Sustainability and Industrial Design: A Study on AC EV Chargers' Material Selection

Mustafa CANBULAT[1*] [iD], Ahmet Fevzi SAVAŞ[2] [iD]

[1]*Department of Industrial Sustainability, Institute of Graduate Programs, Bilecik Seyh Edebali University, Bilecik, Türkiye*
[2]*Department of Mechanical Engineering, Faculty of Engineering, Bilecik Seyh Edebali University, Bilecik, Türkiye*

ABSTRACT

This study investigates sustainable material selection in industrial design and sustainable design, focusing on electric vehicle (EV) charging stations to address emissions. Through an extensive literature review and market analysis, the research highlights the critical importance of sustainable practices amid evolving environmental concerns. The study identifies polycarbonate (PC) as the primary material used in AC charging stations and explores alternatives to reduce emissions. Acrylonitrile butadiene styrene (ABS) emerges as a promising alternative, given its compatibility with PC and established industrial usage. Utilizing the rule of mixture approach, various ABS-PC combinations undergo thorough analysis to assess their impact on emissions, density, mass, mechanical properties, and safety factors. Optimal mixtures are identified based on safety factor values, which determine the part's lifespan under environmental conditions. Implementation of these identified mixtures has the potential to significantly reduce emissions per product, thereby advancing sustainability goals within the EV charging station domain. This study offers a comprehensive framework for designers and engineers to navigate sustainable material selection, advocating for the integration of sustainability considerations into design processes to promote environmental stewardship and sustainable development in the manufacturing sector.

Keywords: Sustainability; Industrial Design; Sustainable Design; Safety Factor; Rule of Mixture

Sürdürülebilirlik ve Endüstriyel Tasarım: AC Elektrikli Araç Şarj Cihazları Malzeme Seçimi Üzerine Çalışma

ÖZ

Bu çalışma, elektrikli araç (EV) şarj istasyonları kaynaklı emisyonlara odaklanarak endüstriyel tasarım ve sürdürülebilir tasarım üzerinden sürdürülebilir malzeme seçimini araştırmaktadır. Kapsamlı literatür taraması ve pazar analizi yoluyla, gelişen çevresel kaygılar karşısında sürdürülebilir uygulamaların kritik öneminin altı çizilmektedir. AC şarj istasyonlarında kullanılan başlıca malzeme olarak polikarbonat (PC) ele alınmış ve emisyonları azaltmak için alternatifleri araştırılmıştır. Akrilonitril bütadien stiren (ABS), polikarbonat ile uyumluluğu ve endüstriyel kullanımıyla dikkat çeken bir alternatif olarak ortaya çıkmıştır. Karışım kuralı yaklaşımı kullanılarak, çeşitli ABS-PC kombinasyonları oluşturulmuş, emisyon, yoğunluk, kütle, mekanik özellikler ve güvenlik faktörleri üzerine detaylı analizlere tabi tutulmuştur. Güvenlik faktörü değerlerine dayanarak, parçanın çevresel koşullar altında ömrünü belirleyen optimal karışımlar tespit edilmiştir. Belirlenen karışımların uygulanması, ürün başına emisyonları önemli ölçüde azaltma potansiyeline sahip olduğu ve bu sayede EV şarj istasyonları alanında sürdürülebilirlik hedeflerine

*Corresponding Author: Mustafa CANBULAT
 E-mail: canbulatmustafa@hotmail.com

yaklaşılabileceğini göstermiştir. Çalışma, tasarımcılar ve mühendisler için sürdürülebilir malzeme seçiminde rehberlik sağlayan kapsamlı bir çerçeve sunmuş olup, endüstrinin çevresel yönetim ve imalat tarafında sürdürülebilir kalkınmayı teşvik etmek amacıyla tasarım süreçlerine sürdürülebilirlik düşüncelerinin entegrasyonunu savunmaktadır.

Anahtar Kelimeler: Sürdürülebilirlik; Endüstriyel Tasarım; Sürdürülebilir Tasarım; Güvenlik Faktörü; Karışım Kuralı

*Corresponding Author: Mustafa CANBULAT
E-mail: canbulatmustafa@hotmail.com

1. INTRODUCTION

In this study, research is conducted on sustainable material selection at the design stage in relation to raw material emission analysis, industrial design and sustainable design for electric vehicle charging stations, whose supply and demand have accelerated with the transition to electric vehicles. As a result of literature and market research, material data will be obtained, emissions from AC electric vehicle charging stations will be determined, material mixtures for a long product lifetime and sustainable use and solutions to reduce emissions will be revealed as a result of analysis. Basic geometric calculations and the rule of mixture approach will be used for this part. Also, it is an exemplary study to facilitate the material selection of designers with thermal stress analysis and to make selections according to the emission and durability relationship through design constraints.

With the increase of environmental disasters in the 20th century, the concept of sustainability has gained its current meaning and importance with the definition of the WorldWatch Institute and has taken its place in the international arena (Barbosa et al., 2014). As a result of this journey, which started with the increase in mechanization and the Industrial Revolution, production accelerated and supply and demand increased in direct proportion to each other. With easier access to products, the population growth rate has accelerated (Lucas Jr., 2004). An increasing population has brought with it increased demand and therefore supply. For this reason, mass production technologies have improved day by day and more efforts have been made for high-capacity production. These situations mean that the linear economy is getting stronger, and resource consumption has increased with the motto of "take, make, throw away" and therefore the demand for energy has increased (Sterev, 2019). Increasing energy demand has increased global warming by directly triggering greenhouse gas emissions, which is the world's biggest problem (Letcher, 2021). These events have required technological innovations to reduce emissions, and an environment has been created in which these problems can be overcome by making the policies and technologies developed by countries mandatory for other countries.

In line with the Sustainable Development Goals, the United Nations has shared specific targets with the global community to reduce emissions, encompassing political, human, and industrial aspects (United Nations, 2023). On the other hand, the European Union has introduced concepts such as carbon taxes, regulations, and emissions trading systems to reduce emissions, to prevent producers in its region from suffering financial losses when producing green products, to reduce emissions, and to spread the concept of sustainability all over the world. In this context, the 0 emission target, called "Net Zero" in line with the European Union emission targets, has concerned and affected the countries that export products to Europe (European Commission, 2023). If companies within the European Union are above a certain economic size, it is mandatory to reduce the damage they cause to nature, and it has become an obligation to pay carbon

taxes according to the emissions they create. In this context, the sectors and scopes affected by the relevant regulations will continue to increase every year as of 2024. Along with these regulations, the fact that companies from other countries that will export products to Europe will also pay carbon tax has raised emission awareness all over the world and various regulations are being made to pay less carbon tax and cause less damage to nature (Andersen and Ekins, 2009).

