Average (°C)		
Sunny	19	12
Partly Cloudy	16	11
Rainy	18	11
Heavy Rain	12	10
Rainy	18	11
Sunny	17	11
Partly Cloudy	15	14
Cloudy	17	12
Partly Cloudy	15	9
Rainy	15	9
Sunny	15	9
Cloudy	14	9
Sunny	15	8
Rainy	14	11
Rainy	13	11
Sunny	15	10

Table 2 Kadıköy Seasonal Temperature Averages

KADIKÖY 2022 Winter Temperature Average (°C)		
Rainy	7	4
Partly Cloudy	6	4
Sunny	9	5
Partly Cloudy	9	5
Partly Cloudy	7	2
Cloudy	7	3
Snowy	8	3
Snowy	7	3
Sunny	9	3
Cloudy	9	5
Partly Cloudy	7	4
Cloudy	6	2
Rainy	7	3
Heavy Rain	5	2
Rainy	7	4
Cloudy	9	3

KADIKÖY 2022 Spring Temperature Average (°C)		
Cloudy	19	12
Partly Cloudy	21	15
Sunny	20	12
Heavy Rain	17	8
Cloudy	16	8
Cloudy	14	9
Sunny	15	8
Sunny	15	7
Rainy	15	7
Cloudy	14	9
Sunny	15	8
Sunny	16	9
Sunny	17	8
Cloudy	15	8
Sunny	12	8
Rainy	13	7

KADIKÖY 2022 Summer Temperature Average (°C)		
Sunny	32	20
Sunny	32	22
Partly Cloudy	32	21
Sunny	31	21
Sunny	30	21
Sunny	34	23
Sunny	30	22
Sunny	30	22
Sunny	29	22
Sunny	29	22
Sunny	29	21
Cloudy	29	21
Sunny	30	21
Partly Cloudy	29	23
Sunny	29	23
Sunny	29	22

KADIKÖY 2022 Autumn Temperature Average (°C)		
Partly Cloudy	21	14
Partly Cloudy	19	14
Heavy Rain	18	11
Heavy Rain	18	10
Cloudy	18	11
Sunny	17	11
Sunny	15	12
Cloudy	19	14
Partly Cloudy	15	9
Rainy	15	9
Cloudy	15	8
Cloudy	13	8
Sunny	15	9
Rainy	13	10
Heavy Rain	14	9
Partly Cloudy	16	11

Using this data, we calculated which weather conditions occurred with what frequency on the days we selected for the 4 seasons and the average temperatures in the morning and evening hours on these days.

Winter

Table 3 Weather Conditions of districts on Winter

	Sunny	Partly cloudy	Cloudy	Rainy	Heavy Rain	Snowy	Average Daytime Temperature (°C)	Average Night Temperature (°C)
Kadıköy	2	4	4	3	1	2	7	3
Avcılar	2	2	5	4	1	2	7.4375	3
Beylikdüzü	2	3	4	3	2	2	7.6875	3.25
Beşiktaş	2	4	3	3	2	2	7.5	2.4375
Üsküdar	2	3	4	4	1	2	7.6875	2.4375
Ataşehir	1	4	3	4	2	2	7.5	2.4375
Pendik	0	3	4	5	1	3	7.5	2.5
Sarıyer	2	2	5	3	2	2	7.5	2.3125
Beykoz	0	3	3	4	4	2	7.4375	2.75
Maltepe	1	2	4	6	1	2	7.6875	3

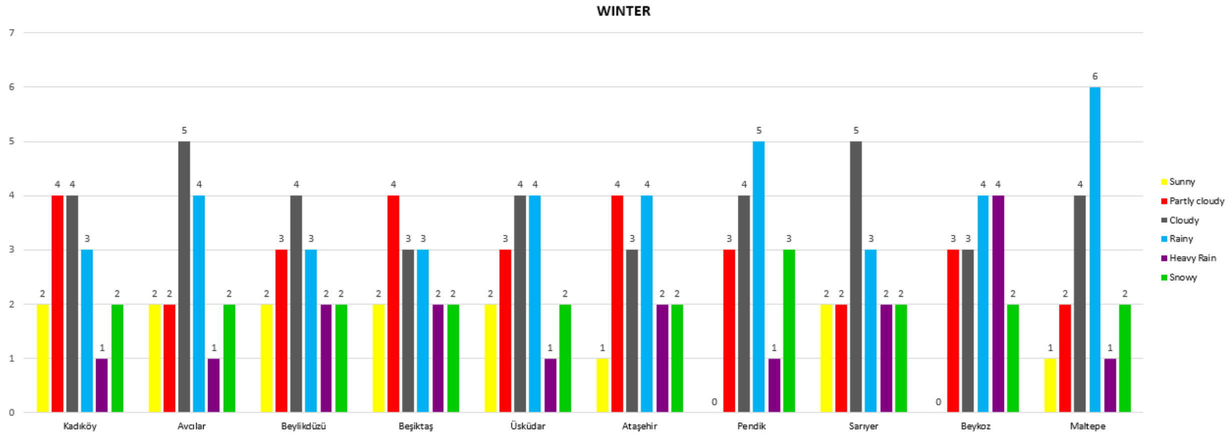

Figure 19 Frequency of weather conditions in Winter

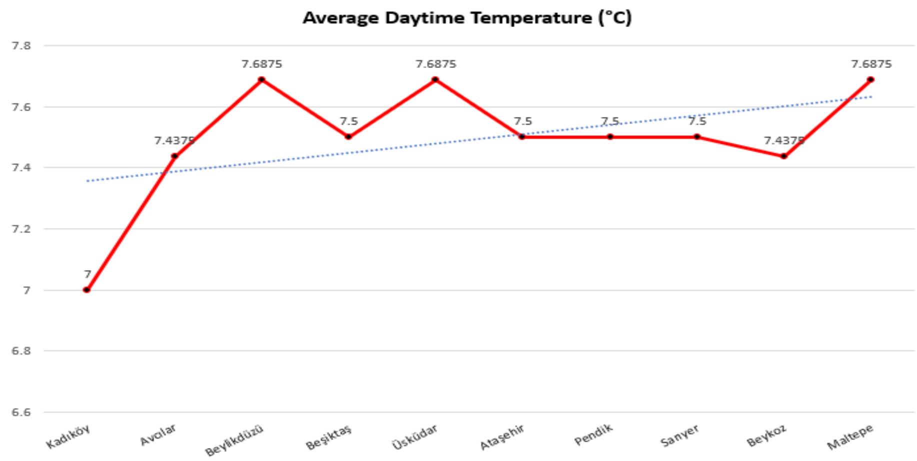

Figure 20 Average Daytime Temperature in Winter

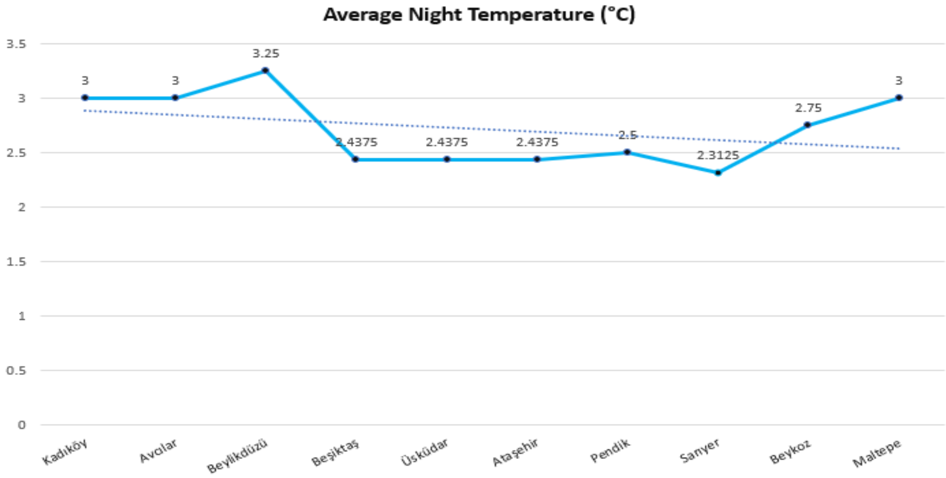

Figure 21 Average Night Temperature in Winter

The districts where sunny and partly cloudy weather conditions are more common in winter are Kadıköy, Maltepe, Beşiktaş and Beylikdüzü. The districts with the highest temperature levels during the day are Maltepe, Beylikdüzü and Üsküdar.

SPRING

Table 4 Weather Conditions of districts on Spring

	Sunny	Partly cloudy	Cloudy	Rainy	Heavy Rain	Snowy	Average Daytime Temperature (°C)	Average Night Temperature (°C)
Kadıköy	7	1	5	2	1	0	15,875	8.9375
Avcılar	6	2	4	2	2	0	15.6875	9.5625
Beylikdüzü	6	2	4	1	3	0	15.1875	9.125
Beşiktaş	6	1	5	3	1	0	15.1875	7.6875
Üsküdar	7	3	2	2	2	0	15.3125	7.5
Ataşehir	7	2	3	2	2	0	15.75	7.6875
Pendik	6	2	3	3	2	0	15.4375	7.75
Sarıyer	4	3	6	2	1	0	15.4375	7.1875
Beykoz	4	3	4	3	2	0	15.1875	8
Maltepe	6	3	2	4	1	0	15.5625	7.8125

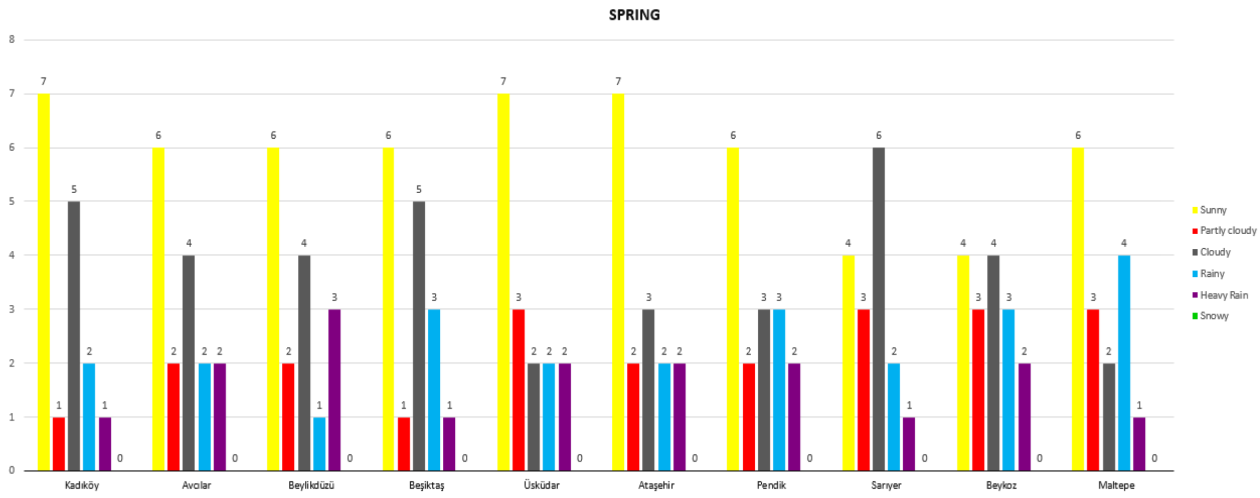

Figure 22 Frequency of weather conditions in Spring

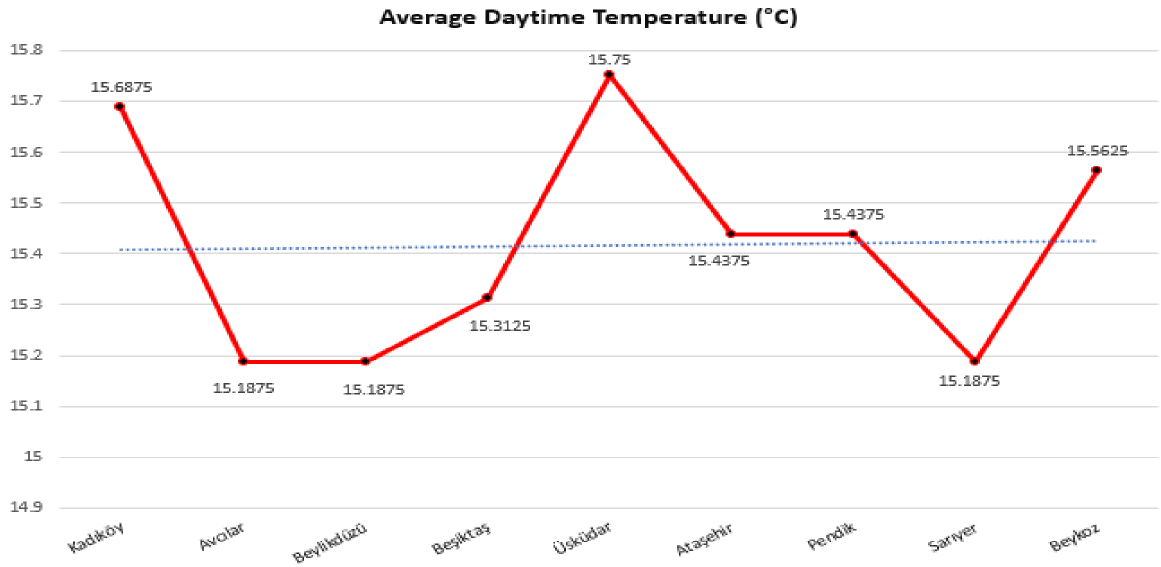

Figure 23 Average Daytime Temperature in Spring

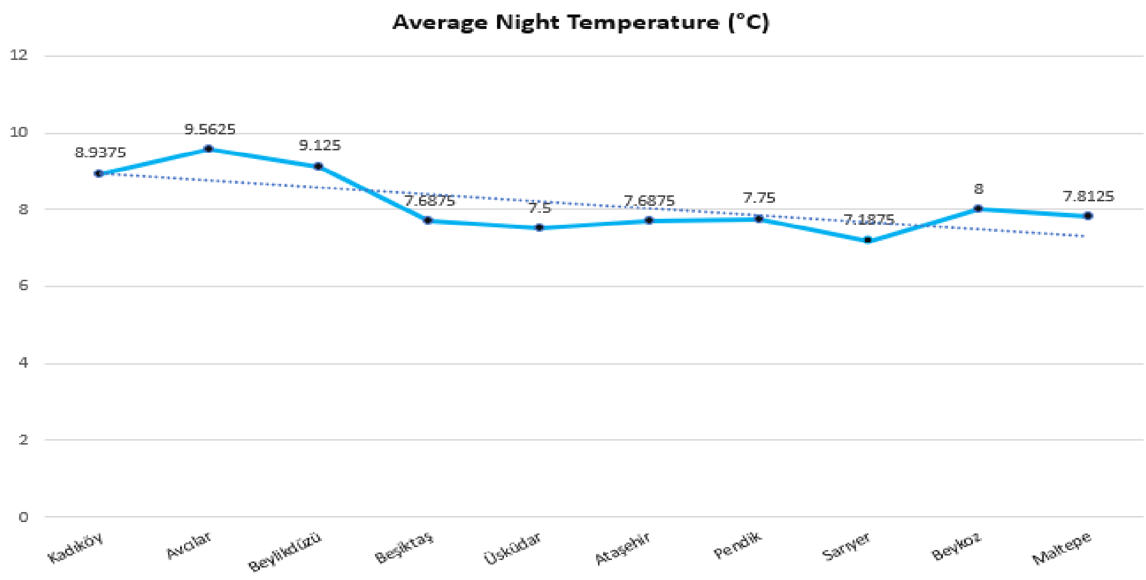

Figure 24 Average Night Temperature in Spring

The districts where sunny and partly cloudy weather conditions are more common in spring are Kadıköy, Maltepe, Ataşehir and Üsküdar. The districts with the highest temperature levels during the day are Kadıköy, Beykoz and Üsküdar.

