ADVANCED RESEARCH AND APPLICATIONS IN ENGINEERING TECHNOLOGIES

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CONTENTS

PREFACE

We are honored to provide advanced scientific information on polymeric materials, environmental engineering, polymer engineering and civil engineering studies. We are happy to contribute to international scientific studies. This international scientific book was first published and presented in sections. The prepared book consists of five sections explaining new and current topics. It is a professional book containing important methods and applications in the field of polymeric materials, environmental engineering, polymer engineering and civil engineering.

This study contains very valuable studies by Serdar Osman Yılmaz, Tanju Teker, Sercan Kavak (Friction properties of Cr_7C_3 reinforced polymer matrix composites); Tanju Teker, Serdar Osman Yılmaz, Sercan Kavak (Effect of Cr_7C_3 filler percentage on compressive performance of an epoxy resin); Hasan Murat Öztemiz, Şemsettin Temiz (Low-velocity drop impact behaviour s-core sandwich panel composites: Fem and experimental analysis); Zeynep Seda Taylan, Hülya Özkoç (A Case study in water footprint assessment: Ambarlı advanced biological wastewater treatment plant); Zeynep Kamile Cenk, Ayşe Mehlika Top, Büşra Öztürk, Rümeysa Nur Yılmaz, İdil Ayçam, (Comparative analysis of green building certificates and assessment of Turkey in the context of B.E.S.T. and YES-TR). We would like to thank the managers and staff of IKSAD Publishing House.

Editor

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CHAPTER 1

FRICTION PROPERTIES OF Cr_7C_3 REINFORCED POLYMER MATRIX COMPOSITES

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1. INTRODUCTION

In recent years, polymer composites have been used in areas such as the automotive, aerospace and chemical industries. They are attracting industrial attention as promising structural materials, notable for their lower weight compared to traditional metallic materials. Applications include tribological components and parts, brake pads, bearings and seals, characterized by the self-lubrication of polymers (Verma & Tiwari, 2021, Amirbeygi et al., 2019). The main reasons why epoxy resins are preferred in industrial applications are their easy processing ability and cost effectiveness. Epoxies offer low shrinkage, high adhesion and excellent strength. Epoxy resins are widely used as matrix in various applications (Jamali et al., 2018; Chang et Al., 2004; Chang et al., 2006). Epoxy resin is a thermosetting polymer and offers excellent adhesion properties. When applied to the surface of metallic materials, it interacts with active hydrogen groups and functions as a protective coating. Additionally, the epoxy coating improves the wear resistance behavior of the metal (Chang & Friedrich, 2010; Megahed et al., 2018; Megahed et al., 2019). Epoxy matrix composites contain lightness, high strength, wear resistance and high load carrying capacity. Epoxies are widely preferred for advanced composite materials used in engineering applications. However, it brings some limitations due to the cross-linking nature of the 3D network structure and the inherent fragility of these connections. The inherent brittleness of epoxy often contributes to the wear of the material during performance. Therefore, it is aimed to provide better mechanical friction reduction. For this reason, many studies have been done on combining epoxy resin with other materials (Khun et al., 2014; Veerapaneni & Dandu, 2015). There are studies in the literature on fillers such as Al_2O_3, TiO_2, SiO_2, SiC, MoS_2, Si_3N_4, ZnO, ZrO_2, CNTs to improve the mechanical, friction and wear performance of nanocomposites (Wei et al., 2018). Ai et al., (2015) reported the effects of Al_2O_3 and SiO_2 nanoparticles on the impact behavior, hardness and wear resistance of composites. Nano Al_2O_3 reduced wear and increased hardness and impact energy by 30% to 80%. Sakka et al., (2017) studied the effect of graphite and carbon nanotube on the tribological properties of composite. The filler additive reduced the friction coefficient and wear percentage of the epoxy resin. Hanumantharaya et al., (2018) examined the tribological behavior of epoxy composites reinforced with B_4C. High percentage of B_4C increased density, hardness and strength, but decreased tensile performance. In this study, frictional properties of Cr_7C_3 reinforced polymer matrix composites were examined.

2. RESEARCH AND FINDINGS

2.1. Materials and methods

Epoxy resin (LY 556) and hardener (HY 951) were used as matrix materials. Cr_7C_3 with a size of 75 µm was chosen as the filling material. The proportions of the composite samples are indicated in Table 1. Epoxy and Cr_7C_3 were heated at 60 °C for 1 h. The hardener was mixed with epoxy and Cr_7C_3 particles in a ratio of 1:10. The composite plates were compressed with a hydraulic press at 100 ºC and 50 kg pressure for 1 h to prevent voids. The composites were allowed to cool for 24 h and then removed from the mold. The surface of the samples was analyzed by scanning electron microscopy (SEM). The friction coefficient was detected using a ball-on-disk micro tribometer.

Table 1. Composition of samples (wt.%).