In addition to the policies developed to reduce emissions, technologies have also had to adapt to this situation. In energy production, which is the sector that causes the most emissions globally, fossil fuel energy production was intended to be reduced, and renewable energy production from the sun and wind is encouraged. Since vehicles are one of the sectors where fossil fuel is used the most, electric vehicles have been developed and launched under alternative fuel vehicle technologies. With the support and incentives of policies in the global market, the conversion of vehicles to electric has been much faster than expected, and supply and demand have grown rapidly (Thompson, 2023). On the one hand, steps are being taken to reduce emissions, on the other hand, the world is struggling with the concept of sustainability with the emissions of transformation brought about by change. While producing electric vehicles, plastics and metals that are harmful to nature are produced, and the supply is trying to keep up with the demand, and continues to increase emissions. In addition, due to battery technologies, production is limited in mines, which are among the world's limited resources (Jones et al., 2020). Under the circular economy, the linear economy is again applied. In order to be a fully circular economy, resources must be recycled instead of being depleted, or must be destroyed without harming nature and produced without harming nature (Morseletto, 2020). Implementing a 100% circular economy model among product manufacturers has become very difficult. Due to issues such as water, energy and emissions, the models applied cannot be fully circular, but efforts are made to be more circular.

The industrial design discipline has a wide range, from market research to data collection for product needs, from design constraints and concept drawing to computer-aided design and prototype making, from product life cycle services to machine-human interface design, from material selection and analysis for the product to after-sales support and data collection (Industrial Designers Society of America, 2024). Within the scope of this study, three design strategies will be investigated due to their global impact and importance in terms of sustainability. These strategies are European Union Ecodesign, dematerialization, and green product design.

1.1. Sustainable Design Strategies

The EcoDesign strategy has evolved over time, aiming to express product design that minimizes harm to ecological life through various definitions. However, the multitude of approaches proposed by different sources has made it challenging to measure the effectiveness of the EcoDesign approach, leading to

discrepancies in the understanding of what EcoDesign entails. In response, the European Union Commission has established regulations and defined specific criteria for EcoDesign, ensuring that products adhere to measurable standards of environmental friendliness (European Commission, 2024). The EcoDesign approach has also been given to the products of manufacturers and designers as an incentive label, thus increasing the emphasis on studies in this field. Today, with the European Commission EcoDesign approach, the product's reproducibility is examined in terms of how durable it is, its reusable features, the ability to increase its features without changing the product, its repairability, the presence of non-cyclical materials, energy and resource efficiency, recyclable content, reproducibility, carbon and other footprints in the environment, and the damage it causes to nature is comprehensively determined. Based on these results, it is determined whether the product will receive the EcoDesign label or not. Since it is defined that each product will have a digital product passport within the framework of the relevant regulations of the European Commission, it is known that such sustainability parameters of the products will also be recorded in this passport (European Commission, 2024). In this sense, the EcoDesign strategy is not only an environmentally friendly product design strategy, but also one of the design strategies that should be followed in order to be least affected by the European Commission carbon tax regulations.

It is known that different sources have different approaches to sustainable product design strategies, and another strategy that meets in a typical cluster and is known globally in terms of its widespread use is the dematerialization strategy (Watkins et al., 2021). This strategy involves reducing the materials that need to be used on the basis of product design and reducing the use of materials, including the packaging prepared for the sale of the products (Mouëllic et al., 2023). In this strategy, where simplicity is prioritized in terms of service design, the manufacturer will be able to reduce carbon tax, reduce emissions, and reduce material and production expenses because it uses fewer materials. Since this strategy is also directly related to the material focus used in the production of the products, it also includes designing the product with a completely different material that will create fewer emissions, instead of the material determined in direct proportion to emission reduction.

The green product design strategy involves designing new products within the framework of the circular economy and the unsustainable damage that products cause to the environment. It includes the direct use of green materials and the creation of environmentally friendly products (Xue et al., 2021). In this context, a sustainable supply chain constitutes one of the important points of the green product design strategy. In these cases, where indirect emissions such as scope-2 and scope-3 are also calculated and added to the business in the emission calculations determined by the European Commission, the size of the emissions occurring at the stages in the supply chain is also critical (European Commission, 2019). However, the green product design strategy encompasses more than just minimizing the environmental impact of a product. It also has social effects, which in turn contribute to increased profits. When a product is manufactured using

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a green product design strategy, both its sales price and quantity tend to rise, leading to higher profit margins due to its popularity. The global increase in the number of environmentally conscious consumers, often referred to as green consumers, further boosts the sales and profitability of green products. Therefore, the green product design strategy involves not only calculating indirect emissions such as those from the supply chain alongside direct emissions within the product life cycle but also adding the monetary equivalent of these emissions to the product.

1.2. European Market and Known Brands for EV Chargers

Electric vehicles and electric vehicle charging stations, which stand out worldwide within the scope of developing alternative fuel vehicles and reducing fossil fuel-based emissions, show today's new supply-demand increase trend (Agamloh et al., 2020). This change in all vehicles used worldwide is accepted as a market target, and in this sector, fossil fuel vehicles are being replaced by vehicles called electric vehicles, which work by storing electrical energy. As the change occurred faster than expected, problems such as emissions, supply and demand imbalances began to emerge. Due to various factors such as uninterrupted mass production, cost and time, vehicles are not renewed and converted to electric, but are replaced by electric vehicles produced from scratch. This situation has brought about the question of how sustainable electric vehicles are (Ionnides and Wall-Reinius, 2015). The fact that the demand for electric vehicle charging stations has increased dramatically has enabled various products to be produced in various parts of the world and sold in both regional and global markets.

When we look at what is happening, the mass production craze continues in the face of these moves made by the world to get rid of emissions, and the consumption of finite resources, especially the mines required for the production of energy storage units, is accelerating (Jones et al., 2020). The amount of thermoplastic used outside of recycling also increases due to the market size. Reducing emissions is not a legal regulation everywhere in the world, such as in the countries within the European Union (Baer, 2002). In those with legal regulations, deterrent penalties are unavailable in all countries.