SUMMER

Table 5 Frequency of weather conditions in Summer

	Sunny	Partly cloudy	Cloudy	Rainy	Heavy Rain	Snowy	Average Daytime Temperature (°C)	Average Night Temperature (°C)
Kadıköy	13	2	1	0	0	0	30.25	21.6875
Avcılar	14	1	1	0	0	0	30.125	21.8125
Beylikdüzü	13	3	0	0	0	0	30.0625	21.875
Beşiktaş	15	1	0	0	0	0	29.5625	21.25
Üsküdar	12	2	2	0	0	0	29.5625	21.1875
Ataşehir	13	1	2	0	0	0	29.5	21.125
Pendik	10	4	2	0	0	0	29.3125	20.875
Sarıyer	13	3	0	0	0	0	29.6875	21.125
Beykoz	11	1	4	0	0	0	28.75	21.625
Maltepe	11	4	1	0	0	0	29.3125	21.1875

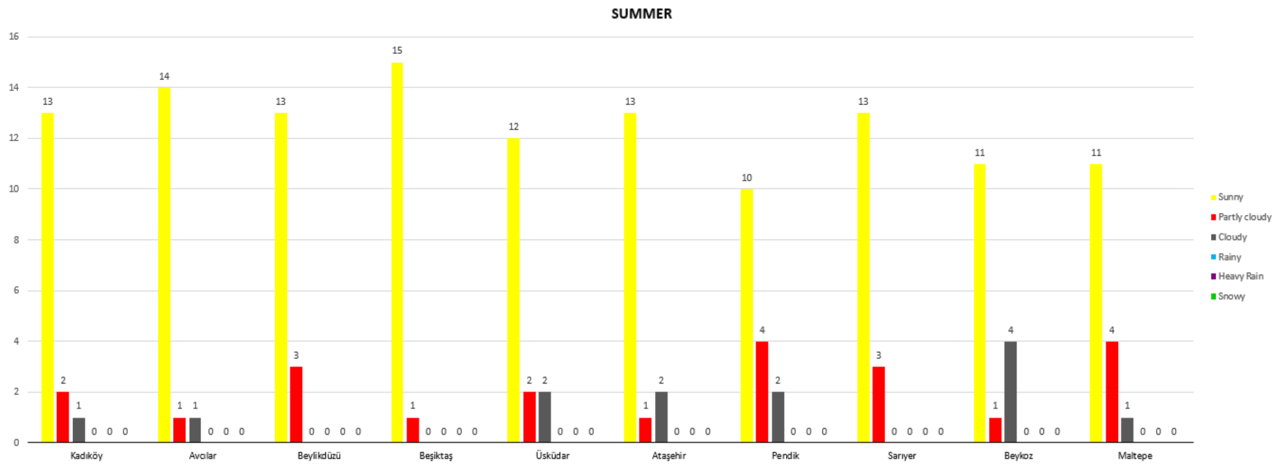

Figure 25 Frequency of weather conditions in Summer

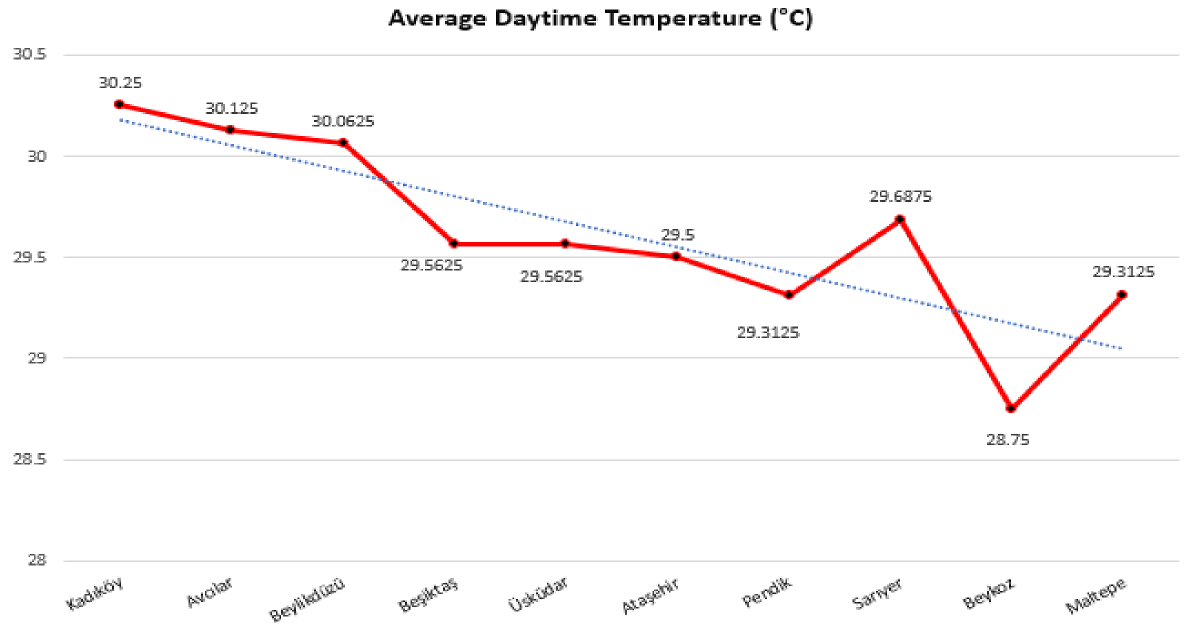

Figure 26 Average Daytime Temperature in Summer

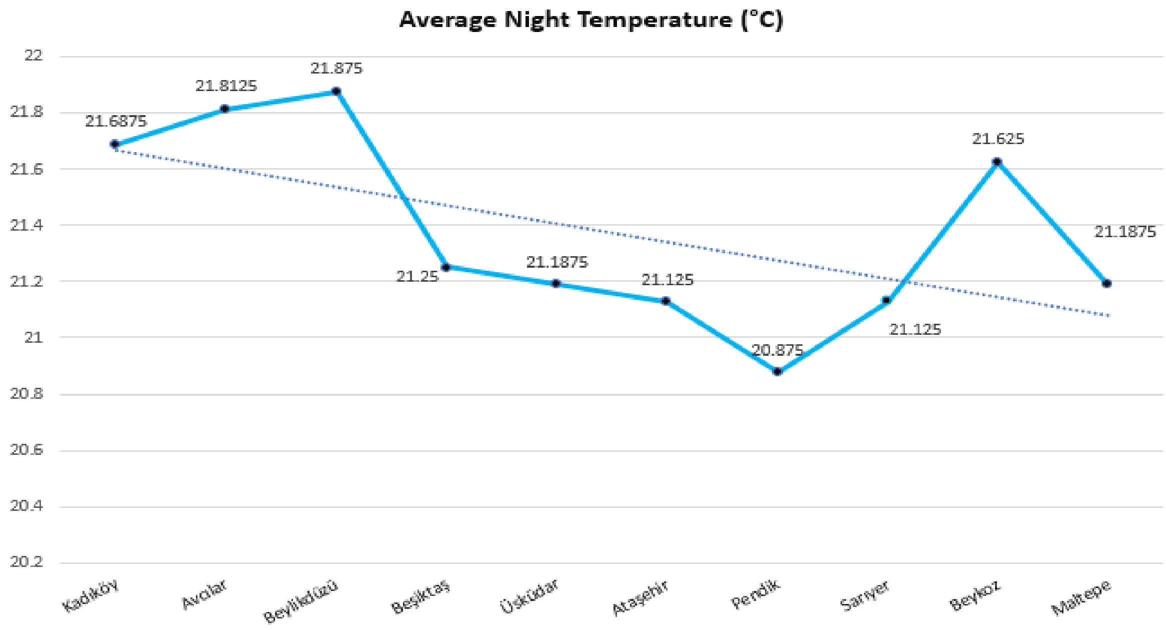

Figure 27 Average Night Temperature in Summer

The districts where sunny and partly cloudy weather conditions are more common in summer are Kadıköy, Beşiktaş and Sarıyer. The districts with the highest temperature levels during the day are Kadıköy, Avcılar and Beylikdüzü.

AUTUMN

Table 6 Frequency of weather conditions in Autumn

	Sunny	Partly cloudy	Cloudy	Rainy	Heavy Rain	Snowy	Average Daytime Temperature (°C)	Average Night Temperature (°C)
Kadıköy	3	4	4	3	2	0	16.3125	10.625
Avcılar	3	7	2	2	2	0	16.375	11
Beylikdüzü	3	5	4	3	1	0	16.1875	10.75
Beşiktaş	3	5	4	2	2	0	16.4375	11.3125
Üsküdar	5	3	3	3	2	0	16.25	11.1875
Ataşehir	6	2	3	2	3	0	16.375	10.625
Pendik	5	3	2	1	5	0	15.5	10.5
Sarıyer	4	5	3	2	2	0	16.625	10.9375
Beykoz	4	4	1	2	5	0	16.5	10.875
Maltepe	4	4	3	1	4	0	16.0625	10.125

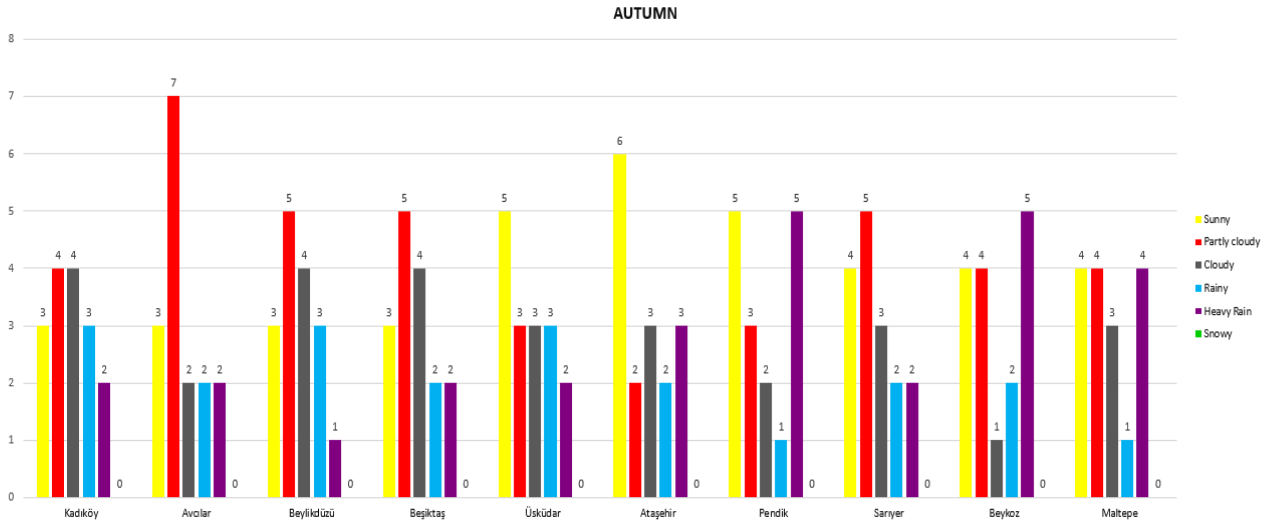

Figure 28 Frequency of weather conditions in Autumn

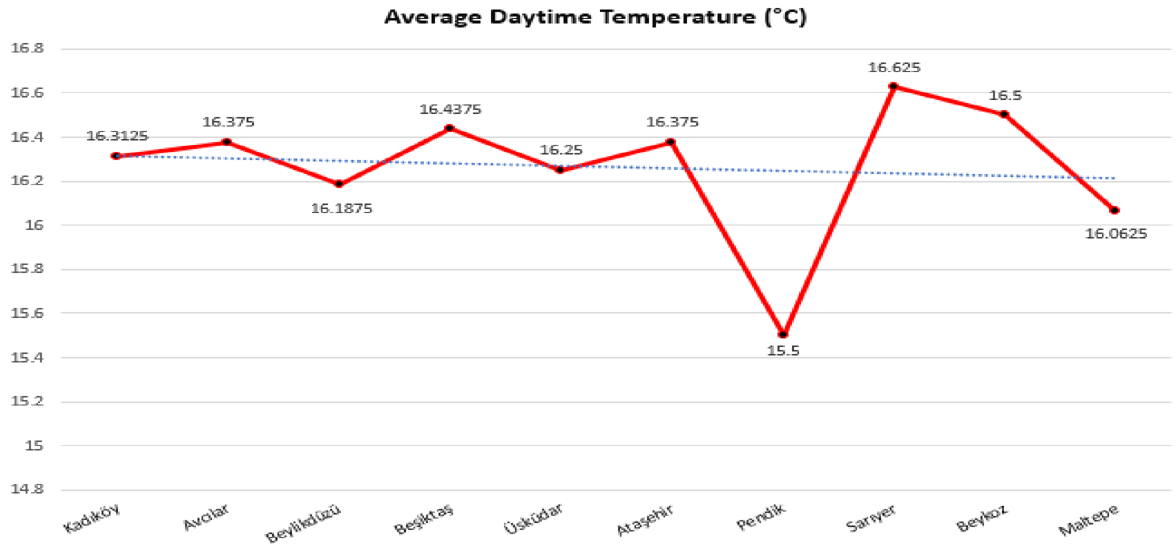

Figure 29 Average Daytime Temperature in Autumn

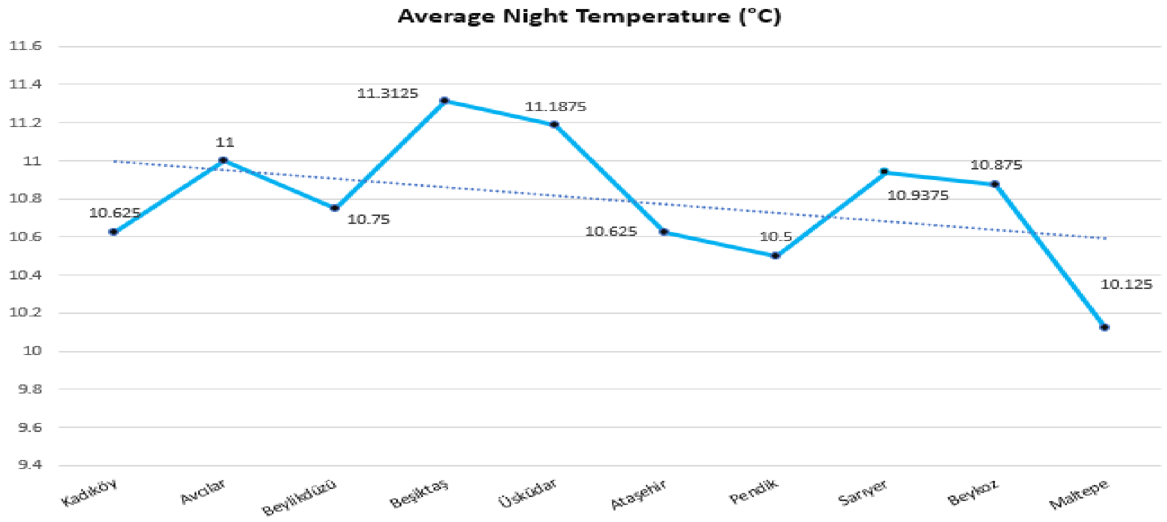

Figure 30 Average Night Temperature in Autumn

The districts where sunny and partly cloudy weather conditions are more common in autumn are Avcılar, Ataşehir and Sarıyer. The districts with the highest temperature levels during the day are Ataşehir, Beşiktaş, Beykoz and Sarıyer.

We calculated the average frequency of weather conditions and daytime temperatures in these 4 seasons (since we will use solar panels, the air temperature during the day is more important than the air temperature in the evening).

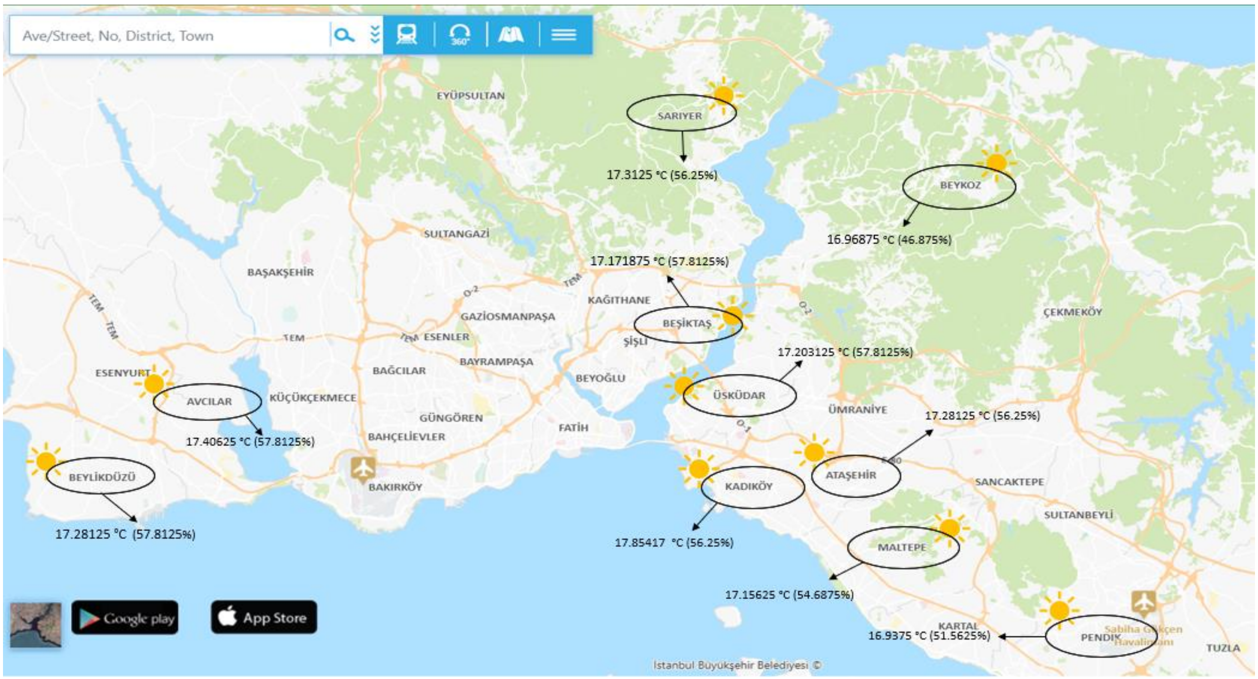

Figure 31 Average Temperatures among districts

3. Another point taken into consideration when determining the route was the route lengths of alternative projects and Istanbul's suitability for these lengths. So, We identified 2 candidate Metrobus lines by looking at temperature levels, infrastructure suitability and population factors.