Sample no	Rate of compositions
S1	%65 Cr_7C_3 + %35 Epoxy resin
S2	%70 Cr_7C_3 + %30 Epoxy resin
S3	%75 Cr_7C_3 + %25 Epoxy resin

2.2. Experimental results

The surface SEM photograph of sample S3 is shown in Fig. 1. Cr_7C_3 particles were homogeneously distributed in the epoxy matrix.

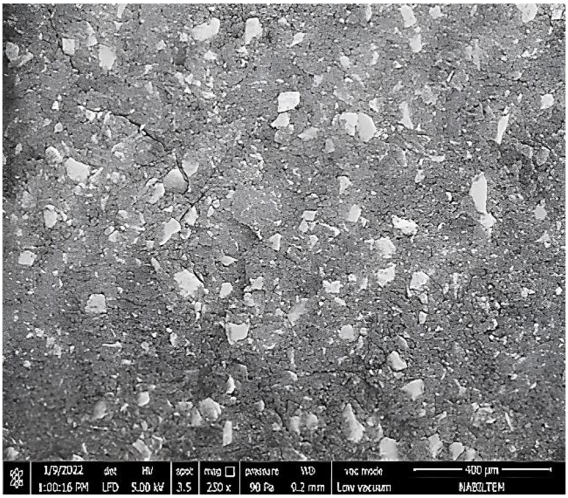

Figure 1. The surface SEM micrographs of sample S3.

Fig. 2 shows the friction coefficient graph of the S1 sample at 2 km with a load of 35 N and a speed of 0.5 m/s. The friction coefficient increased until the 2500th second and then became stable. At the 3000th second, the film layer formed and broke, then became stable again.

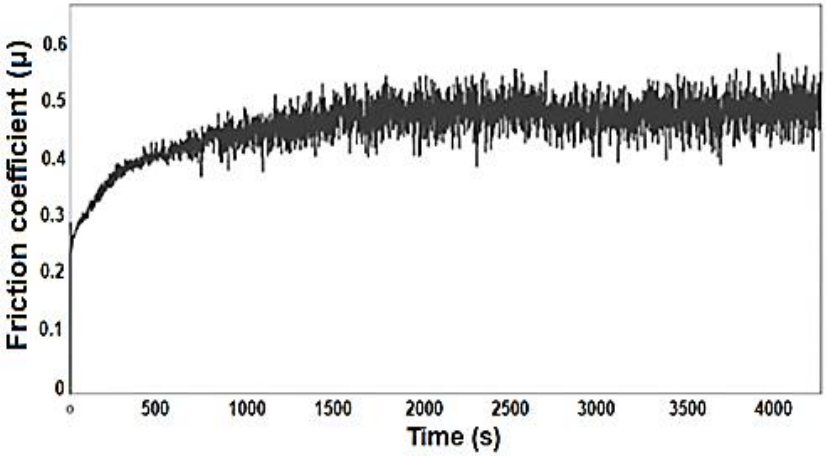

Figure 2. Friction coefficient graph of sample S1.

The impact of surface roughness on the friction of epoxy composites is important. A rougher surface can create higher friction through mechanical locking. Therefore, as the surface roughness of composites decreases, friction may also decrease (Zhang et al., 2019). Figure 3 shows the friction coefficient graph of the S3 sample at 2 km with a load of 35 N and a speed of 0.5 m/s. The friction coefficient increased until the 1500th second and then became stable. After the 1500th second, a film layer formed on the surface. Addition of filler material increased the friction coefficient. This increase is associated with the presence of carbide particles and increased abrasive wear (Zhang et al., 2012). The addition of wt.65% Cr_7C_3 reduced the friction coefficient at low speed, but the addition of wt.% Cr_7C_3 filler material increased the friction coefficient.

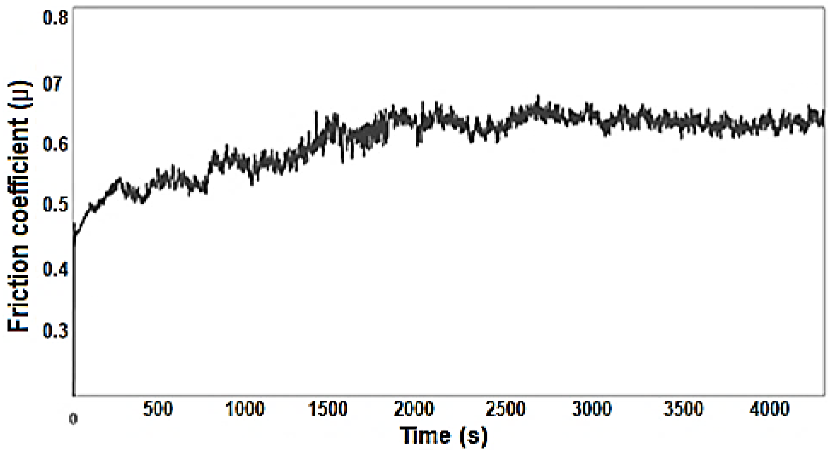

Figure 3. Friction coefficient graph of sample S3.