Charging at electric vehicle charging stations is carried out in two types: AC and DC. AC stands for alternating current, while DC stands for direct current (Schwarzer and Ghorbani, 2015). However, due to differences in infrastructure, cost and internal parts, AC and DC electric vehicle charging stations are quite different in terms of price differences, materials and design (Kieldsen et al., 2016). While AC charging stations are cheaper, smaller and portable, DC charging stations are larger and consist of metal structures.

According to International Energy Agency data, by the end of 2022, 600.000 AC electric vehicle charging stations have been installed in public areas (International Energy Agency, 2023). While 360.000 of these were installed in China, it was observed that China had more than 1 million stocks in terms of global market

stock. It has been stated that by the end of 2022, more than half of the AC electric vehicle charging station product stocks in the world market are in China. According to the International Energy Agency 2022 year-end data, it is stated that there are more than 117.000 stock AC electric vehicle charging stations in the Netherlands, 74.000 in France, and more than 64.000 in Germany.

Within the scope of market research, research was conducted on the products available in the market and the technical features and optional features of these products. According to the research, the main AC electric vehicle charging stations operating within the European Union countries were selected (Sevdari, 2020). The reason for this selection was the European Union, which has a remarkable goal of reducing emissions when viewed globally. The European Union wants to reduce greenhouse gas emissions by around 55% which is in line with its 2030 targets (European Commission, 2020). Accordingly, the products selected within the scope of market research are; ABB- Terra, EVBox- BusinessLine, Kempower- AC Satellite, Schneider Electric- EVlink ProAC, and Siemens – VersiCharge.

ABB-Terra product has single-phase and three-phase features and can provide products up to 22 kW in the AC electric vehicle charging station category (ABB, 2022). It has the IP54 standard. The EVBox – BusinessLine product has been introduced to the market with up to 22 kW per socket (EVBox, 2023). The product's IP rating is 45. The Kempower-AC Satellite product appears as a floor-mounted product with an aluminum frame (Kempower, 2024). Apart from the protection standard of IP 54, the product is also marketed as a DC Charger with a similar design. The Schneider Electric- EVlink Pro AC product is produced with polycarbonate material with IP55 protection standard (Schneider Electric, 2023a). The Siemens – VersiCharge product is an AC electric vehicle charging station, which has single phase AC output up to 11.5 kW (Siemens, 2023). The IP standard is a protection rating called "Ingress Protection". According to this rating, the deterioration of electrical and electronic products due to sand or water ingress was intended to be bound to a certain standard. Accordingly, it is stated to what extent the products can withstand water or sand (International Electrotechnical Commission, 2024).

Table 1: Selected Products and General Specifications.

Product Names	Product Dimensions (Width x Length x Height (mm))	Body Material	Net Weight
ABB- Terra	195 x 320 x 110	*	4.1 KG
EVBox- BusinessLine	205 x 255 x 600	Polycarbonate	10 KG
Kempower- AC Satellite	300 x 300 x 1518	Aluminium	33 KG
Schneider Electric- EVlink ProAC	317 x 153 x 529	Polycarbonate	7.2 KG
Siemens – VersiCharge	181 x 96 x 409	**	7.7 KG

The information obtained from researching the products determined within the scope of market research and extracting their technical data is given in Table 1. Accordingly, it has been observed that companies in

the European Union market use thermoplastic material in the outer body in the production of AC charging stations. When looking at these materials in general, polycarbonate comes to the fore, while ABS, namely acrylonitrile butadiene styrene and various mixtures are also used, varying according to the usage and performance demands of the companies (Greco, 1996).

2. METHODS AND ANALYSIS

A literature review was conducted on the selected AC electric vehicle charging station products to select sample materials for the product to be designed industrially under sustainable design. With the data obtained from this, the materials used in the AC electric vehicle charging station were determined. As a result of the literature review, detailed material usage data for sustainability was obtained for one of the products researched. Within the scope of the study, in order to select the material used on the body of the product in accordance with the European Commission EcoDesign parameters, the raw material emission of the product, whose data is available, is calculated with the CCaLC 2 software and constitutes the constraint in this study. With this constraint, the optimum material that will reduce emission values and provide a longer product lifetime according to the design features will be determined at the design stage. According to the physical properties of the materials, the optimum mixture is calculated by a theoretical calculation called the "Rule of Mixture" (Wongpajan et al., 2016). According to the resulting optimum material and emission values, it is aimed to conduct a theoretical study that will guide designers on sustainable material selection before mass production or engineering design. The target will be achieved by using the Autodesk Fusion360 software in the material properties to be analyzed in the study and parameters such as mass and volume to be obtained based on the geometric features of the design.

Two main software programs were used in this study. One of them is Computer aided Design (CAD) software for engineering and design, and the second is for emission calculations. Autodesk Fusion360 is CAD software that allows for basic static and dynamic analyses. It has an embedded and expandable material library. While the software offers free usage for academic studies, it is a paid software for industry. The CCaLC 2 open-source software was used for material emission calculations and access to the EcoInvent Material Database based on material sources. This software was developed by the University of Manchester and does not charge any fees. However, the EcoInvent Material Database is a paid database, and access to it through the CCaLC 2 software is limited and free.

In Autodesk Fusion 360, which facilitates the definition of materials and submission for analysis on the designed part, material selection is done as shown in Figure 1.
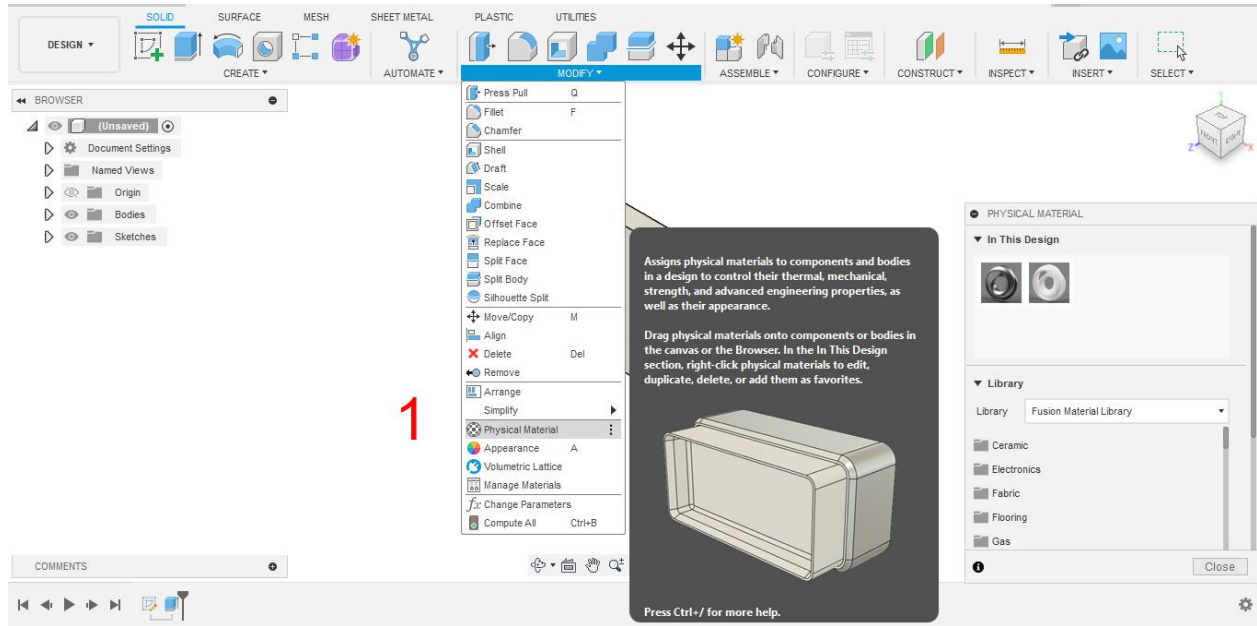
Figure 1. Autodesk Fusion360 Material Selection