First Candidate: Söğütlüçeşme-Pendik

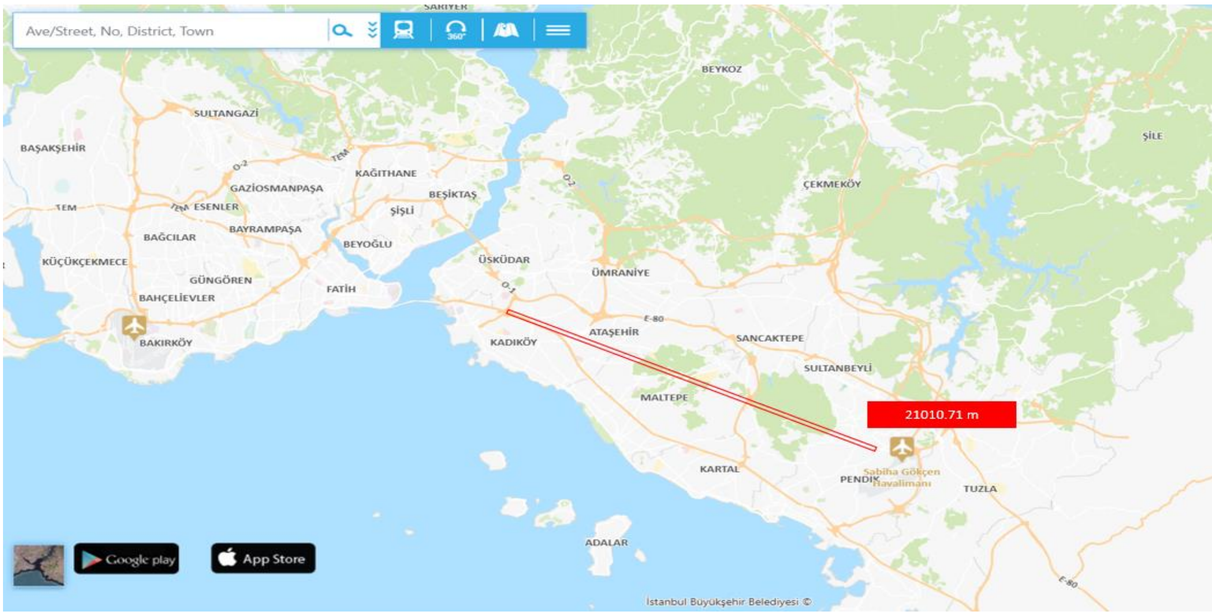

Figure 32 Söğütlüçeşme-Pendik Route

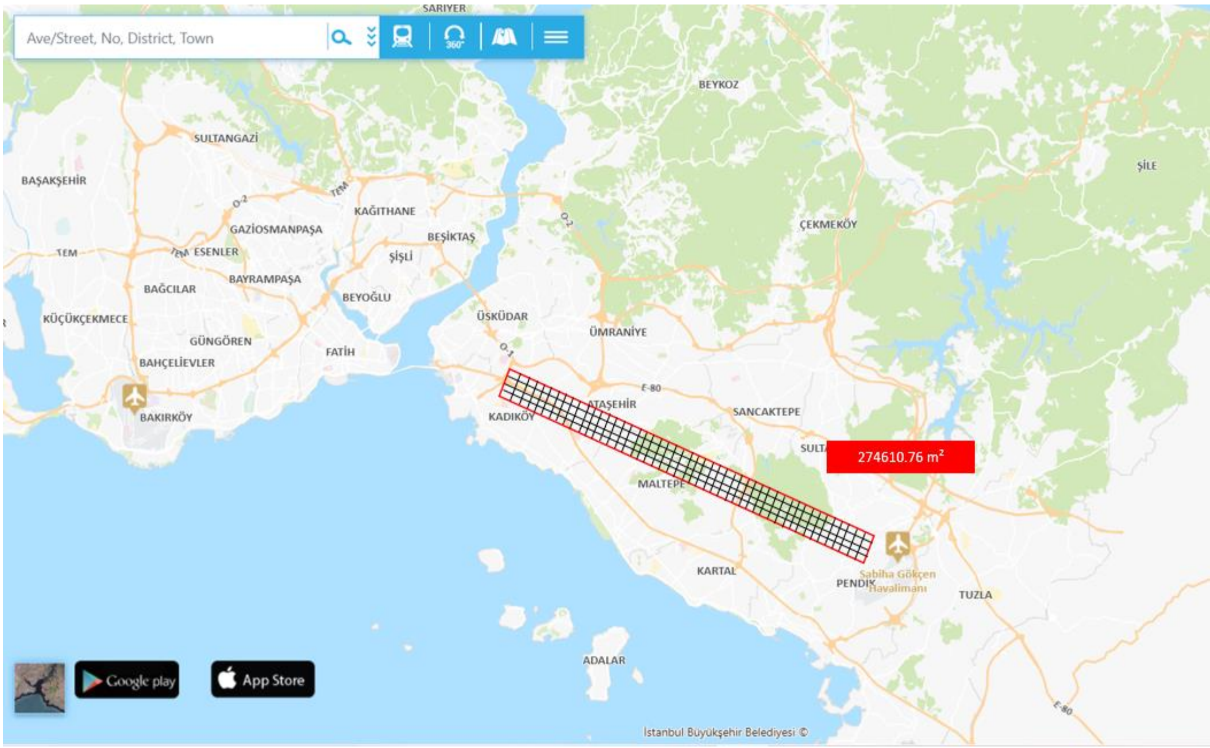

Figure 33 Söğütlüçeşme-Pendik Route Total Area

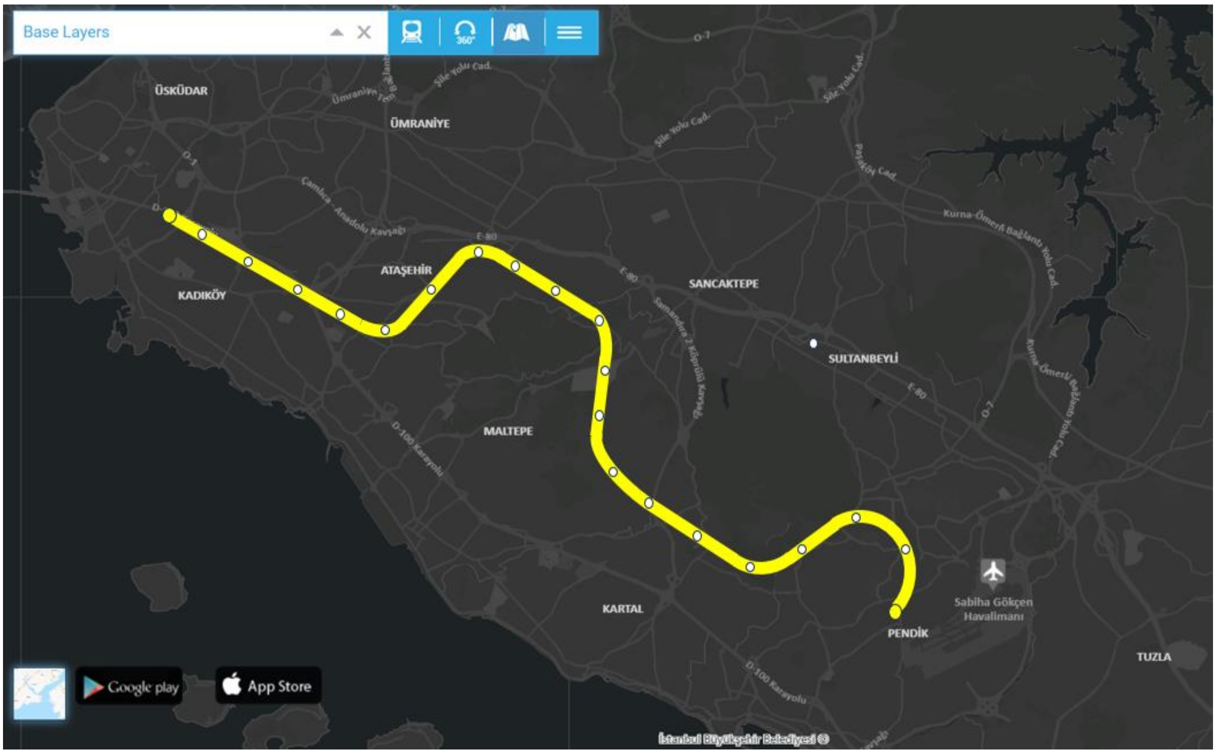

Figure 34 Söğütlüçeşme-Pendik Route Stations

Söğütlüçeşme-Pendik line consists of approximately 21 km and 274 thousand square meters. This line consists of a total of 21 stations, including 4 main stations.

Second Candidate: Sarıyer-Ümraniye

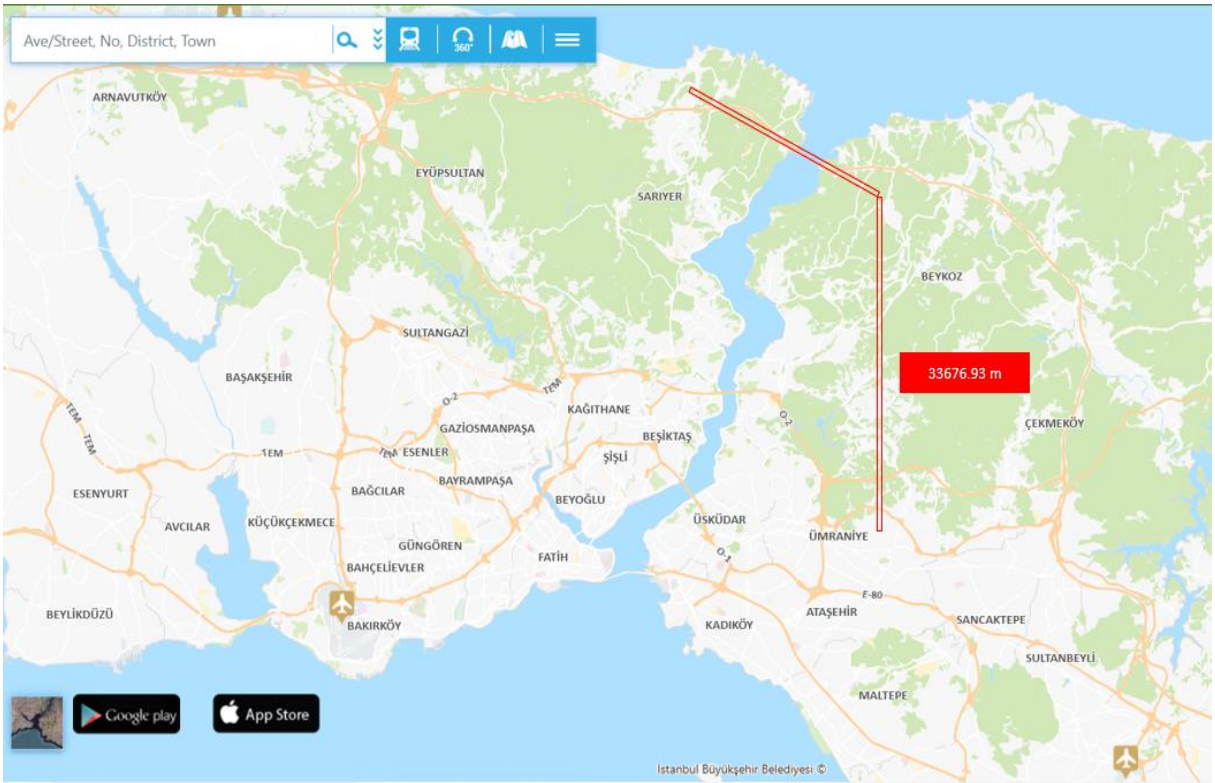

Figure 35 Sarıyer-Ümraniye Route

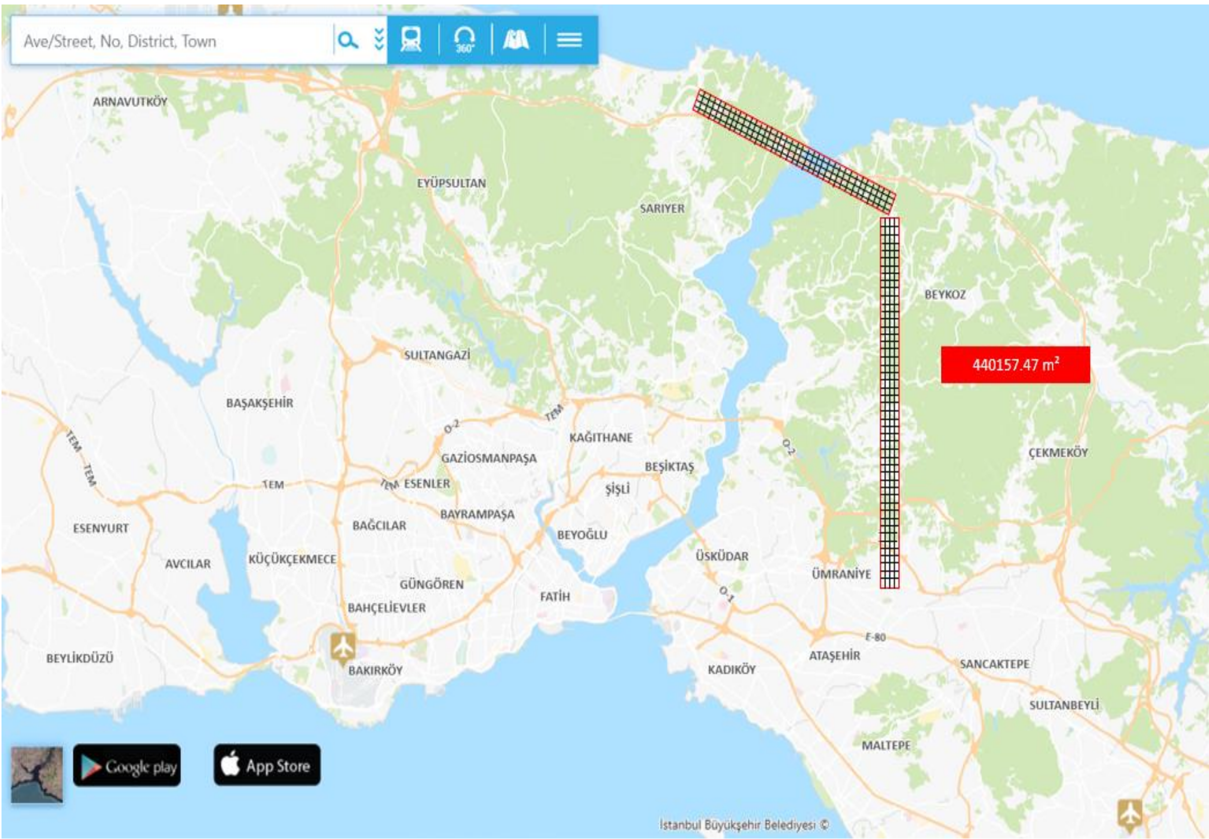

Figure 36 Sarıyer-Ümraniye Total Area

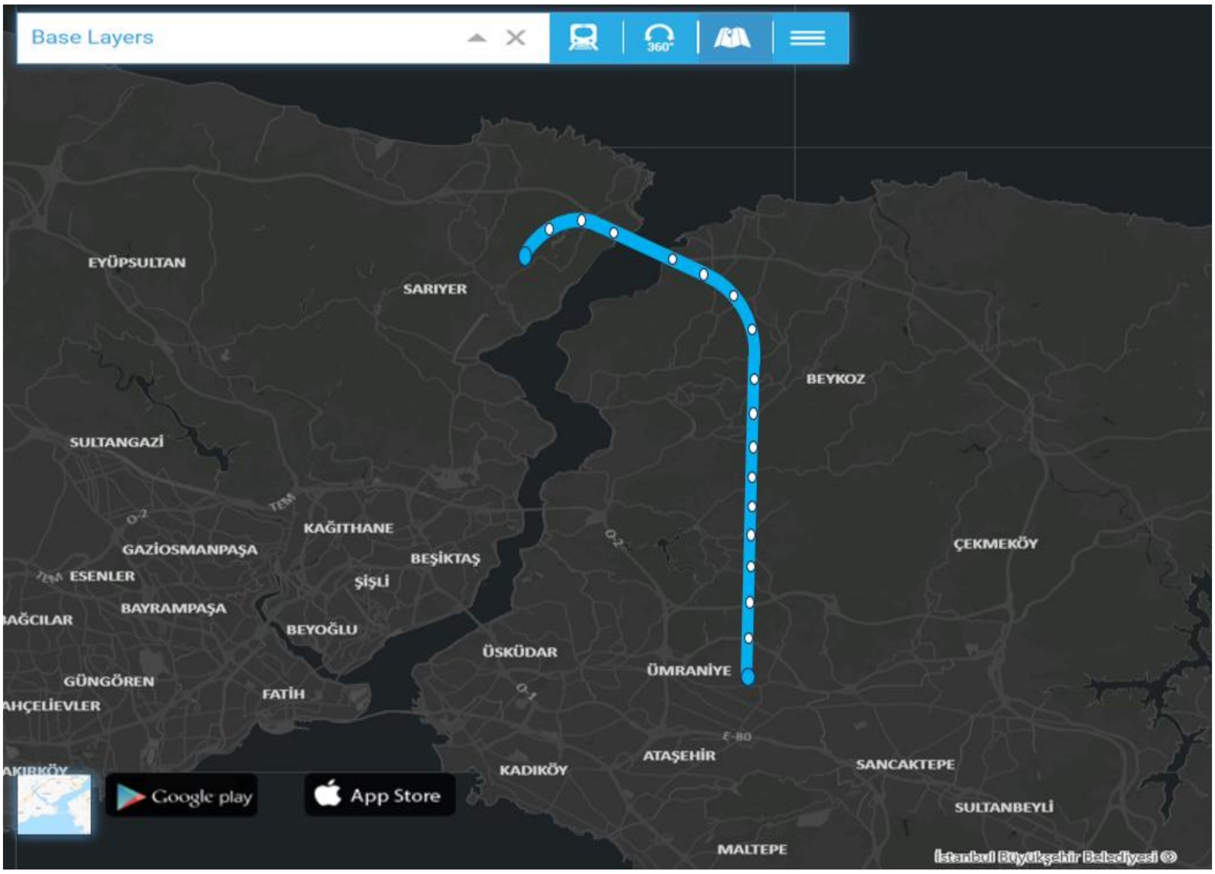

Figure 37 Sarıyer-Ümraniye Route Stations

Sarıyer-Ümraniye line consists of approximately 33.6 km and 440 thousand square meters. This line consists of a total of 18 stations, including 5 main stations.