When defining the material for the designed part, click on the 'Physical Material' section, select the desired material from the opened material library, and then drag and drop it onto the part to be defined, as shown in Figure 1.
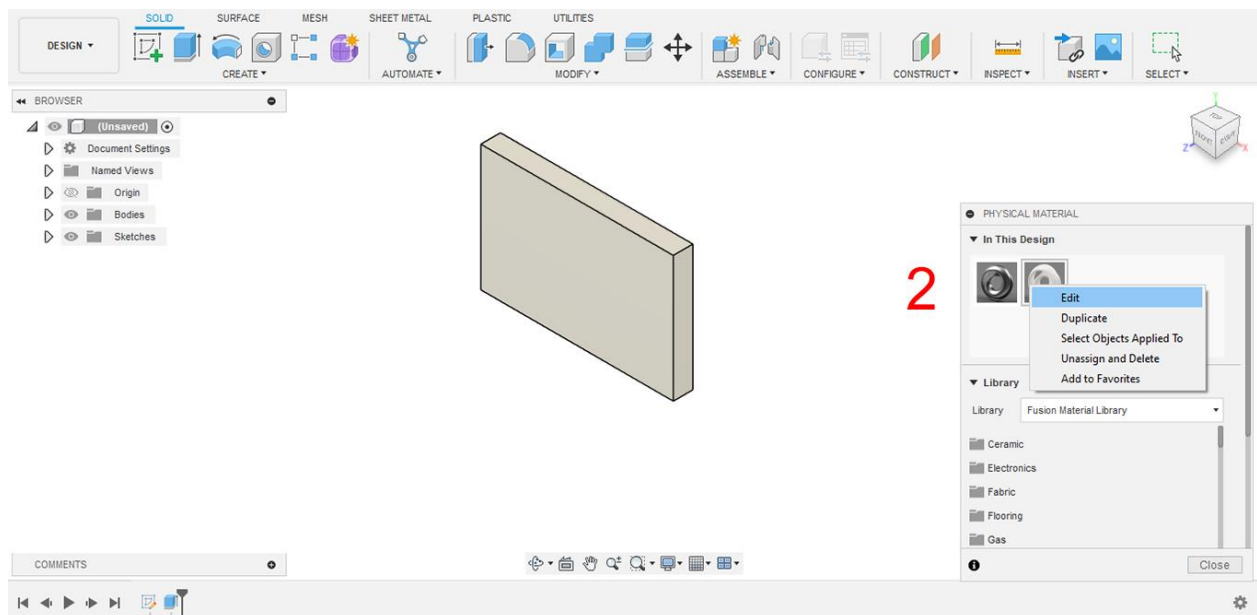

Figure 2. Autodesk Fusion360 Material Properties

As shown in Figure 2, by right-clicking and selecting the edit button, the properties of the desired material can be modified or its details viewed. Additionally, a new material not available in the library can be manually added, allowing for the definition of a new material by changing its name and all its mechanical and thermal properties.
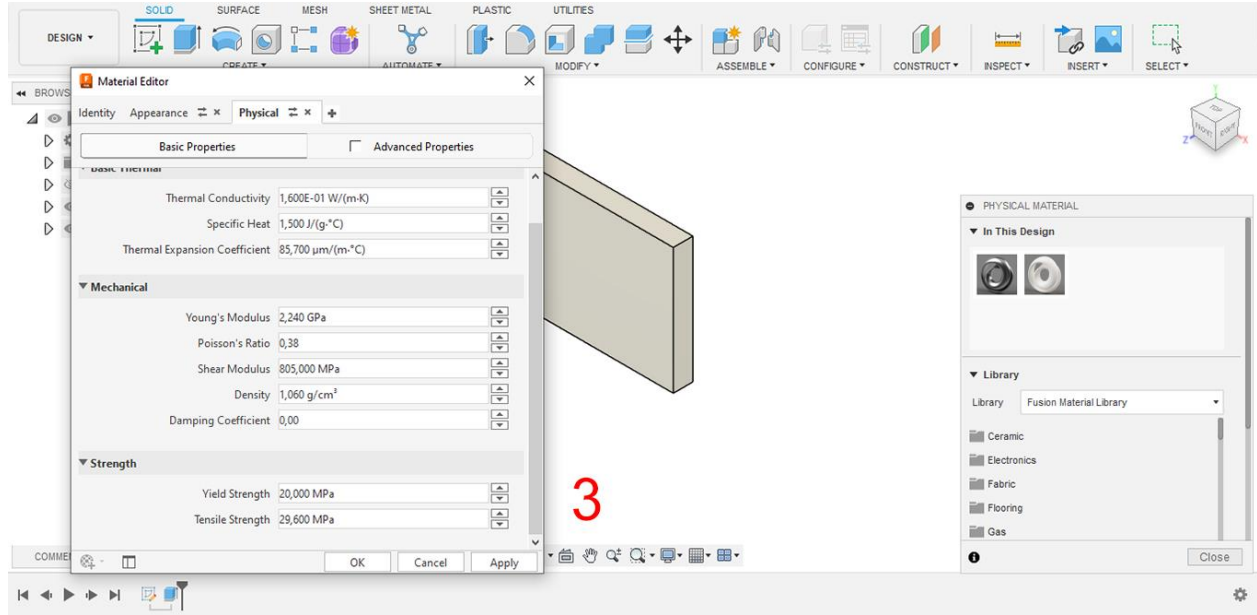

Figure 3. Autodesk Fusion360 Material Editor

Figure 3 displays the basic mechanical and thermal properties of the ABS material defined for calculations and obtained from the Autodesk Fusion 360 Material Library. New materials can be defined by performing the edit operation from this screen.