The length of the existing Beylikdüzü-Söğütlüçeşme line is approximately 52 km and the number of stops is 44. This rate is one of the factors affecting which metrobus line should be chosen. Because the distance between the stops is a point that needs to be taken into consideration.

Considering all these factors, although the 2nd candidate metrobus line covers a length of 33.6 km and an area of 440 thousand square meters, there are only 18 stations on the line due to the suitability of the infrastructure, population density and socioeconomic status of the districts through which the line passes. Even though it is so long and covers such a large area, it has fewer stations than the first candidate. Since it has fewer stations, it is expected that it will take longer to amortize the money and resources spent on the project than the first candidate line. Apart from these cases, considering the sample data used, the temperature levels, the frequency of favorable weather conditions and the population of the districts through which the lines pass, the second candidate line is in a very disadvantageous position.

The network map of the 1st candidate line, which is the metrobus line whose project we will implement, is as follows:

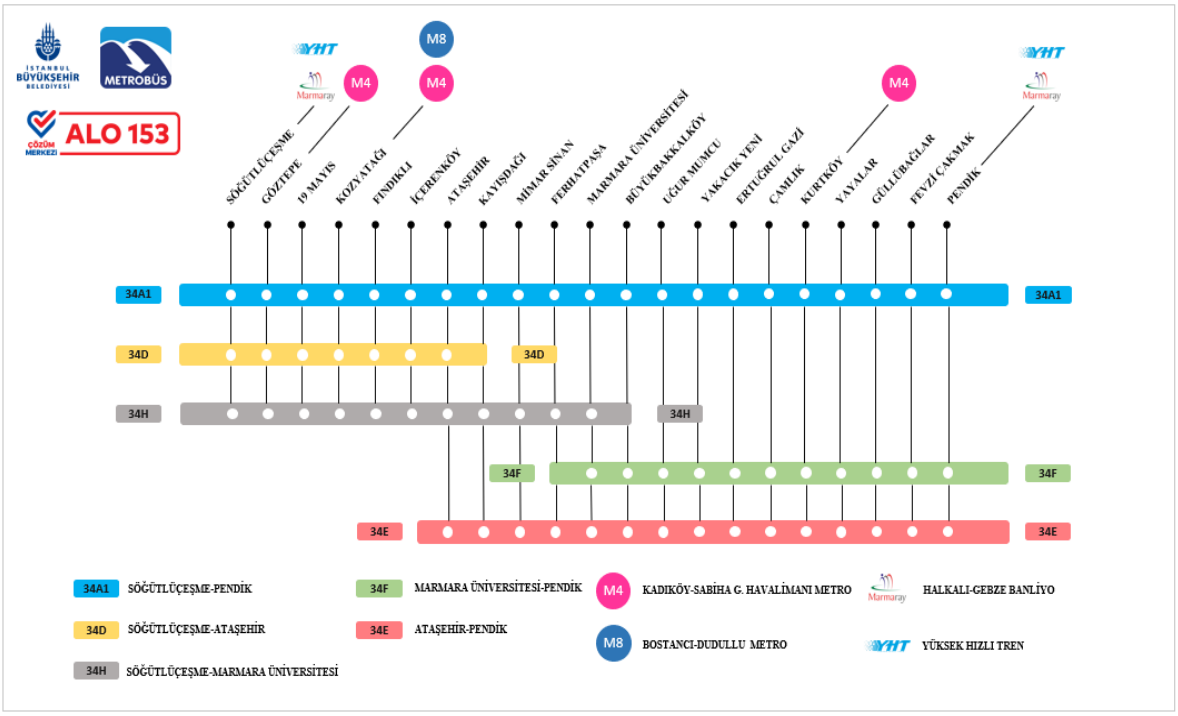

Figure 38 Metrobus Lines designed in this project

We used simulations to better explain the design of the terminals. The simulated terminals can be seen in Figure 39-40.

Figure 39 Simulation of the Terminal

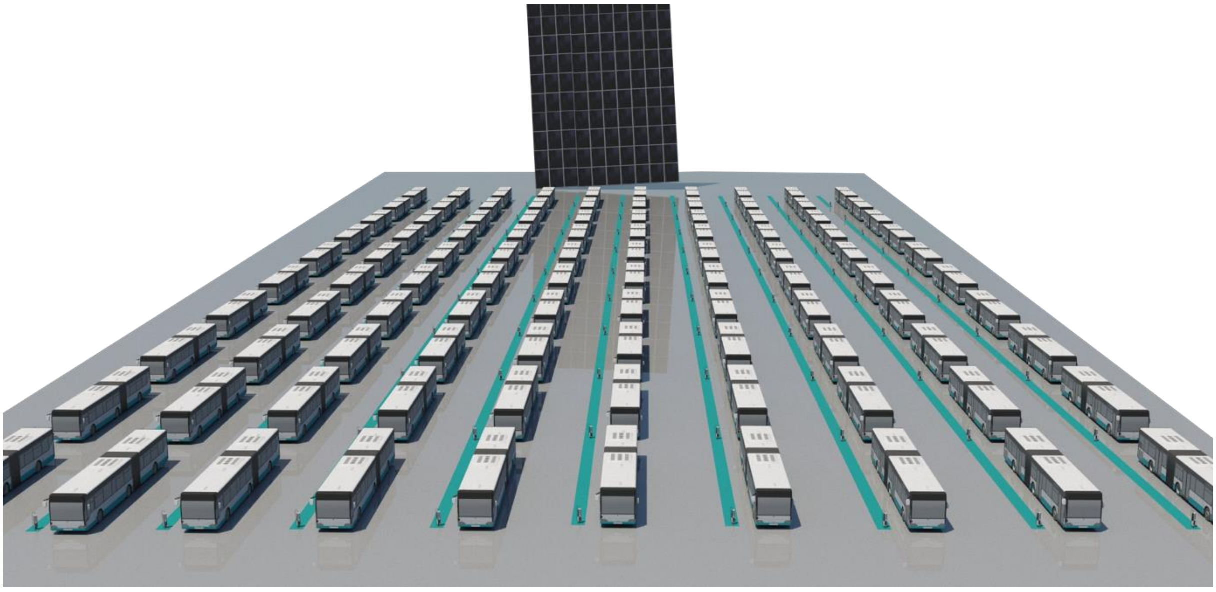

Figure 40 Simulation of the Terminal from another perspective

2.2 Solar Panel Design

We decided to establish a standalone system for Metrobus that works solar powered which we will design in our project. To use it in the design, we need solar panels, batteries, a charge controller, and an inverter.

- **Solar Panels**

Thanks to solar panels, heat and light energy from the sun are converted into electrical energy. Among the many different types of solar panels, to choose the right one for our project we focused on durability, weight, efficiency, lifespan, maintenance, cost, available roof area, and optimum orientation factors. At the end of our examinations, we decided to use Monocrystalline Silicon panels for the following reasons:

Figure 41 Monocrystalline Solar Panel

Durability:

- The durability of solar panels is determined by their ability to withstand environmental influences and harsh weather conditions.
- Monocrystalline and Silicon panels show high resistance to these situations compared to thin-film options.

Weight:

- Lighter panels take up less space.
- Thin-film panels are lighter panels than Monocrystalline and Silicon and require less space.
- Metrobuses have limited space, and when choosing a solar panel, it may be more advantageous to choose the panel that requires less space.

Efficiency:

- The efficiency of solar panels is determined by what percentage of the heat and light energy falling on the surface of the panels is converted into electrical energy while converting solar energy into electrical energy.
- Monocrystalline panels are the panels with the highest efficiency.

Lifespan:

- The longevity of a panel is an important factor in long-term performance and return on investment.
- Monocrystalline panels have a longer lifespan compared to thin-film panels.

Maintenance:

- Panels that can be maintained more easily are more advantageous.
- It is more economical in the long run.
- Monocrystalline and polycrystalline panels have lower maintenance needs.

Cost:

- The cost of solar panels varies depending on the parameters.
- Monocrystalline and Silicon panels are more expensive than Thin-film panels. However, in general, it is a moderately expensive panel.
- In the longer term, although Monocrystalline and Silicon panels are less advantageous in terms of upfront cost, the benefits they offer in the long term cannot be ignored.

Roof Space:

- Roof space in Metrobuses is limited.
- In cases where roof space is limited, the efficiency ratio comes into play.
- Monocrystal panels require less space due to high efficiency.

Although different choices stand out in some areas, Monocrystalline Silicon panels are the most suitable choice for our design.

- **Batteries**

Thanks to batteries, heat and light energy converted into electrical energy by the panels are stored. Among the many different types of batteries, to choose the right one for our design we focused on safety, lifespan, weight, durability, maintenance, and cost factors. At the end of our examinations, we decided to use Lithium Iron Phosphate (LiFePO4) batteries for the following reasons:

Figure 42 Lithium Iron Phosphate (LiFePO4) batteries

Safety:

- LiFePO4 batteries have a stable structure.
- They have a safer chemistry than other lithium-ion batteries, having stable thermal stability and therefore less risk of overheating, thus reducing the risk of thermal runaway and fire.

Lifespan:

- Since we attach importance to long-term storage in our solar panels, LiFePO4 batteries are a more logical choice for us.
- It has a longer lifespan than our other choices.

Weight:

- When looking for a balance between energy density and weight, LiFePO4 batteries are one of the best choices.
- It does not have the highest energy density among lithium-ion batteries, but they are lighter than traditional lead-acid batteries, and its overall weight efficiency wins.

Durability:

- The most important feature of LiFePO4 batteries is that they have a durable and flexible structure.

- They offer more energy storage capacity and longer battery life by having deeper charge and discharge cycles.

Maintenance:

- It requires minimal maintenance compared to some other battery types.

Cost:

- Since LiFePO4 is a new type of battery chemistry, it is less demanding and less productive, making it a more expensive option.
- Although it has a high upfront cost when thinking about it in the long term, its long lifespan and requiring less maintenance than other types make it more advantageous.

Compatibility with Solar Charging:

- LiFePO4 batteries are compatible with solar charging systems.

Environmental Impact:

- Considering the contents of LiFePO4 batteries, they do not contain toxic substances such as nickel or cobalt and therefore can be easily recycled.
- This puts them in an environmentally friendly profile.

- **Charge Controller and Inverter**

For the solar-powered Metrobus system, we use a Maximum Power Point Tracking (MPPT) charge controller and a Pure Sine Wave Inverter. At the end of our examinations, we chose these for the following reasons:

Figure 43 Maximum Power Point Tracking (MPPT) charge controller and a Pure Sine Wave Inverter

MPPT Charge Controller

MTTP devices are used to transfer the energy provided by solar panels to batteries.

High Efficiency:

- MPPT Charge Controllers are devices that convert solar energy with high efficiency ensuring optimum energy harvesting. MPPT controllers are known for their high efficiency in converting solar energy.

Versatility:

- MPPT Charge Controller devices can work compatible with many solar panel structures.
- This provides flexibility for Metrobus design.

Temperature Compensation:

- Batteries are devices that are affected by the high or low temperature of the air.
- MPPT Charge Controller devices have sensors that catch these temperature changes. MPPT controllers monitor this using sensors that detect environmental temperature changes.
- It maximizes battery life and efficiency by adjusting itself according to these changes.

Optimal Charging for LiFePO4 Batteries:

- It can be configured to provide the best charging profile for LiFePO4 batteries.

Pure Sine Wave Inverter

Pure Sine Wave Inverters convert the direct current to alternating current.

Clean and Stable Power:

- Pure Sine Wave Inverters produce a quality AC power output.
- This is important for sensitive electronic devices on the Metrobus.

Compatibility with Electronics:

- Pure Sine Wave Inverters can work efficiently with many devices.
- This reduces the risk of issues.

Reduced Heat Generation:

- Pure Sine Wave Inverters produce less heat than others.
- It optimizes efficiency and safety in a way demonstrating its effect, especially in captive areas.

Versatility:

- They can provide the necessary power for the electrical needs arising in many areas of the Metrobus.

Compatibility with LiFePO4 Batteries:

- It transforms productively the direct current power in LiFePO4 batteries into alternating current power for the electrical system in the Metrobus system to be designed.

The solar-powered Metrobus design, which will be designed using Monocrystalline Silicon panels, LiFeP04 batteries, a Maximum Power Point Tracking (MPPT) charge controller, and a Pure Sine Wave inverter, will be an efficient, compatible, meeting needs and reliable system.

2.3 Environmental, Social, and Economic Impact

The goal of the solar-powered metro system is to provide effective and environmentally friendly transportation. This system lowers greenhouse gas emissions, promotes sustainable urban development, and powers electric metrobuses using renewable energy sources. The effects of the Metrobus system on the economy, society, and environment are discussed in this section.

1. Environmental Impact:

The metrobus powered by solar energy has major environmental advantages. Solar-powered Metrobuses are an environmentally friendly substitute for conventional diesel or gasoline-powered buses since they run on renewable energy. This system lowers air pollution and greenhouse gas emissions, supporting sustainable transportation and urban development policies. Metrobuses with solar power also lessen reliance on finite fossil fuels.

Road transportation is responsible for a considerable number of transportation-related emissions; of these emissions, passenger cars and buses account for 41.5% of total emissions. Since road transport accounts for three-quarters of all transport emissions, it is responsible for 15% of all CO2 emissions, or 21% of the emissions of the entire transport sector.[3] In this regard, it is possible to argue that the solar-powered metrobus, despite its apparent diminutive size, holds great promise for lowering this significant portion of traffic on the roads [45].

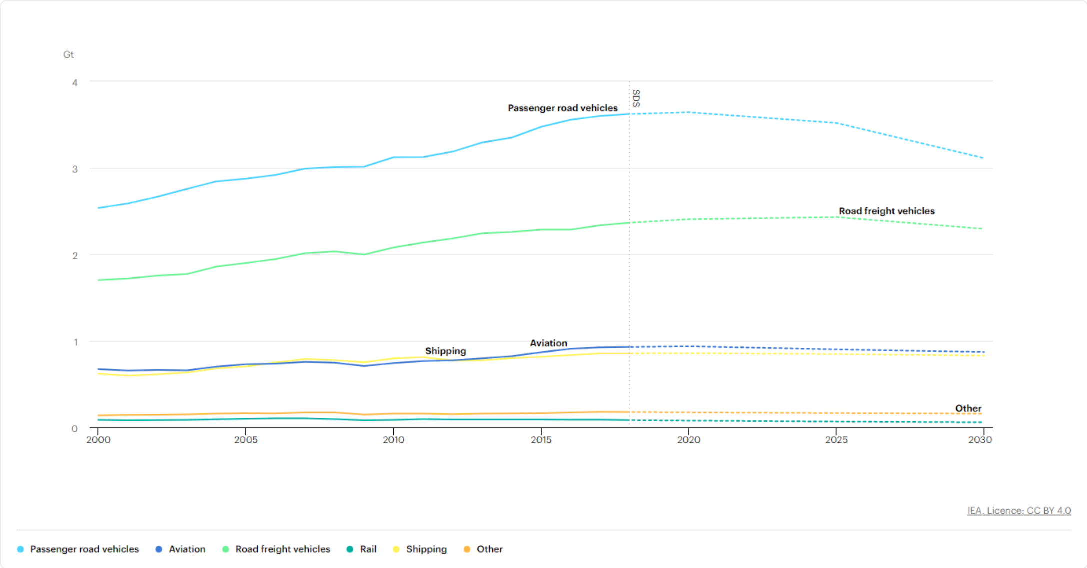

Figure 44 Transport sector CO2 emissions by mode in the Sustainable Development Scenario, 2000-2030 Adapted from [46]

A metrobus system's annual emissions are determined by a variety of factors, including fuel type, vehicle technology, operating environment, and more. As a result, pinpointing the precise emissions of metrobuses is challenging. However, the above-mentioned report from the International Energy Agency shows an increase in CO2 emissions from the automotive sector in a scenario where fossil fuel use continues without a transition to solar-powered vehicles. It's quite unsettling to imagine a world with these high CO2 emissions. Therefore, it is crucial from an ecological standpoint that automobiles like metrobuses run on solar power. According to research, Santiago, Chile's installation of a solar-powered metro system reduced carbon dioxide emissions by 5,700 tons annually. [47]

Furthermore, by promoting the use of renewable energy sources, solar-powered metrobus activities aid in mitigating the adverse effects of climate change, such as the loss of biodiversity, extreme weather, and decreased agricultural productivity. Solar-powered metrobuses, in contrast to conventional metrobuses powered by fossil fuels, do not release harmful pollutants like carbon monoxide, nitrogen oxides, and particulate matter because they do not release exhaust gases while operating. This also removes the chance that these substances could hurt air quality and cause health issues in general.

One more way that our Metrobus project is helping the environment is by lowering noise and visual pollution. It is powered by a more sustainable and clean energy source than traditional cars. This contributes to a cleaner urban environment by lowering emissions and airborne pollutants. Solar-powered metrobuses typically have a sleek, contemporary design. This will improve the overall aesthetics of city transportation, which will improve the aesthetics of the surrounding area. In addition, metrobus operates more quietly than conventional combustion engines. Lowering road noise pollution and urban traffic noise lowers ambient noise levels.

2. Economic Impact

Solar-powered metro systems have very positive economic effects. Data from 1990 to 2019 indicates that the use of solar energy has a positive impact on employment and capital growth in the economy. We anticipate favorable outcomes from a comparable metro bus project in Turkey because of this circumstance. In the first place, it boosts employment and domestic industry, which helps Turkey's economy grow. By creating more jobs locally, the manufacturing of solar panels, energy storage devices, electric cars, and other components can support employment. Employment may also rise because of the need for skilled workers for system installation and maintenance.