While raw material emission calculations are made with the CCaLC 2 software,

$$\sum CO_2(kg) = Emissions\ per\ Kg\ x\ Used\ Raw\ Material\ (Kg) \tag{1}$$

Equation is used to find results (Canbulat and Savaş, 2023). Using this equation (1), the emissions caused by the use of raw material will be revealed according to the amount and type of material used. The Rule of Mixture equation is (Wongpajan et al., 2016),

$$ß_c^u = V_f\,ß_f + V_m ß_m \tag{2}$$

$ß_c^u$ refers to the predicted property of the mixture, V_f and V_m indicate the percentage ratios of the mixtures, $ß_f$ and $ß_m$ indicate the values of the desired properties of the materials to be mixed (2). Apart from the products in the literature review, the volume will be determined based on the material used, and this will strengthen the estimation aspect of the study as a parameter in terms of the weight and lightness of the

material in the optimum material selection. The equation to be used for the material density (d), mass (m), volume (V) relationship (Hawkes, 2004),

$$m = V \ x \ d \tag{3}$$

In this equation, m stands for mass, V stands for volume, and d stands for density (3). In choosing the optimum material, the mixture ratios will be evaluated in terms of density, weight, CO^2 emissions, tensile strength, yield strength and safety factor, and the safety factor value will be analyzed with the material to be defined on plates with 3 mm wall thickness and 1000 mm width, according to the working coefficient under atmospheric conditions. Since the load on the part will not be defined, only atmospheric conditions will be defined and analysis will be made by establishing a relationship between how much it can be used under these conditions and the safety factor.

Safety factor value calculations are of critical importance in Computer Aided Design (CAD) and analysis software. It shows the state of the part under load or stress according to a certain score by calculating the time when disintegration will begin. The equation used on the basis of the calculations is (Niklas, 2000),

$$Safety \ Factor = \frac{Breaking \ Stress}{Load \ Capability} \tag{4}$$

With given equation (4), safety factor values will be calculated. The product for which detailed information was obtained in terms of material and emission values in the literature research is Schneider Electric-EVlink ProAC.

According to the information obtained for the AC electric vehicle charging station product, the mass of the product, including its accessories and carrying box, is given as 8674 grams, approximately. The product transport box, made of 100% cardboard, weighs 1480 grams, according to the information given. In addition to the total mass of the product, 2.5 grams of battery, 555 grams of electronic card, and 25 grams of electrolyte capacitor masses are given. According to the information given, it is understood that the product tries to comply with EcoDesign design criteria and that the company wants to complete the design with a more environmentally friendly approach. The relevant sustainability information, the recycling potential is given as 76%, and this calculation is based on the "ECO'DEEE recyclability and recoverability calculation method, version V1, 20 Sep. It was stated that it was made within the scope of "2008 presented to the French Agency for Environment and Energy Management: ADEME" (Schneider Electric, 2023a; 2023b; 2023c).

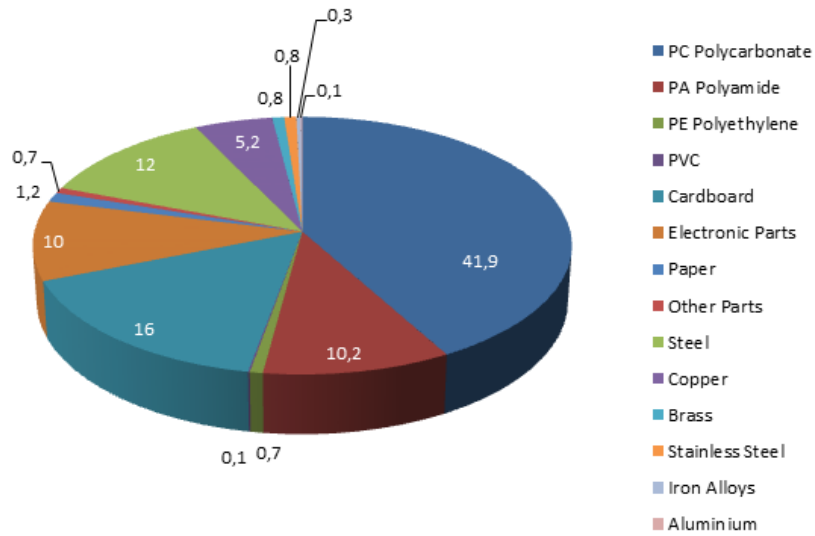## Schneider Electric- EVlink ProAC
Materials

Figure 4. Materials and Percentages of the Selected Product (Schneider Electric, 2023a)

Figure 4 shows the material percentage distribution for the product for which detailed material data is available.

Table 2. ABS and PC Material Specifications

Materials	Density (g/cm^3)	Overall Emissions (Kg / CO^2)	Tensile Strength	Yield Strength
ABS	1.06	4.40	29.6 MPa	20 MPa
PC	1.2	7.79	68.9 MPa	62.01 MPa

As a result of the literature review, Table 2 is made according to Autodesk Fusion 360 material library. While the emission per kilogram of the ABS material is lower than the PC material, it is understood that the PC material is much superior in performance criteria. This means that a mixture between the two materials will be effective in finding the desired properties. By mixing two opposite features, it will be possible to achieve optimum results.

3. FINDINGS

According to the research and information obtained, polycarbonate is generally chosen as the material used in the shell structure of the electric vehicle charging station. According to the material distribution given in Figure 4, it was concluded that 3878.62 grams of polycarbonate was used. Including parts such as battery,

electronic card, electrolyte capacitor, the total mass of the product is 9256.85 grams. When we look at the general thermoplastic usage, it is seen that 944.19 grams of polyamide, 64.79 grams of polyethylene, 9.25 grams of PVC and 3878.62 grams of polycarbonate are used, and the total thermoplastic usage is 4896.85 grams. In the situation where polycarbonate usage is 3878.62 grams,

$$3878.62 = 1.2 \; x \; V \tag{5}$$

With this calculation, V will be resulted as 3232.183 cm^3 (5). The material mixtures to be used to obtain this geometry and their density ratios are given in table 3. The mass was determined according to the density of the mixture, and total emissions were calculated according to this mass. With the Rule of Mixture approach, calculations were made for tensile and yield strength values according to the mixture, and finally, the stage of creating safety factor values with thermal stress analysis was started. At this stage, definitions were made under room temperature conditions of 25ºC as a restriction to the study. 25ºC is also a standard reference point for the International Organization for Standardization (ISO) and ASTM Standards (Shackelford, 2014).

Within the framework of the restrictions, in order for the volume value of the plate with a thickness of 3 mm and a width of 1000 mm to reach 3232.183 cm^3,

0,3 cm x 100 cm = 30 cm^2

$$3232.183 \; / \; 30 = 107.739 \; cm \tag{6}$$

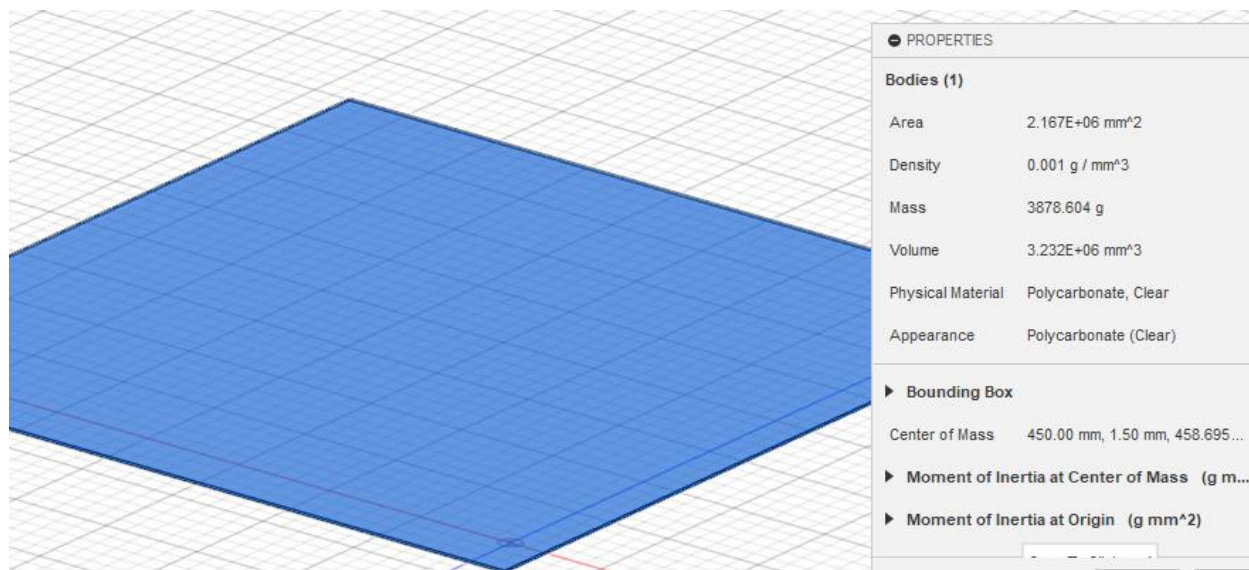The third measure can be found using this equation (6).

Figure 5. Part Form to be Analyzed Under Atmospheric Conditions

The form, based on the measurements specified in the calculations, is provided in Figure 5.
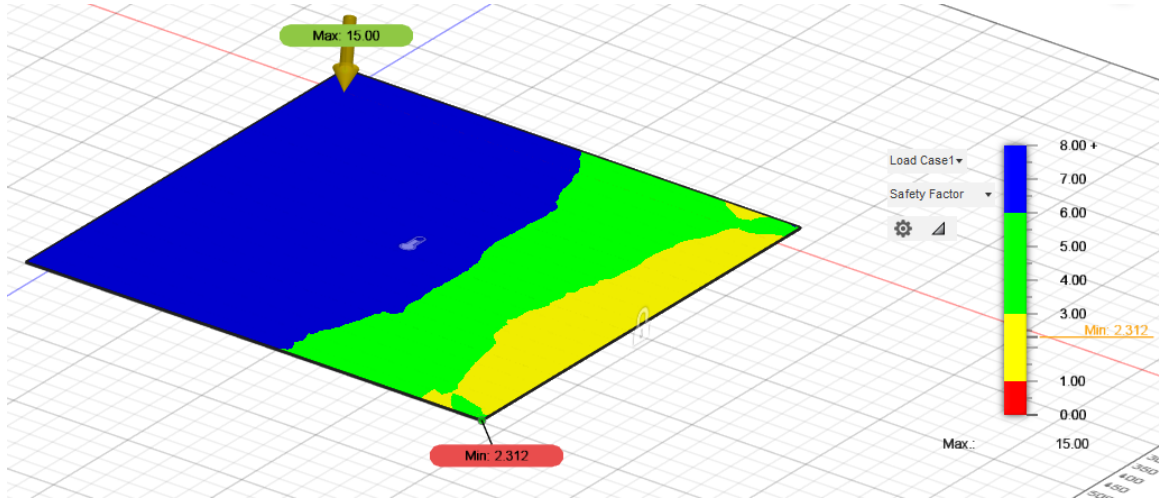

Figure 6. Plate Included in Safety Factor Analysis

The plate shown in Figure 6 was mounted on the wall on a single surface and subjected to a temperature of 25°C. The plate in the image belongs to the part made of 100% ABS material and shows the distribution of thermal stress.

Table 3. Rule of Mixture Results for ABS and PC

ABS (Rate of Mixture)	PC (Rate of Mixture)	Density (g/cm³)	Overall Weight (g)	Overall Emissions (Kg / CO²)	Tensile Strength	Yield Strength	Min. Safety Factor
0	100	1.2	3878.6196	30.214	68.9	62.01	6.534
10	90	1.186	3833.369038	28.561	64.97	57.809	6.149
20	80	1.172	3788.118476	26.94	61.04	53.608	5.754
30	70	1.158	3742.867914	25.349	57.11	49.407	5.353
40	60	1.144	3697.617352	23.789	53.18	45.206	4.944
50	50	1.13	3652.36679	22.26	49.25	41.005	4.526
60	40	1.116	3607.116228	20.761	45.32	36.804	4.1
70	30	1.102	3561.865666	19.294	41.39	32.603	3.666
80	20	1.088	3516.615104	17.856	37.46	28.402	3.223
90	10	1.074	3471.364542	16.45	33.53	24.201	2.772
100	0	1.06	3426.11398	15.074	29.6	20	2.312

In Table 3, While calculating the minimum safety factor value, not only mechanical properties but also thermal conductivity (W/(m.K)), specific heat (J/(g.°C)), thermal expansion coefficient µm/(m•°C) parameters were included in the calculations. In addition, young's modulus (GPa) was added to the mechanical parameters and safety factor results were obtained.