By lowering energy imports, the nation's energy independence is strengthened using solar-powered metrobuses. Replacing fossil fuels with cleaner energy sources can lower energy costs and boost economic growth. Furthermore, by promoting innovation and investing in green technologies, solar-powered Metrobus systems can aid in the nation's technological advancement. By emphasizing green and sustainable technologies, these systems can boost research and development efforts and aid in the establishment of business divisions that are dedicated to this area.

By offering a greener mode of transportation, metrobus systems powered by solar energy demonstrate the nation's commitment to environmental conservation. This could improve travelers' perceptions of you and boost traveler spending. In addition, by boosting passenger confidence and satisfaction, solar-powered Metrobuses—where service quality is a crucial factor—can raise fare revenues. This system provides a more comfortable and eco-friendly mode of transportation, which will draw in more passengers.

Metrobus systems that run on solar energy develop a long-term sustainable transportation model and are resilient to changes in energy prices. This makes it possible for operators of public transportation to offer reasonably priced and ecologically friendly services. Data from 19 different countries between 1990 and 2019 were analyzed, and the results show that using solar energy has a positive impact on the growth of capital and employment in the economy [48]. Our project's target profit transfer indicates that, in less than 24 months, it will be able to significantly boost the nation's economy.

3. Social Impact

The social impacts of metrobuses powered by solar energy are extremely significant. The health improvement is one of these benefits. With the population growth in Istanbul, the use of public transportation also increases. Fossil fuel-powered vehicles cause air pollution and negatively affect human health. Because solar-powered metro buses reduce pollution and offer a more environmentally friendly mode of transportation, they can be a significant step towards safeguarding human health.

Another socioeconomic impact is accessibility. The only reasonably priced modes of transportation in Istanbul's densely populated Anatolia district are typically buses and metros. By offering a new mode of transportation, the installation of a solar-powered Metrobus could improve access to healthcare, education, and job opportunities.

Other significant effects include lowering social inequality and raising employment. Social inequality issues can be lessened by elements like enhancing transportation in low-income areas and choosing a convenient, traffic-free route. The Turkish unemployment issue can be resolved by the solar-powered metrobus project, which generates new employment opportunities outside of the public transportation industry. Increased demand for installation, operation, maintenance, and training services can lead to more job openings across a range of specializations. [49] These initiatives, which boost the local economy while offering eco-friendly transportation choices, can boost economic expansion and are crucial in the battle against unemployment.

2.4 Project Budget

When starting the cost analysis, we first started by determining the important expense items. We aimed to facilitate expense calculations by discussing the necessary expenses for the metrobus line we will create under three subheadings. These titles are the followings:

1. Labor Expenses

In our calculations under this heading, we calculated our monthly and annual labor expenses by listing all the employee expenses we need in our project, together with their salaries and number of people.

Labor Expenses	NUMBER OF EMPLOYEES	NET SALARY	SGK	ONE WORKER PAYMENT	TOTAL MONEY FOR THE WORKER (MONTHLY)	IN A YEAR
Security guards	90,00	$ 500,00	$ 150,00	$ 650,00	$ 58.500,00	$ 702.000,00
Engineer	2,00	$ 1.000,00	$ 300,00	$ 1.300,00	$ 2.600,00	$ 31.200,00
Designer	25,00	$ 750,00	$ 200,00	$ 950,00	$ 23.750,00	$ 285.000,00
Vechile Maintenance Specialist	50,00	$ 800,00	$ 240,00	$ 1.040,00	$ 52.000,00	$ 624.000,00
Drivers	1000,00	$ 600,00	$ 180,00	$ 780,00	$ 780.000,00	$ 9.360.000,00
Line Maintenance and Creation Workers	200,00	$ 700,00	$ 210,00	$ 910,00	$ 182.000,00	$ 2.184.000,00
TOTAL	1367,00	$ 4.350,00	$ 1.280,00	$ 5.630,00	$ 1.098.850,00	$ 13.186.200,00

Figure 45 Labor Expenses

2. Route, Station and Panel / etc. Expenses:

In this section, we determined the type of cement we will use for the route we will create, how much budget we need to allocate, how much budget we need for our panels, batteries, and converters, and finally, we calculated how much cement we need by calculating the square meters we need for the station we will create. The reason why we made route and station calculations separately at this step was that the cement types that needed to be used were different. In addition to all these, we have calculated small additional expenses such as lighting systems that we need to purchase for the stops in this section.

Panels/Road/etc	PIECE	CUSTOMARY PRICE	TOTAL
	BUYING		
Solar Panels	2000	$ 1.000,00	$ 2.000.000,00
Route	1	$ 72.000.000,00	$ 72.000.000,00
Terminal	1	$ 30.933.333,00	$ 30.933.333,00
Batteries (LiFePO4)	575	$ 2.500,00	$ 1.437.500,00
Lighting	21	$ 3.000,00	$ 63.000,00
Charge Controller	575	$ 800,00	$ 460.000,00
Inverter	600	$ 100,00	$ 60.000,00
Land (6 Acres)	2	$ 250.000,00	$ 500.000,00
TOTAL	3774	$ 102.940.733,00	$ 107.453.833,00

Figure 46 Route, Station and Panel / etc. Expenses

a. Solar Panels

Battery charge (kW)	Distance covered (km)
1	**5-8**
12	**60-96**

Depending on the vehicle type, electric vehicles can travel 5 to 8 kilometers per kW of energy. Considering this, there is a 20-kilometer route that we will produce in our project, and the vehicles that are intended to make 3 trips a day on this route need to have an average of 12 kW of energy in their tanks. In our next calculations, we examined how many vehicles we needed. According to the data, there are 500 vehicles within IMM for the current route. Considering that we will decrease the route by 60 percent and keep the frequency of flights stable, the number of vehicles required is around 200.

Number of vehicles	Energy requirement (kW)(Daily)
1	**12**
200	**2400**
%75 Energy loss in system	**9600**

These vehicles require a total of around 9600 kW of energy to complete the trips. To meet this level of energy need, a large number of solar panels are required. For this reason, by using solar panels at both the starting and ending points of our route, we will not restrict this process to a single area. According to the data, the average hourly energy that a 1 square meter panel can produce is 250 watts. Considering that there are 6 hours of sunny time per day on average in Istanbul, each 1 square meter panel produces 1.5 kW of energy per day.

9600/1,5 ≅ 6400 pieces of 1 square meters panel required

Average cost of a solar panel which is 1 square meters = $300

6400x300 = $1,920,000 total cost

b. Batteries, Charge Controller and Inverters

After our price research on the LiFePO4 type batteries we used in our battery selection, we determined that the most suitable battery is the complex battery that can store 4.8 kW of energy, the image of which we share below, and the price of one of them is $2,500. We determined that we needed 563 of these batteries to store the 2700 kW of energy we need. However, in case of any possible mishap, we decided to purchase 12 spare batteries and settled on 575 batteries.

2700/4,8=575 Batteries needed

However, the need for Charge Controllers arising from each battery emerged and we researched the budget we would need to allocate for the purchase of 575 Charge Controllers. The average price of an MPPT model Charge Controller that could handle a minimum of 4 kW energy transfer was around $800. So the total cost is $460,000.

Regarding the inverter, we decided to use "pure sine wave inverter" and since even the 6 kW devices of these devices are quite affordable, we decided to buy 600 units to work with redundancy in order to avoid malfunctions. The total cost of this device, whose unit price was $100, was $60,000.

c. Terminal and Line Creation

During the creation of the station and route, we took two factors into consideration: the first was the size of the vehicles and the other was the area to be covered by the solar panels. In our calculations, we calculated that we needed 90 4x4 solar panels. Additionally, considering that our metrobuses are 2,4x25 meters in size, we calculated that a total of 400x400 meters would be sufficient for us. While creating our route, we added an average of 3 meters of road and around 2 meters of stop space for each direction, considering the width of the metrobuses. As a result of these calculations, we obtained the results in the tables below.

SQUARE METERS (Terminal)	COST OF CEMENTS (Includes labor costs)
1	**$193**
160,000	**$30,933,333**
SQUARE METERS (Route)	COST OF CEMENTS (Includes labor costs)
1	**$400**
180,000	**$72,000,000**

3. Vehicle Expenses

In this section, after calculating the number of vehicles we need to reach the frequency of trips on existing routes, we determined the total expenditure we need to make on vehicles by researching the average electric vehicle prices. When we researched the average price of Mercedes brand electric vehicles, we came across an average of around $445,000 (12,000,000 TL) per vehicle. According to this data, the budget required to create a fleet of 200 vehicles is;

Vechiles	PIECE	PER METROBUS	TOTAL
Buying a METROBUS			
Electric Metrobus	200	$ 445.000,00	$ 89.000.000,00

Figure 47 Vehicle Expenses

4. Land Expenses

In the light of our calculations, we determined that if we use 1 square meter solar panels, the total area we need is 6400 meters by 6400 meters. In our planning, we determined that the amount of land we needed was 6000x6000 meters, considering that our stations would be 400x400 meters at the beginning and end of the route, that is, 800x800 meters in total. As a result of our market research, we calculated that if we purchased a land of this size from Pendik, we would have an expense item of 500000 dollars.

5.Maintenance

As our last expense item, we calculated monthly maintenance costs. By tabulating maintenance costs such as vehicle maintenance costs, solar panel maintenance, ground and station repairs, we calculated our average monthly expense as 53000 dollars.

COSTS	PRICES	
Path maintenance (Monthly)	$	20.000,00
Vechile maintenance (Monthly)	$	30.000,00
Station maintenance (Monthly)	$	3.000,00
Worker Salary (Monthly)	$	1.098.850,00
Sponsorships (Monthly)	$	200.000,00

Figure 48 Maintenance

- **REVENUES**

After listing our expenses, we created our income items. We have determined sponsorships and acbil income as our income items that we will generate regularly every month. When we researched IBB official data, we found that the number of monthly users on the Beylikdüzü-Söğütlüçeşme route, one of the public transportation lines, is around 15 million. We decided to keep the number of passengers stable, considering that the Pendik-Söğütlüçeşme route we created was half of this example in terms of stop length and that it was more densely populated. In addition, we have determined Akbil fees as 1 dollar for full passengers and 50 cents for students. We added 200,000 dollars to the sponsorship income section, which we will earn thanks to the advertisements we will place on each of our vehicles and stops.

AVERAGE USAGE (MONTHLY	PRICE		TOTAL		An annual increase of 10 percent will be applied every year
11000000	$	1,00	$	11.000.000,00	
4500000	$	0,50	$	2.250.000,00	
	TOTAL REVENUE		$	13.250.000,00	

Figure 49 Revenues

- **CASH FLOW ANALYSIS**

While doing our money flow analysis, we focused on whether our project could finance itself in a 2-year projection and decided to determine the success of our project based on this statistic. We also ran our money flow diagrams through two scenarios. In one of these scenarios, we determined the pricing and inflation rate (70%) based on today's conditions, while in the second case, we took the worst case scenario and increased all our expense items by 10 percent and reduced all our income by around 10 percent.

INCOME STATEMENT	0	1	2	3	4	5	6	7	8	9	10	11	12
EXPENSES	$ 196.453.833,00	$ 1.151.850,00	$ 1.203.926,58	$ 1.258.357,61	$ 1.315.249,54	$ 1.374.713,61	$ 1.436.866,14	$ 1.501.828,66	$ 1.569.728,21	$ 1.640.697,59	$ 1.714.875,59	$ 1.792.407,26	$ 1.873.444,24
LABOR	$ -	$ 1.098.850,00	$ 1.148.530,39	$ 1.200.456,88	$ 1.254.731,04	$ 1.311.459,01	$ 1.370.751,71	$ 1.432.725,11	$ 1.497.500,41	$ 1.565.204,28	$ 1.635.969,13	$ 1.709.933,34	$ 1.787.241,57
VECHILES	$ 89.000.000,00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -		$ -
ROUTE, TERMINAL AND STATION CREATION, etc.	$ 107.453.833,00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
MAINTENANCE	$ -	$ 53.000,00	$ 55.396,20	$ 57.900,73	$ 60.518,49	$ 63.254,61	$ 66.114,43	$ 69.103,55	$ 72.227,80	$ 75.493,31	$ 78.906,46	$ 82.473,92	$ 86.202,67
SPONSORSHIPS	$ -	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00
REVENUES	$ -	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00	$ 13.450.000,00
NET INCOME	$ -196.453.833,00	$ 12.298.150,00	$ 12.246.073,42	$ 12.191.642,39	$ 12.134.750,46	$ 12.075.286,39	$ 12.013.133,86	$ 11.948.171,34	$ 11.880.271,79	$ 11.809.302,41	$ 11.735.124,41	$ 11.657.592,74	$ 11.576.555,76
NET INCOME	$ -196.453.833,00	$ 12.298.150,00	$ 12.246.073,42	$ 12.191.642,39	$ 12.134.750,46	$ 12.075.286,39	$ 12.013.133,86	$ 11.948.171,34	$ 11.880.271,79	$ 11.809.302,41	$ 11.735.124,41	$ 11.657.592,74	$ 11.576.555,76
CUMULATIVE CASH FLOW	$ -196.453.833,00	$ -184.155.683,00	$ -171.909.609,58	$ -159.717.967,19	$ -147.583.216,73	$ -135.507.930,34	$ -123.494.796,48	$ -111.546.625,14	$ -99.666.353,35	$ -87.857.050,95	$ -76.121.926,53	$ -64.464.333,79	$ -52.887.778,03

13	14	15	16	17	18	19	20	21	22	23	24
$ 1.958.145,00	$ 2.046.675,19	$ 2.139.207,94	$ 2.235.924,21	$ 2.337.013,14	$ 2.442.672,44	$ 2.553.108,72	$ 2.668.537,96	$ 2.789.185,91	$ 2.915.288,50	$ 3.047.092,34	$ 3.184.855,21
$ 1.868.045,00	$ 1.952.501,66	$ 2.040.776,70	$ 2.133.042,77	$ 2.229.480,31	$ 2.330.277,91	$ 2.435.632,69	$ 2.545.750,70	$ 2.660.847,28	$ 2.781.147,52	$ 2.906.886,68	$ 3.038.310,67
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -		$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 90.100,00	$ 94.173,53	$ 98.431,24	$ 102.881,44	$ 107.532,84	$ 112.394,53	$ 117.476,03	$ 122.787,27	$ 128.338,63	$ 134.140,98	$ 140.205,66	$ 146.544,54
$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00	$ 200.000,00
$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00	$ 14.775.000,00
$ 12.816.855,00	$ 12.728.324,81	$ 12.635.792,06	$ 12.539.075,79	$ 12.437.986,86	$ 12.332.327,56	$ 12.221.891,28	$ 12.106.462,04	$ 11.985.814,09	$ 11.859.711,50	$ 11.727.907,66	$ 11.590.144,79
$ 12.816.855,00	$ 12.728.324,81	$ 12.635.792,06	$ 12.539.075,79	$ 12.437.986,86	$ 12.332.327,56	$ 12.221.891,28	$ 12.106.462,04	$ 11.985.814,09	$ 11.859.711,50	$ 11.727.907,66	$ 11.590.144,79
$ -40.070.923,03	$ -27.342.598,22	$ -14.706.806,16	$ -2.167.730,37	$ 10.270.256,49	$ 22.602.584,05	$ 34.824.475,33	$ 46.930.937,37	$ 58.916.751,46	$ 70.776.462,96	$ 82.504.370,62	$ 94.094.515,41

Figure 50 Good Scenario Cash Flow

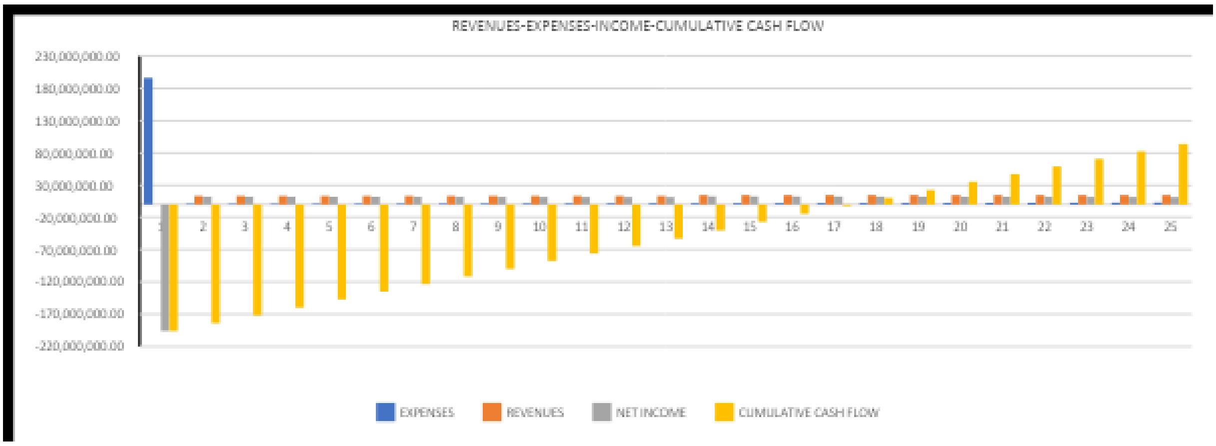

Figure 51 Good Scenario Cash Flow Chart

Our project, which managed to make a profit in the 2-year projection as a result of both scenarios, made a profit at the end of the 15th month in the normal scenario and at the end of the 19th month in the worst case scenario. In addition, in the good scenario, our total profit after 2 years will be around 130 million dollars, while in the bad scenario, we predict that we will make a profit of around 60 million dollars.