4. CONCLUSIONS

An example study on material selection in sustainable industrial design was carried out by making it easier for designers to choose materials and by making it possible to select these materials within the scope of their emission values. In this study, comprehensive literature research was conducted to analyze AC Charger products widely used in Europe in 2022. The analysis aimed to ensure that the material selection for the industrial design of the AC Charger was sustainable. According to the literature, polycarbonate emerged as the most common material. To effectively reduce emissions associated with polycarbonate, ABS, another widely used and mixable material in the industry, was chosen as an alternative. ABS and PC materials were mixed with the rule of mixture approach, and analysis was carried out on all possible mixtures with 10-point changes, and emission, density, mass, tensile strength, yield strength and safety factor results were determined for each mixture. According to the analysis results provided in Table 3, materials with safety factor values between 1 and 3 were found to be inadequate. Safety factor values between 3 and 6 were deemed optimal, while values of 6 and above were considered excessive in terms of price-to-performance ratio, indicating that they are overly robust and costly selections, hence unnecessary for the application. Since safety factor points and colors vary depending on the CAD software, part dimensions and materials, the colors that the software gives to the points are more important than the numerical values of the points. This situation can also be seen in Figure 6.

Since the basis of the study is to make it easier and more accurate for designers to choose the optimum material, the elimination stage should be started after the mixture tables are prepared, as in Table 3. At this stage, it has been shown that when proceeding with the safety factor, only mixtures with green values can be selected, and when it is desired not to be below specific durability values, the options can be reduced by making eliminations colored in yellow in the table. For example, if tensile strength requirements of 50 MPa and above and yield strength requirements of 45 MPa and above were a constraint for AC Charger product design, it is seen that only three mixtures meet these conditions and these are expressed in green color in the mixture percentages. Considering these three mixture options, if one of these three mixtures is used instead of a product produced entirely from PC material, the emission per product body can decrease from 30.214 kg/CO^2 to 23.789 kg/CO^2, that is, the emission per product can decrease by approximately 21.5%.

With this approach, a solution that requires basic physics and mathematics knowledge, which can be applied to the work of all industrial designers, designers and engineers who will design concept industrial products, has been presented to the literature. In this study, the method was used only for thermoplastic materials due to the external body materials of the AC Chargers, and they should not be used in application studies without researching the availability of the mixtures in the market.

RECOMMENDATIONS

The application stages are given as suggestions to designers and engineers in the industrial or academic world who will implement this study. From this point on, the text continues by naming designers and engineers as practitioners.

Practitioners should determine the mechanical and thermal property constraints of the product for which they will define the material selection approach before starting the analysis. Then, the thermoplastic materials they will use or can be used should be determined, and their supply availability in the market should be examined. While the rule of mixture approach can be applied to both mechanical and thermal properties, it can also be used for industry as it can be applied to the price per kilogram.

Raw material emissions should also be determined by the CCaLC2 software, and the mixtures and their properties should be clearly revealed in the table to be created. Since safety factor analysis is required for each mixture, the safety factor value for each mixture must be determined by defining it on the designed part and performing thermal stress analysis under atmospheric conditions (25 ºC and defined gravity).

It should be kept in mind that taking a safety factor analysis directly from the CAD form for the designed product will bring the results closer to reality.

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CONFLICT OF INTEREST

The author stated that there are no conflicts of interest regarding the publication of this article.

CONTRIBUTIONS OF AUTHORS

M.C.: Conceptualization, Methodology, Formal Analysis & Writing, Investigation, Resources.
A.F.S.: CAD & CAS Analysis, Validation, Draft Preparations.

REFERENCES

ABB. (2022). Terra AC Wallbox [Brochure]. Retrieved from https://library.abb.com/d/9AKK107680A2257

Agamloh, E., Jouanne, V. A., Yokochi, A. (2020). An Overview of Electric Machine Trends in Modern Electric Vehicles. *Machines*, 8(2): 20. doi: 10.3390/machines8020020

Andersen, M. S. & Ekins, P. (2009). *Carbon-Energy Taxation: Lessons from Europe*. Oxford University Press, 241-

260.

Baer P. (2002). Equity, Greenhouse Gas Emissions, and Global Common Resources. *Part V. Development And Equity*, Stanford University, 393-408. Retrieved from https://stephenschneider.stanford.edu/Publications/PDF_Papers/15-Ch15(393-408).pdf

Barbosa, G. S., Drach, P. R., Corbella, O. D. (2014). A Conceptual Review of the Terms Sustainable Development and Sustainability. *International Journal of Social Sciences*, III(2), 01–15.

Canbulat, M. and Savaş, A. F. (2023). Sürdürülebilir Tasarım ve Elektrikli Araç Şarj İstasyonları, A. Bilgiç, Ş. Balbay (eds.), *Endüstriyel Sürdürülebilirlik ve Döngüsel Ekonomi Uygulamaları: Dünyadan ve Türkiye'den Yeşil Dönüşüm Örnekleri*, Ankara: Detay Yayıncılık, 1-16.

European Commission. (2024). Ecodesign for Sustainable Products Regulation. Retrieved from https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products-regulation_en

European Commission. (2023). Carbon Border Adjustment Mechanism. Retrieved from https://www.eeas.europa.eu/sites/default/files/documents/2023/Carbon%20Border%20Adjustment%20Mechanism.pdf

European Commission. (2020). 2030 Climate Targets. Retrieved from https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2030-climate-targets_en

European Commission. (2019). Guidelines on reporting climate-related information. Retrieved from https://ec.europa.eu/finance/docs/policy/190618-climate-related-information-reporting-guidelines_en.pdf

EVBox. (2023). BusinessLine CE G4 Product Datasheet [Brochure]. Retrieved from https://branding.evbox.com/web/6605d986cfba05ef/website---evbox-businessline-product-brochures-all-languages/?mediaId=49F209D6-864A-496F-871B7D7B685AE581&viewType=grid

Greco, R. (1996). Polycarbonate Toughening By ABS, E. Martuscelli, P. Musto, G. Ragosta (eds.), *Advanced Routes For Polymer Toughening,* Netherlands: Polymer Science Library, 10, 469-526.