INCOME STATEMENT	0	1	2	3	4	5	6	7	8	9	10	11	12
EXPENSES	$ 215.199.216,30	$ 1.448.853,18	$ 1.512.204,93	$ 1.578.724,27	$ 1.648.569,57	$ 1.721.907,14	$ 1.798.911,59	$ 1.879.766,26	$ 1.964.663,67	$ 2.053.805,94	$ 2.147.405,33	$ 2.245.684,69	$ 2.348.878,01
LABOR	$ -	$ 1.208.735,00	$ 1.269.171,75	$ 1.332.630,34	$ 1.399.261,85	$ 1.469.224,95	$ 1.542.686,19	$ 1.619.820,50	$ 1.700.811,53	$ 1.785.852,11	$ 1.875.144,71	$ 1.968.901,95	$ 2.067.347,04
VECHILES	$ 97.000.000,00	-	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-	$ -
ROUTE, TERMINAL AND STATION CREATION	$ 118.199.216,30	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
MAINTENANCE	$ -	$ 58.300,00	$ 61.215,00	$ 64.275,75	$ 67.489,54	$ 70.864,01	$ 74.407,22	$ 78.127,58	$ 82.033,95	$ 86.135,65	$ 90.442,43	$ 94.964,56	$ 99.712,78
SPONSORSHIPS	$ -	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18
REVENUES	$ -	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31	$ 11.703.557,31
NET INCOME	$ -215.199.216,30	$ 10.254.704,13	$ 10.191.352,38	$ 10.124.833,04	$ 10.054.987,74	$ 9.981.650,17	$ 9.904.645,72	$ 9.823.791,05	$ 9.738.893,65	$ 9.649.751,37	$ 9.556.151,98	$ 9.457.872,63	$ 9.354.679,30
NET INCOME	$ -215.199.216,30	$ 10.254.704,13	$ 10.191.352,38	$ 10.124.833,04	$ 10.054.987,74	$ 9.981.650,17	$ 9.904.645,72	$ 9.823.791,05	$ 9.738.893,65	$ 9.649.751,37	$ 9.556.151,98	$ 9.457.872,63	$ 9.354.679,30
CUMULATIVE CASH FLOW	$ -215.199.216,30	$ -204.944.512,17	$ -194.753.159,79	$ -184.628.326,75	$ -174.573.339,01	$ -164.591.688,84	$ -154.687.043,12	$ -144.863.252,07	$ -135.124.358,42	$ -125.474.607,05	$ -115.918.455,06	$ -106.460.582,44	$ -97.105.903,14

13	14	15	16	17	18	19	20	21	22	23	24
$ 2.457.231,00	$ 2.571.001,64	$ 2.690.460,82	$ 2.815.892,95	$ 2.947.596,69	$ 3.085.885,61	$ 3.231.088,98	$ 3.383.552,52	$ 3.543.639,24	$ 3.711.730,29	$ 3.888.225,90	$ 4.073.546,28
$ 2.170.714,40	$ 2.279.250,12	$ 2.393.212,62	$ 2.512.873,25	$ 2.638.516,92	$ 2.770.442,76	$ 2.908.964,90	$ 3.054.413,14	$ 3.207.133,80	$ 3.367.490,49	$ 3.535.865,02	$ 3.712.658,27
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 104.698,42	$ 109.933,34	$ 115.430,01	$ 121.201,51	$ 127.261,59	$ 133.624,67	$ 140.305,90	$ 147.321,20	$ 154.687,26	$ 162.421,62	$ 170.542,70	$ 179.069,83
$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18	$ 181.818,18
$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23	$ 12.855.731,23
$ 10.398.500,22	$ 10.284.729,58	$ 10.165.270,41	$ 10.039.838,28	$ 9.908.134,54	$ 9.769.845,61	$ 9.624.642,24	$ 9.472.178,70	$ 9.312.091,99	$ 9.144.000,93	$ 8.967.505,33	$ 8.782.184,94
$ 10.398.500,22	$ 10.284.729,58	$ 10.165.270,41	$ 10.039.838,28	$ 9.908.134,54	$ 9.769.845,61	$ 9.624.642,24	$ 9.472.178,70	$ 9.312.091,99	$ 9.144.000,93	$ 8.967.505,33	$ 8.782.184,94
$ -86.707.402,91	$ -76.422.673,33	$ -66.257.402,92	$ -56.217.564,64	$ -46.309.430,10	$ -36.539.584,49	$ -26.914.942,25	$ -17.442.763,54	$ -8.130.671,56	$ 1.013.329,37	$ 9.980.834,70	$ 18.763.019,64

Figure 52 10% Bad Scenario Cash Flow

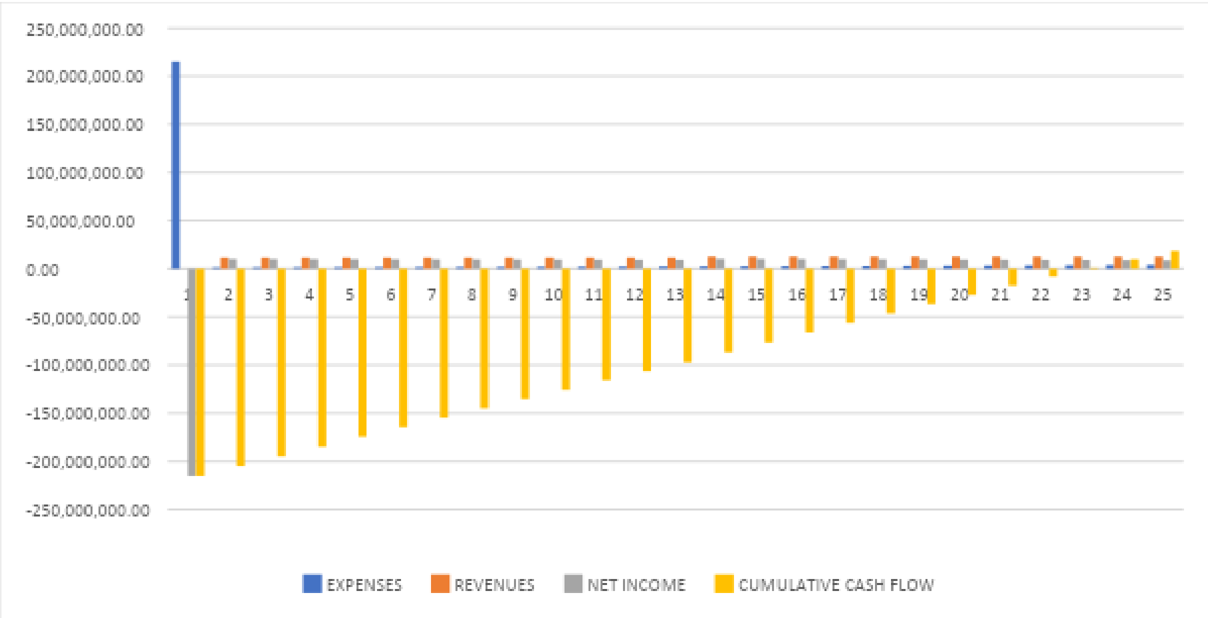

Figure 53 10% Bad Scenario Cash Flow Chart

- **FINANCIALS**

We found 3 opportunities for our project to raise financing. These opportunities;

1. **State Treasury**

We have determined our most important candidate for financing our project as the state treasury. The fact that the service we will offer is a municipal service, directly considering the public's benefit, aiming to protect the environment and making transportation easier were the factors that strengthened our position in terms of supporting and funding this project by the state.

2. **IMF Loan**

Our backup plan as an alternative solution was the loan we planned to receive as a result of our applications to the IMF. In the light of our research, we learned that the interest rate offered by the IMF to countries for loan requests not exceeding 300 percent of the quota is 1.66 (interest rate + service rate). Although this information is not exact, it has been approximately confirmed by the data on the loans Turkey received in the past[51]. In the light of this information, we determined that the total payment of a loan of 220 million dollars with a 2-year repayment starting 1 year later exceeded 294 million dollars. Although we predicted that our project could handle this cost in both possible and worst-case scenarios, we decided to rank this option third because the biggest cost was in this possibility. [51]

IMF INTEREST APPLICATION = Simple Interest Rate (1,16) + Service Fee (0.5)	1.66%
Amount of loan applied for	$ 220.000.000,00
Formula for Monthly Payback = (Amount of Loan × Monthly Interest Rate) / (1-(1+Monthly Interest Rate)**(Total Payback Month))	$ 12.250.535,14
Although the time period we envisaged for the creation of our project was 6 months, we calculated the payback after 1 year, taking into account possible mishaps while making the calculations.	

MONTH	Amount Paid
1	$ 12.250.536,00
2	$ 12.250.536,00
3	$ 12.250.536,00
4	$ 12.250.536,00
5	$ 12.250.536,00
6	$ 12.250.536,00
7	$ 12.250.536,00
8	$ 12.250.536,00
9	$ 12.250.536,00
10	$ 12.250.536,00
11	$ 12.250.536,00
12	$ 12.250.536,00
13	$ 12.250.536,00
14	$ 12.250.536,00
15	$ 12.250.536,00
16	$ 12.250.536,00
17	$ 12.250.536,00
18	$ 12.250.536,00
19	$ 12.250.536,00
20	$ 12.250.536,00
21	$ 12.250.536,00
22	$ 12.250.536,00
23	$ 12.250.536,00
24	$ 12.250.536,00
TOTAL	$ 294.012.864,00

In this scenario, there is an additional expense of approximately 50 million dollars. Considering that the approximate profit we will obtain in our optimal calculations is around 135 million dollars, it is an easily financeable method.

Figure 54 IMF Loan

3. Sponsorship

Our other option was to find a sponsor who could partner with our project periodically. Within the framework of our market research and interviews, we decided that the most suitable sponsorship offer was the company that offered an investment of 220 million dollars in return for sharing fifty percent of the income from the start of the project. In this proposal, the company proposed to seize 50 percent of the project's ticket revenues as payment for 4 years. In this scenario, we need to make a payment of 159 million dollars at the end of the second year and 318 million dollars at the end of the entire period. Although the total payment amount was higher than the IMF loan, the wider payment process, the depreciation of the currency and the fact that the sponsorship provided us with much more comfort in the payments at the end of 2 years made us prefer this scenario to the IMF.

Sponsors ask for 50 percent of monthly ticket income for 5 years in return for financing.

Our Monthly Ticket Revenue	$ 13.250.000,00

Payments will start as of the beginning of the project.

MONTH	Amount Paid
1	$ 6.625.000,00
2	$ 6.625.000,00
3	$ 6.625.000,00
4	$ 6.625.000,00
5	$ 6.625.000,00
6	$ 6.625.000,00
7	$ 6.625.000,00
8	$ 6.625.000,00
9	$ 6.625.000,00
10	$ 6.625.000,00
11	$ 6.625.000,00
12	$ 6.625.000,00
13	$ 6.625.000,00
14	$ 6.625.000,00
15	$ 6.625.000,00
16	$ 6.625.000,00
17	$ 6.625.000,00
18	$ 6.625.000,00
19	$ 6.625.000,00
20	$ 6.625.000,00
21	$ 6.625.000,00
22	$ 6.625.000,00
23	$ 6.625.000,00
24	$ 6.625.000,00
...	$ 6.625.000,00
48	$ 6.625.000,00
TOTAL	$ 318.000.000,00

The sponsor method is also quite sustainable for our project, and considering that the money will lose value because the payment plan is spread over a longer period, it can be said that it is a more effective scenario than taking out a loan from the IMF.

At the end of the 2nd year	$ 159.000.000,00

Figure 55 Sponsorship

- **COMPARISON OF TWO POSSIBLE PROJECT IDEAS**

Line name	Line length	Number of vehicles to serve	Cost of vehicles ($)	Amount of energy needed (kW)(daily)	Total solar panel need (1m^2)	Budget required for route, terminal and panels ($)	Total Cost ($)
Beylikduzu - Pendik	74	700	311,500,000	30,000	200000	3,150,000,000	3,463,500,000
Sogutlucesme - Pendık	21	200	89,000,000	2,700	6400	107,453,833	196,453,833

2.5 Risk Analysis

Risk Analysis is a practice that aims to identify potential issues that newly implemented or existing projects might encounter and to deal with these problems. In the risk analysis process, factors that may pose a potential threat must first be analyzed and then precautions must be taken against these threats. It should be checked whether these measures will work or not by carrying out various analysis and simulation studies. [55]

The Risk Analysis process basically consists of 4 steps:

- **Identification of Risk**: The first stage of risk analysis is to define the risk. At this stage, the potential risks of the project are determined by working together with the project stakeholders.

- **Analysis and Evaluation of Risks**: Potential risks identified at this stage are analyzed and evaluated in detail. The main purpose of this stage is to predict to what extent these risks may damage the project and what consequences they will have. These predictions are based on mathematical data and simulations.

- **Classification of Risks and Precautions**: At this stage, previously identified and analyzed risks are listed according to their importance and risk level. After this sorting process, various precautionary activities are carried out for each risk, starting from threats that pose a high risk.

- **Monitoring of Risks and Activities**: Thanks to this stage, which includes the systematic monitoring of the activities carried out in the first 3 stages, risk analyzes and measures taken remain current and do not pose a threat. If a threatening situation occurs, immediate action is taken.

Figure 56 Risk Management Process

Risk Analysis Types

- Quantitative Risk Analysis
- Qualitative Risk Analysis
- Threat Analysis
- Needs Assessment Analysis
- Root Cause Analysis

2.5.1 Risk Management Table

		PROBABILITY				
		Rare	Unlikely	Possible	Likely	Almost Certain
	Catastrophic	Pandemic Diseases	Fire in Stations or Battery	Damage to Converters	Run out of Battery	Natural Disaster
	Major	Delays of Maintenance on Solar Panels	Bottlenecks of Charging Stations	Variability of Weather	Sudden Vehicle Malfunctions	Disturbance Due to Construction
	Moderate	Insufficient Supply of Solar Panels	Wrong Electrical Wiring System	Delays in Transportation	Fluctuations in currency exchange rates	Dangerous Incidents in Route
	Minor	Design Mistakes	Delays in Construction	Lack of Maintenance	Inadequate Training for Maintenance Staff	Insufficient Vehicles for Special Events
	Insufficient	Lack of Lighting System	Public Resistance to new route	Escalator or Elevator Malfunction	Insufficient Vehicle Capacity	Air Condition System Disorder

	Minimum Risk
	Low Risk
	Moderate Risk
	High Risk
	Extreme Risk

Figure 57 Risk Management Table

There are 5 different risk types in the Risk Assessment table: Minimum Risk, Low Risk, Medium Risk, High Risk and Extreme Risk. Purple-Extreme, Red-High, Orange-Moderate, Yellow-Low and Green-Minimum represent risks. When determining these risk types, the probability of the risk occurring, and the magnitude of its impact are taken into consideration. For example, if the batteries that enable the transfer of energy from the sun to the metrobuses in the form of fuel energy run out of charge, public transportation activity will be disrupted, and this will result in the suffering of customers. We foresee that some batteries in our project will face this type of situation several times a year, depending on the weather conditions of Istanbul. For this reason, the possibility of this risk occurring is certain, even if it occurs a few times a year, and the result of this risk is the disruption of public transportation activities for a few days. In short, the risk of "Run Out of Battery" is an extreme risk for us and it is the risk that requires the quickest action and therefore the risk representing by purple.

2.5.2 Risk Mitigation

Risk Mitigation is basically the process carried out to reduce or eliminate the risks that the project may encounter. In this process, the risks that the project may encounter during the construction and activity phases, are dealt with by considering their severity. [56] Various precautions are found and put into action to prevent the threats posed by risks from occurring.

Risk Description	Importance Level of Risk	Mitigation Measures
Run out of Battery	**Extreme Risk**	1. Using long-lasting and large-capacity batteries, 2. Monitoring, controlling, and optimizing energy use by smart energy technology integration, 3. Implementing regular maintenance programs to prevent sudden energy loss.
Natural Disaster	**Extreme Risk**	1. Reviewing emergency plans and organizing staff training sessions to ensure rapid and effective intervention in crises, 2. Strengthening the infrastructure, preparing logistic support and finally making plans against disaster situations.
Disturbance Due to Construction	**Extreme Risk**	1. Determining alternative roads and routes for the local people during the construction process, 2. Sharing the potential impacts and measures taken with the local people transparently during the project operation and organizing meetings to receive feedback and responding to their concerns regularly,
Damage to Converters	**High Risk**	1. Using high-quality and durable materials, 2. Creating regular maintenance programs, and effective process planning for rapid response to malfunctions and spare parts supply.
Sudden Vehicle Malfunctions	**High Risk**	1. Having extra vehicles for sudden Metrobus failures, 2. Using vehicle tracking systems that monitor the location and status of the vehicles, 3. Performing regular maintenance of the vehicles and ensuring sufficient spare parts stock.
Fluctuations in Currency Exchange Rates	**High Risk**	1. Regularly monitoring currency markets and adjusting financial forecasts accordingly. 2. Diversifying suppliers and negotiating fixed-price contracts. 3. Maintaining communication with financial institutions for timely updates on market trends. 4. Implementing currency hedging strategies to minimize the impact of exchange rate fluctuations.
Dangerous Incidents in Route	**High Risk**	1. Implementing advanced safety and surveillance systems on Metrobuses. 2. Conducting regular safety training sessions for Metrobus drivers and staff. 3. Establishing communication protocols with local authorities to respond quickly to incidents.
Insufficient Vehicles for Special Events	**High Risk**	1. Establishing connections with event organizers to coordinate transportation needs in advance and conducting demand forecasting for the required number of vehicles. 2. Implementing a flexible scheduling system to allocate additional vehicles during peak demand. 3. Maintaining a contingency fleet to meet unexpected demand.
Air Condition System Disorder	**High Risk**	1. Checking air conditioning units to identify potential issues regularly before they escalate. 2. Establishing partnerships with reliable maintenance service providers for prompt repairs. 3. Equiping Metrobuses with backup cooling systems to ensure passenger comfort during potential malfunctions.