Hawkes, S. J. (2004). The Concept of Density. *Journal of Chemical Education*, 81 (1), 14. doi: 10.1021/ed081p14

Industrial Designers Society of America. (2024). What Is Industrial Design? Retrieved from https://www.idsa.org/about-idsa/advocacy/what-industrial-design

International Electrotechnical Commission. (2024). IP Ratings. Retrieved from https://www.iec.ch/ip-ratings

International Energy Agency. (2023). Trends in charging infrastructure. Retrieved from https://www.iea.org/reports/global-ev-outlook-2023/trends-in-charging-infrastructure

Ionnides, D. and Wall-Reinius, S. (2015). Sustainable mobility in the periphery: Are electric vehicles the answer? *ETOUR*, Mid Sweden University, 2015; 3.

Jones, B., Elliott, R. J.R., Nguyen-Tien, V. (2020). The EV Revolution: The Road Ahead For Critical Raw Materials Demand. *Applied Energy*, 280, 115072. doi:10.1016/j.apenergy.2020.115072

Kempower. (2024). AC Satellite, Technical Datasheet [Brochure]. Retrieved from https://mediabank.kempower.com/l/65mpVmfjQGmZ

Kieldsen, A., Thingvad, A., Martinenas, S., Sørensen, T. M. (2016). Efficiency Test Method for Electric Vehicle Chargers, *In Proceedings of EVS29 - International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium,* 19-21 June, Montréal, Québec.

Letcher, T. M. (2021). 1 - Global warming-a complex situation. *Climate Change (3rd Edition) Observed Impacts on Planet Earth*, 3-17. doi: 10.1016/B978-0-12-821575-3.00001-3

Lucas Jr., R. E. (2004). The Industrial Revolution: Past and Future. *Economic Education Bulletin, American Institute for Economic Research,* XLIV (8), 1-8.

Morseletto, P. (2020). Targets For A Circular Economy. *Resources, Conservation and Recycling*, 153, 104553. doi:

10.1016/j.resconrec.2019.104553

Mouëllic, M. L., Ventura, A., Heller, K., Loh, A., Roch, R., Spitzbart, J., Zanotelli, P. (2023, March 27). Six Strategies for Designing Sustainable Products. *Boston Consulting Group.* Retrieved from https://www.bcg.com/publications/2023/six-strategies-to-lead-product-sustainability-design

Niklas, K. J. (2000). Computing factors of safety against wind-induced tree stem damage. *Journal of Experimental Botany*, 51 (345), 797-806. doi: 10.1093/jexbot/51.345.797

Schneider Electric. (2023a). Charging station, EVlink Pro AC/AC Metal [Brochure]. Retrieved from https://www.se.com/uk/en/product/EVB3S22N4/charging-station-evlink-pro-ac-ac-metal-22kw-32a-3p+n-t2s-socketoutlet-rdcdd-6ma-mnx-aux-

Schneider Electric. (2023b). Product Environmental Profile, EVlink ProAC 7.4 kW [Brochure]. Retrieved from https://download.schneider-electric.com/files?p_enDocType=Environmental+Disclosure%20&p_File_Name=PEP+ecopassport+SCHN-00768-V01.01-EN_1.pdf

Schneider Electric. (2023c). Product End of Life Instructions, EVlink ProAC 7.4 kW [Brochure]. Retrieved from https://download.schneider-electric.com/files?p_Doc_Ref=ENVEOLI2202024&p_enDocType=Circularity+Profile&p_File_Name=EoLI_ENVEOLI2202024_5.pdf

Schwarzer, V. and Ghorbani, R. (2015). Current State-of-the-Art of EV Chargers. Electric Vehicle Transportation Center, University of Central Florida. Retrieved from https://www.hnei.hawaii.edu/wp-content/uploads/Current-State-of-the-Art-EV-Chargers.pdf

Sevdari, K. (2020). Electric Vehicle Chargers Market Outlook. *DTU, Department of Electrical Engineering, Denmark*, 2020. Retrieved from https://backend.orbit.dtu.dk/ws/portalfiles/portal/246855622/Electric_vehicle_chargers_market_outlook_2020.pdf

Shackelford, J. F. (2014). *Introduction to Materials Science for Engineers, 8th Edition*. Pearson.

Siemens. (2023). VersiCharge AC series [Brochure]. Retrieved from https://assets.new.siemens.com/siemens/assets/api/uuid:03a863c4-306e-46b0-8b43-2831fac37a93/versicharge-gen-3-datasheet-si-ep-1683.pdf

Sterev, N. (2019). New Industrial Business Models: From Linear To Circular Economy Approach. *Trakia Journal of Sciences*, 17 (1), 511-523. doi:10.15547/tjs.2019.s.01.082

Thompson, M. (2023, September 25). EV Growth Is Surging Faster Than Expected & Could Hit Two-Thirds Of Sales By 2030, Studies Say. *RepairerDrivenNews*. Retrieved from https://www.repairerdrivennews.com/2023/09/25/ev-growth-is-surging-faster-than-expected-could-hit-two-thirds-of-sales-by-2030-studies-say

United Nations. (2023). Sustainable Development Goals. Retrieved from https://www.un.org/sustainabledevelopment/news/communications-material

Watkins, M., Casamayor, J. L., Ramirez, M., Moreno, M., Faludi, J., Pigosso, D. C. A. (2021). Sustainable Product Design Education: Current Practice. *She Ji: The Journal of Design, Economics, and Innovation*, 7 (4), 611-637. doi: 10.1016/j.sheji.2021.11.003

Wongpajan, R., Mathurosemontri, S., Takematsu, R., Xu, H. Y., Uawongsuwan, P., Thumsorn, S., Hamada, H. (2016). Interfacial Shear Strength of Glass Fiber Reinforced Polymer Composites by the Modified Rule of Mixture and Kelly-Tyson Model. *Energy Procedia*, 89(2016), 328-334. doi: 10.1016/j.egypro.2016.05.043

Xue, K., Sun, G., Wang, Y., Niu, S. (2021). Optimal Pricing and Green Product Design Strategies in a Sustainable Supply Chain Considering Government Subsidy and Different Channel Power Structures. *Sustainability*, 13(22), 12446. doi: 10.3390/su132212446