Fire in Stations or Battery	**Moderate Risk**	1. Implementing strict safety protocols for battery handling and charging. 2. Installing fire detection and suppression systems in Metrobus stations and battery charging areas. 3. Conducting regular fire drills and training sessions for station staff. 4. Using fire-resistant materials and designs in Metrobus stations and battery storage facilities.
Delays in Transportation	**Moderate Risk**	1. Regular maintenance of Metrobuses to reduce the occurrence of malfunctions and prevent delays that may occur due to malfunctions. 2. Planning the departure times by taking into account situations such as traffic congestion on the bridge.
Variability of Weather	**Moderate Risk**	1. Storing surplus energy through backup batteries as a precaution against unfavorable situations, and meeting the energy need from this storage on days when daily energy production is insufficient, 2. Storing tire chains that vehicles can attach to in our stations as spares for heavy snowy days.
Inadequate Training for Maintenance Staff	**Moderate Risk**	1. Placing vehicle maintenance teams and road maintenance teams at certain points along our route at intervals to ensure providing support as soon as possible 2. Inspecting the asphalt at the end of each month and carrying out the necessary operations at the points that require maintenance.
Insufficient Vehicle Capacity	**Moderate Risk**	1. Determining the sufficiency of seating areas in vehicles in advance by running operations taking into account the average age of the regional population, the number of seats in the surrounding public vehicles, public dissatisfaction with the surrounding public vehicles, and similar criteria. 2. Adding or removing the number of seats according to the needs of the public.
Pandemic Diseases	**Low Risk**	1. In case of a lockdown, continue to use the energy produced efficiently by concentrating our number of trips during business hours to provide transportation for people going to work, 2. Directing the remaining amount of energy produced to other areas such as lighting public buildings, and providing energy for computer systems in public institutions, etc.
Bottlenecks of Charging Stations	**Low Risk**	1. Determining the most used hours of charging stations, the Metrobus schedule can be arranged accordingly, 2) Maintaining and monitoring charging stations at routine intervals, immediate intervention can be provided in case of possible situations.
Wrong Electrical Wiring System	**Low Risk**	1. Performing prototype tests of the system to specify any wrong in the electrical wiring system and to fix it in advance. 2. Carrying out regular inspections by experts during and after the installation process. 3. Providing spare parts for the components used in the electrical installation as a precaution for solving possible problems quickly
Delays in Construction	**Low Risk**	1. Creating projections with all the stakeholders while planning the time management, 2. Taking into account the worst-case scenario on main points such as supply times and construction times to determine the date on which the project will be completed in the worst case.
Lack of Maintenance	**Low Risk**	1. Constituting a regular maintenance program for Metrobuses and meticulous inspection of each system part, 2. By taking into account the analysis of data and feedback, identifying areas for improvement more accurately.
Escalator or Elevator Malfunction	**Low Risk**	1. Implementing a strict and routine maintenance schedule to ensure elevators and escalators are regularly inspected and serviced to prevent breakdowns. 2. Installing sensors and monitoring systems to detect potential issues in real-time for proactive maintenance and minimizing downtime. 3. Developing a swift emergency response plan, including a dedicated team that can quickly address breakdowns. This may involve having technicians stationed nearby during peak hours.

Delays of Maintenance on Solar Panels	**Minimum Risk**	1. Carrying out planned and unplanned inspections for solar panels frequently and systematically. 2) Calculating the work-hour sufficiency of the employees responsible for the maintenance and repair of solar panels in advance.
Insufficient Supply of Solar Panels	**Minimum Risk**	1. Calculating the number of solar panels required for the project in advance. 2. To have an idea about the stocks of the suppliers we will order from and to determine an alternative supplier list against insufficient stocks. 3) To measure the quality of the ordered solar panels. ordering a few solar panels in advance and passing them through various tests.
Design Mistakes	**Minimum Risk**	1. Carrying out various operational studies for the location of solar panels and charging stations to avoid possible mistakes. 2) To determine a few alternative studies and choose the actual design among these alternatives so that the use of the areas is compatible both mathematically and in terms of layout.
Lack of Lighting System	**Minimum Risk**	1. To use the lighting systems that the municipality currently uses at other stops and public transportation. 2. To follow up on complaints about lighting malfunctions through the municipality's reporting line and to respond quickly to these complaints.
Public Resistance to New Route	**Minimum Risk**	1. Conducting incentive campaigns and events to attract people's attention 2. By sharing data regarding the performance of the Metrobus with the public, the public's trust in this system can be increased and their acceptance becomes easier. 3. Responding to the public's problems by listening to why people resist. 4. To present the trial processes of the designed Metrobus to the public and enable them to see the performance and advantages of these systems.

Figure 58 Risk Mitigation Table

2.6 Time Scale (Gantt Chart) and Communication Plan

2.6.1 Gantt Chart

We designed a Gantt chart to represent and schedule tasks in our project visually. The chart provides us with a clear timeline, task dependencies, and overall progress while it helps us with efficient project planning, coordination, and monitoring. Figure 57 shows overview of the real timeline of our project. In order to examine the tasks, you can look Figure 58-62. However, we also designed another Gantt Chart for the schedule of our design project, you can also see it on Figure 63.

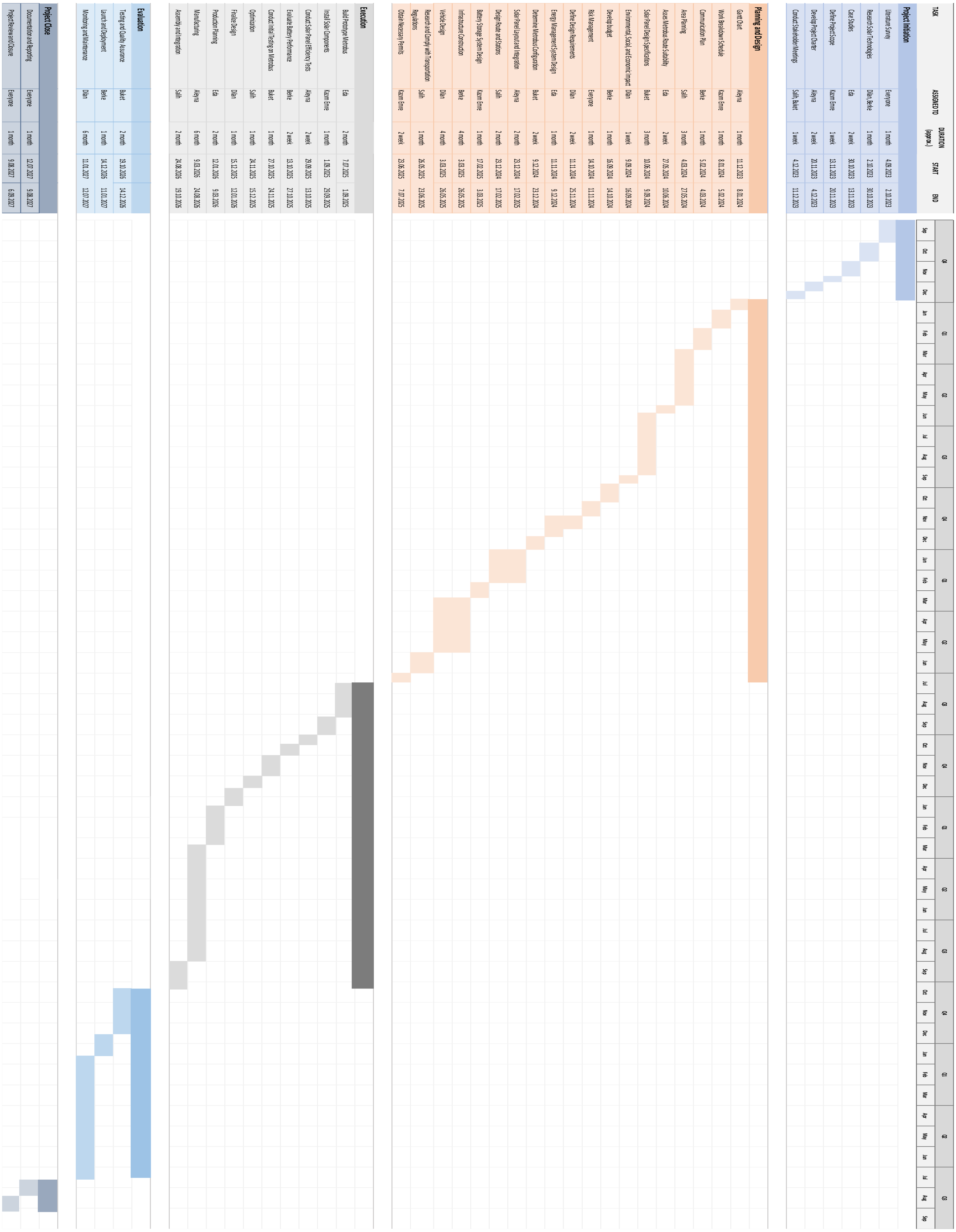

Figure 59 Overview of the real project Gantt chart

TASK	ASSIGNED TO	DURATION (approx.)	START	END
Project Initiation				
Literature Survey	Everyone	1 month	4.09.2023	2.10.2023
Research Solar Technologies	Dilan, Berke	1 month	2.10.2023	30.10.2023
Case Studies	Eda	2 week	30.10.2023	13.11.2023
Define Project Scope	Kazım Emre	1 week	13.11.2023	20.11.2023
Develop Project Charter	Aleyna	2 week	20.11.2023	4.12.2023
Conduct Stakeholder Meetings	Salih, Buket	1 week	4.12.2023	11.12.2023

2023			
Q4			
Sep	Oct	Nov	Dec

Figure 60 Project Initiation Tasks in Gantt Chart

TASK	ASSIGNED TO	DURATION (approx.)	START	END
Planning and Design				
Gantt Chart	Aleyna	1 month	11.12.2023	8.01.2024
Work Breakdown Schedule	Kazım Emre	1 month	8.01.2024	5.02.2024
Communication Plan	Berke	1 month	5.02.2024	4.03.2024
Area Planning	Salih	3 month	4.03.2024	27.05.2024
Asses Metrobus Route Suitability	Eda	2 week	27.05.2024	10.06.2024
Solar Panel Design Specifications	Buket	3 month	10.06.2024	9.09.2024
Environmental, Social, and Economic Impact	Dilan	1 week	9.09.2024	16.09.2024
Develop budget	Berke	1 month	16.09.2024	14.10.2024
Risk Management	Everyone	1 month	14.10.2024	11.11.2024
Define Design Requirements	Dilan	2 week	11.11.2024	25.11.2024
Energy Management System Design	Eda	1 month	11.11.2024	9.12.2024
Determine Metrobus Configuration	Buket	2 week	9.12.2024	23.12.2024
Solar Panel Layout and Integration	Aleyna	2 month	23.12.2024	17.02.2025
Design Route and Stations	Salih	2 month	23.12.2024	17.02.2025
Battery Storage System Design	Kazım Emre	1 month	17.02.2025	3.03.2025
Infrastructure Construction	Berke	4 month	3.03.2025	26.05.2025
Vehicle Design	Dilan	4 month	3.03.2025	26.05.2025
Research and Comply with Transportation Regulations	Salih	1 month	26.05.2025	23.06.2025
Obtain Necessary Permits	Kazım Emre	2 week	23.06.2025	7.07.2025

2024			2024			2024			2024			2025			2025			2025		
Q1			Q2			Q3			Q4			Q1			Q2			Q3		
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep

Figure 61 Planning and Design Tasks in Gantt Chart

TASK	ASSIGNED TO	DURATION (approx.)	START	END
Execution				
Build Prototype Metrobus	Eda	2 month	7.07.2025	1.09.2025
Install Solar Components	Kazım Emre	1 month	1.09.2025	29.09.2025
Conduct Solar Panel Efficiency Tests	Aleyna	2 week	29.09.2025	13.10.2025
Evaluate Battery Performance	Berke	2 week	13.10.2025	27.10.2025
Conduct Initial Testing on Metrobus	Buket	1 month	27.10.2025	24.11.2025
Optimization	Salih	1 month	24.11.2025	15.12.2025
Finalize Design	Dilan	1 month	15.12.2025	12.01.2026
Production Planning	Eda	2 month	12.01.2026	9.03.2026
Manufacturing	Aleyna	6 month	9.03.2026	24.08.2026
Assembly and Integration	Salih	2 month	24.08.2026	19.10.2026

2025			2025			2026			2026			2026			2026		
Q3			Q4			Q1			Q2			Q3			Q4		
Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Figure 62 Execution Tasks in Gantt Chart

TASK	ASSIGNED TO	DURATION (approx.)	START	END
Evaluation				
Testing and Quality Assurance	Buket	2 month	19.10.2026	14.12.2026
Launch and Deployment	Berke	1 month	14.12.2026	11.01.2027
Monitoring and Maintenance	Dilan	6 month	11.01.2027	12.07.2027

2026			2027			2027			2027		
Q4			Q1			Q2			Q3		
Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep

Figure 63 Evaluation Tasks in Gantt Chart

TASK	ASSIGNED TO	DURATION (approx.)	START	END
Project Close				
Documentation and Reporting	Everyone	1 month	12.07.2027	9.08.2027
Project Review and Closure	Everyone	1 month	9.08.2027	6.09.2027

Figure 64 Project Close Tasks in Gantt Chart

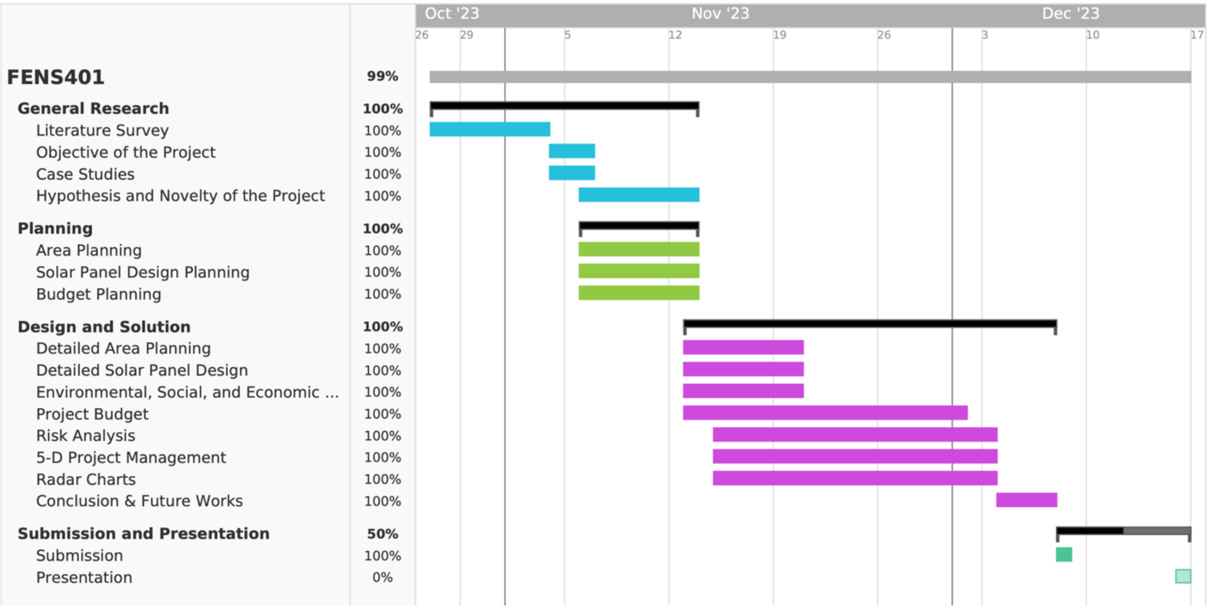

Figure 65 Gantt Chart of FENS401 Projec

2.6.2 Communication Plan

During the project design, we had meetings every week and communicated as much as possible. Luckily, we had a good synergy and didn't encounter any disputes in the process. Also, we utilized some technologies to easily communicate such as Zoom, WhatsApp, and Trello. We conducted our meetings mostly online and preferred Zoom. During our weekly meetings, we informed each other about what we made the previous week and brainstormed to develop our findings. To follow each task easily, we preferred to use a tool which is called Trello as seen in Figure 26. It helps us to follow the deadlines and who is assigned to the tasks.

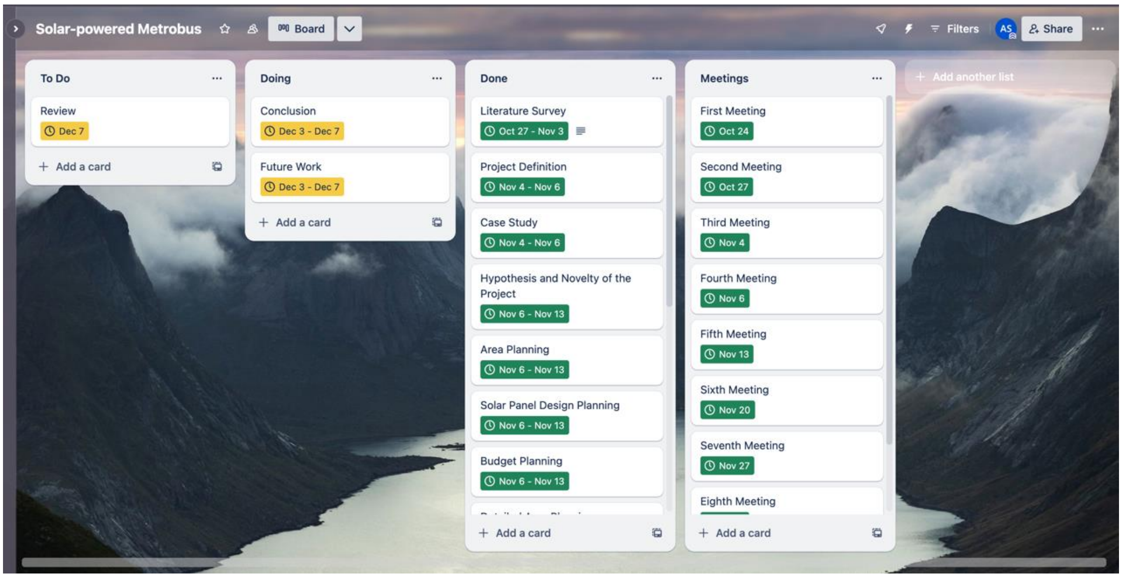

Figure 66 Trello Board of our project

2.7 5-Dimensional Project Management and Radar Charts

2.7.1 First (Project Concept) Complexity Map

At this stage of the project, 5 different dimensions in which activities were carried out throughout the project and the factors affecting these dimensions were discussed. Each factor was evaluated at the beginning, middle and final stages of the project. Dimension evaluation results made at the beginning of the project:

Table 7 Schedule Factors for First Complexity Map

Schedule Factors	Not a Factor	Minor Factor	Major Factor
Timeline Requirements			x
Risk Analysis	x		
Milestones			x
Schedule Control			x
Optimization's Impact on Project Schedule		x	
Resource Availability		x	
Scheduling System/Software			x
Work Breakdown Structure			x
Earned Value Analysis	x		

Table 8 Technical Factors for First Complexity Map

Techinal Factor	Not a Factor	Minor Factor	Major Factor
Scope Of The Project			x
İstanbul's Internal Structure			x
Route Options and Selection		x	
Warranties		x	
Disputes			x
Delivery Methods			x
Contract Formation	x		
Design Method			x
Review/Analysis		x	
Existing Conditions			x
Construction Quality	x		
Safety/Health			x
Optimization Impact Construction Quality	x		
Typical Climate		x	
Technology Usage			x
Selection of City and Transportation Type		x	

Table 9 Context Factors for First Complexity Map

Context Factors	Not a Factor	Minor Factor	Major Factor
Sustainability Goals			x
Resource Availability	x		
Public			x
Utility Coordination			x
Highway Coordination		x	
Enviromental Limitations		x	
Social Equity		x	
Maintaining Capacity		x	
Global/National Economics	x		
Demographics		x	
Global/National Cases			x
Political		x	
Procedural Law		x	
Local Acceptance			x
Local Workforce	x		
Marketing	x		
Project Visualization	x		
Area Planning		x	
Land Use Impact		x	
Intermodal	x		
Determination of Number of Stops and Main Station	x		
Local Economics	x		
Growth Inducement		x	
Land Acqusition		x	
Designers	x		
Cultural Impacts			x
Weather Conditions		x	
Unexpected Events		x	

Table 10 Financing Factors for First Complexity Map

Financing Factors	Not a Factor	Minor Factor	Major Factor
Global Participation		x	
Monetization of Existing Assets		x	
Legislative Process		x	
Federal Funding		x	
Borrowing Against Future Funding	x		
Revenue Generation			x
Project Manager Financial Training		x	
Bond Funding	x		
Determination of Ticket Prices		x	
Transition to Alternate Financing Sources		x	
Vehicle Miles Traveled Fees		x	
State Funding	x		
Carbon Credit Sales			x
Advance Construction	x		
Risk Analysis		x	
Public-Private Partnerships	x		
Financial Management Software	x		

Table 11 Cost Factors for First Complexity Map

Cost Factors	Not a Factor	Minor Factor	Major Factor
Cost Control	x		
Material Cost Issues	x		
Risk Analysis			x
Incentive Usage	x		
Payment Restrictions	x		
User Costs/Benefits		x	
Optimaztion's Impact On Project Cost	x		
Estimate Formation		x	
Contingency Usage		x	
Government Resource Cost Allocation	x		

Table 12 Scores for First Complexity Map

Dimension	Score
Schedule	64.4444
Technical	55
Context	33.5714
Financing	24.7059
Cost	20

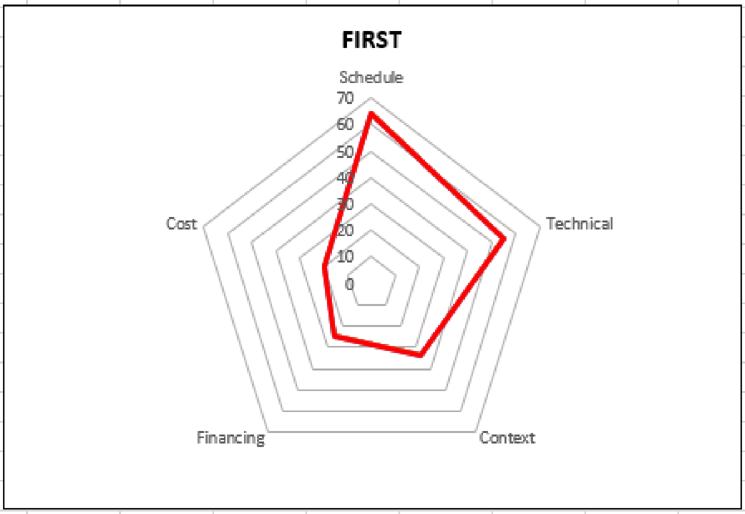

Figure 67 Radar Chart for First Complexity Map

2.7.2 Second (Project Authorization) Complexity Map

In the middle of the project, decision-making and implementation practices began to be made because of the research, rather than the research and idea stages. Second dimension evaluation results:

Table 13 Schedule Factors for Second Complexity Map

Schedule Factors	Not a Factor	Minor Factor	Major Factor
Timeline Requirements			x
Risk Analysis		x	
Milestones			x
Schedule Control			x
Optimization's Impact on Project Schedule			x
Resource Availability			x
Scheduling System/Software			x
Work Breakdown Structure		x	
Earned Value Analysis	x		

Table 14 Technical Factors for Second Complexity Map

Techinal Factor	Not a Factor	Minor Factor	Major Factor
Scope Of The Project			x
İstanbul's Internal Structure		x	
Route Options and Selection		x	
Warranties			x
Disputes			x
Delivery Methods		x	
Contract Formation	x		
Design Method			x
Review/Analysis			x
Existing Conditions			x
Construction Quality		x	
Safety/Health			x
Optimization Impact Construction Quality		x	
Typical Climate			x
Technology Usage			x
Selection of City and Transportation Type		x	

Table 15 Context Factors for Second Complexity Map

Context Factors	Not a Factor	Minor Factor	Major Factor
Sustainability Goals			x
Resource Availability			x
Public			x
Utility Coordination			x
Highway Coordination			x
Enviromental Limitations			x
Social Equity		x	
Maintaining Capacity			x
Global/National Economics			x
Demographics			x
Global/National Cases		x	
Political		x	
Procedural Law		x	
Local Acceptance			x
Local Workforce		x	
Marketing		x	
Project Visualization		x	
Area Planning			x
Land Use Impact			x
Intermodal			x
Determination of Number of Stops and Main Station			x
Local Economics			x
Growth Inducement			x
Land Acqusition			x
Designers		x	
Cultural Impacts			x
Weather Conditions			x
Unexpected Events			x

Table 16 Financing Factors for Second Complexity Map

Financing Factors	Not a Factor	Minor Factor	Major Factor
Global Participation			x
Monetization of Existing Assets			x
Legislative Process		x	
Federal Funding			x
Borrowing Against Future Funding			x
Revenue Generation			x
Project Manager Financial Training		x	
Bond Funding			x
Determination of Ticket Prices			x
Transition to Alternate Financing Sources			x
Vehicle Miles Traveled Fees			x
State Funding			x
Carbon Credit Sales		x	
Advance Construction		x	
Risk Analysis			x
Public-Private Partnerships			x
Financial Management Software		x	

Table 17 Cost Factors for Second Complexity Map

Cost Factors	Not a Factor	Minor Factor	Major Factor
Cost Control			x
Material Cost Issues			x
Risk Analysis			x
Incentive Usage		x	
Payment Restrictions		x	
User Costs/Benefits			x
Optimaztion's Impact On Project Cost		x	
Estimate Formation			x
Contingency Usage			x
Government Resource Cost Allocation		x	

Table 18 Scores for Second Complexity Map

Dimension	Score
Schedule	60
Technical	63.75
Context	68.5714
Financing	77.6471
Cost	68

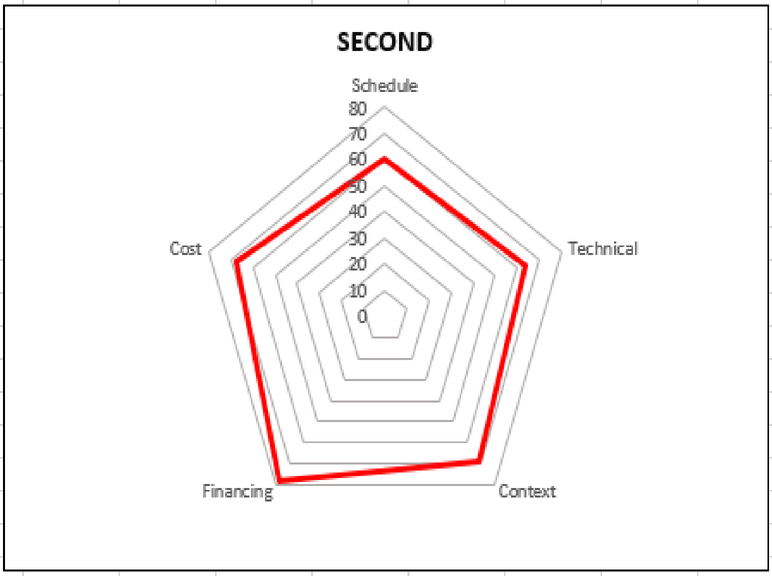

Figure 68 Radar Chart for Second Complexity Map

2.7.3 Third (Project Execution) Complexity Map

At the end of the project, the sustainability and Monitoring phase of the project began. Third dimension evaluation results.

Table 19 Schedule Factors for Third Complexity Map

Schedule Factors	Not a Factor	Minor Factor	Major Factor
Timeline Requirements		x	
Risk Analysis			x
Milestones		x	
Schedule Control			x
Optimization's Impact on Project Schedule			x
Resource Availability	x		
Scheduling System/Software		x	
Work Breakdown Structure		x	
Earned Value Analysis			x

Table 20 Technical Factors for Third Complexity Map

Techinal Factor	Not a Factor	Minor Factor	Major Factor
Scope Of The Project			x
İstanbul's Internal Structure	x		
Route options and selection	x		
Warranties		x	
Disputes		x	
Delivery Methods			x
Contract Formation			x
Design Method	x		
Review/Analysis			x
Existing Conditions		x	
Construction Quality			x
Safety/Health			x
Optimization Impact Construction Quality			x
Typical Climate	x		
Technology Usage			x
Selection of City and Transportation Type	x		

Table 21 Context Factors for Third Complexity Map

Context Factors	Not a Factor	Minor Factor	Major Factor
Sustainability Goals			x
Resource Availability		x	
Public		x	
Utility Coordination		x	
Highway Coordination		x	
Enviromental Limitations		x	
Social Equity		x	
Maintaining Capacity		x	
Global/National Economics			x
Demographics	x		
Global/National Cases	x		
Political		x	
Procedural Law		x	
Local Acceptance	x		
Local Workforce		x	
Marketing			x
Project Visualization			x
Area Planning	x		
Land Use Impact			x
Intermodal	x		
Determination of Number of Stops and Main Station	x		
Local Economics			x
Growth Inducement			x
Land Acqusition		x	
Designers	x		
Cultural Impacts		x	
Weather Conditions	x		
Unexpected Events		x	

Table 22 Financing Factors for Third Complexity Map

Financing Factors	Not a Factor	Minor Factor	Major Factor
Global Participation		x	
Monetization of Existing Assets		x	
Legislative Process		x	
Federal Funding		x	
Borrowing Against Future Funding		x	
Revenue Generation		x	
Project Manager Financial Training			x
Bond Funding		x	
Determination of Ticket Prices	x		
Transition to Alternate Financing Sources		x	
Vehicle Miles Traveled Fees	x		
State Funding		x	
Carbon Credit Sales	x		
Advance Construction	x		
Risk Analysis		x	
Public-Private Partnerships		x	
Financial Management Software		x	

Table 23 Cost Factors for Third Complexity Map

Cost Factors	Not a Factor	Minor Factor	Major Factor
Cost Control		x	
Material Cost Issues		x	
Risk Analysis			x
Incentive Usage	x		
Payment Restrictions		x	
User Costs/Benefits		x	
Optimaztion's Impact On Project Cost		x	
Estimate Formation		x	
Contingency Usage	x		
Government Resource Cost Allocation			x

Table 24 Scores for Third Complexity Map

Dimension	Score
Schedule	51.1111
Technical	47.5
Context	29.2857
Financing	28.2353
Cost	26

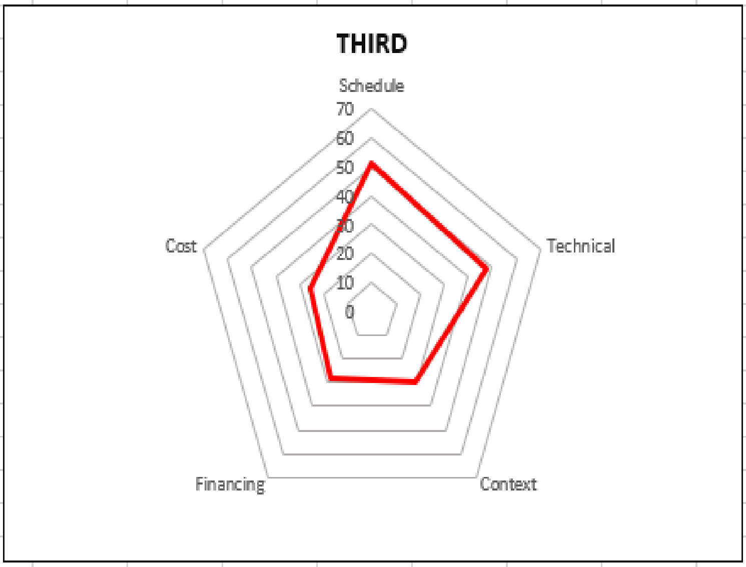

Figure 69 Radar Chart for Third Complexity Map

3. CONCLUSION

Nowadays, with the development of the world, the energy resources used appear to be a much more important issue. Serious problems such as air pollution, CO2 emissions, climate change, global warming caused by preferred fossil fuels, and resource insufficiency arising from population growth have led countries to search for a new energy source. As a result of this search, it turned out that the best solution is renewable energy sources obtained through natural means. Among the many types of renewable energy sources such as wind energy and wave energy, solar energy is one of the most important. Solar power has begun to integrate into our lives in many different areas such as industry and agriculture. With the development of technology, one of the areas where it has the most presence is the field of transportation. Many vehicles such as buses, trains, and Metrobuses have begun to be designed with solar energy, and it is predicted that this will become much more common in the future. With this project, we designed a standalone Metrobus system operating on the Söğütlüçeşme-Pendik route, which we chose by considering population density, temperature, weather conditions, and infrastructure suitability factors. Metrobuses were designed to operate using solar energy in an area of 6000x6000 meters. They can provide their energy both from the solar panels placed on the vehicles and from the solar panels placed in the terminals covering a total area of 800x800 meters in two areas, Söğütlüçeşme and Pendik. This project aims to make it a part of daily life by integrating solar energy into Metrobuses in the most efficient and least costly way and it aims to make our world cleaner and healthier by preventing the harm caused by non-renewable energy sources.

4. FUTURE WORK

Recently, environmental problems caused by fossil fuels have been increasing rapidly. Several problems caused by fossil fuels, especially climate change, endanger human life. This risky situation has led to environmental awareness among people and a decrease in the demand for fossil fuels. Additionally, the gradual depletion of fossil fuels has been effective in ensuring a transition towards sustainable energy. As the demand for sustainable energy sources increases rapidly, transportation systems are also adapting to this change, just as other systems do. It is possible to say that this trend will increase rapidly in the future. At the same time, we predict that the solar energy-powered metrobus system we developed within the scope of our project will see more widespread use in the future, and similarly, solar energy will be used in other public vehicles.

Our project will lead to an increase in future solar-powered vehicles. The expected increase in solar-powered BRT is based on several factors. Beyond being an environmentally friendly alternative, these metrobuses provide social, economic, and technological advantages. The solar-powered metrobus we developed offers lower operating and energy costs compared to fossil fuel-powered metrobuses. This will be beneficial for our country's economy. At the same time, the spread of solar-powered metrobuses will alleviate the unemployment problem by contributing to the creation of new business lines. From an environmental perspective, solar-powered BRTs will keep carbon emissions to a minimum by using a clean energy source, thus protecting the environment, and improving air quality. This environmentally friendly approach will encourage the choice of public transportation systems. This will alleviate the traffic problem, especially in crowded cities, such as Istanbul.

Our project is not only expandable in the coming years, but also can be integrated into other means of transportation with the system we envision. Rapidly developing technology shows that our project can develop in parallel with this progress and become more profitable. Future technology developments will contribute to the emergence of more efficient and compact solar panels. This will allow us to collect more solar energy. This excess energy collected can be used in various areas. For example, by using it in water purification systems, the problem of finding clean water can be solved in the future. In summary, we predict that individuals who see that public transportation systems powered by sustainable energy make cities cleaner, greener, and more livable will invest more in this field in the future.

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