The reason for the decrease in friction of composite materials was the increase in Cr_7C_3 content. During repeated sliding, the cyclic stress concentration in front of the steel ball caused small cracks perpendicular to the sliding direction to expand on the surface. As a result, it formed a network of microcracks and produced microwave traces in the wear (Jiang et al., 2018; Naeimirad et al., 2016). As seen in Figure 4, the friction coefficient increased as the amount of Cr_7C_3 in the samples increased. This was caused by the hardness of the carbides and the roughness of their surfaces. When the friction surfaces of the two materials came into contact, the carbide increased friction by providing more friction and contact area. Increasing the Cr_7C_3 content reduced the friction coefficient of the overall sliding of the epoxy composite. This confirmed that the Cr_7C_3-modified epoxy resin composite had lower friction than pure epoxy resin. The greater contact between the steel ball and the composite material causes more friction during sliding contact. Thus, high Cr_7C_3 content increases the hardness and elastic modulus of the epoxy composite by reducing contact with the steel ball (Vaisakh et al., 2016).

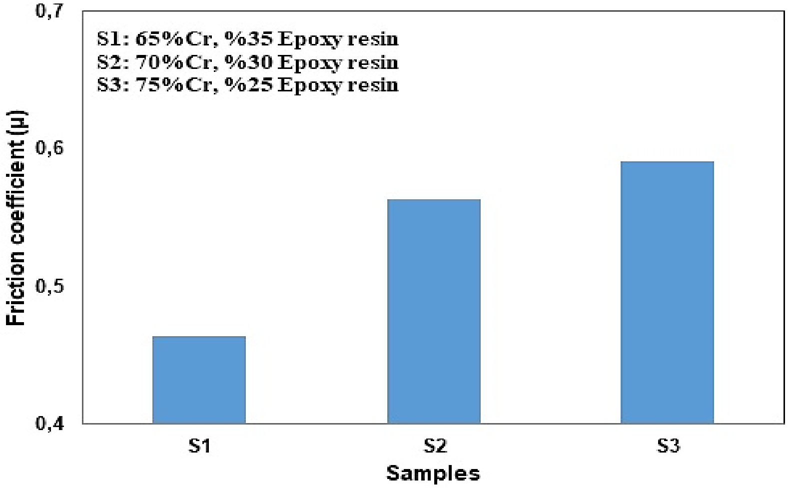

Figure 4. Effect of Cr_7C_3 additive on friction coefficients of samples.

The hardness of carbides affected the friction behavior of composite materials. Harder carbides provide higher wear resistance, but can also result in a higher coefficient of friction (Vaisakh et al., 2016). The increase in the amount of carbide causes the material surface to become harder and rougher and may cause the coefficient of friction to increase (Ayatollahi et al., 2012). However, the amount of carbide was not the only determining factor on the friction coefficient. In addition, other factors such as material composition, distribution of carbides, properties of the binder material and surface roughness also significantly affected the friction behavior.

3. CONCLUSIONS

The impact of Cr_7C_3 content on the friction features of epoxy composites was investigated.

- The highest friction coefficient was detected in 75% Cr_7C_3 rate.
- The friction coefficient was measured as 0.66 in composites containing 70% Cr_7C_3, and 0.48 in composites containing 65% Cr_7C_3.
- High percentage of Cr_7C_3 reduced the compressive fracture stress and increased the brittleness of the composites.

- High Cr_7C_3 content reduced the friction and wear of epoxy composites.
- The increased brittleness of epoxy composites resulted in surface fatigue wear.
- Cr_7C_3 had a significant impact on the friction values of composites.

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CHAPTER 2

EFFECT OF Cr_7C_3 FILLER PERCENTAGE ON COMPRESSIVE PERFORMANCE OF AN EPOXY RESIN

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1. INTRODUCTION

Epoxy resins (ER) have productive features such as excellent hardness, strength, reduced shrinkage. ER are high performance polymer resins preferred in aerospace and automotive sectors (Singh et al., 2022; Rajsekhar & Gattu, 2022; Ma et al., 2021). The brittleness of epoxy resin prevents the use of composites in areas requiring impact resistance. Composites with polymer matrices and hard particles often develop significant internal stresses during the manufacturing operation. These internal stresses result from the difference between the thermal expansion properties in the composition. They significantly affect the mechanical performance of the material and depend on the hardening process, filler shape, content and distribution (Kostagiannakopoulou et al., 2021; Bian et al., 2020; Hsieh et al., 2010).

Researchers are trying various hardeners and reinforcements to increase the impact and fracture resistance of epoxy resins. Interfacial bonds are determined by the surface properties of the fibers (roughness and porosity), the chemical structure of the matrix, the presence of voids, adhesion and residual thermal stresses (Jumahat et al., 2010; Ji et al., 2005). By adding both soft particles and hard fillers to epoxy resins, their mechanical properties and durability can be increased. These materials are called hybrid particle composites (Patnaik et al., 2009; 10). B_4C, SiC, and Al_2O_3 enhance the mechanical properties of epoxy. Shokrieh et al. (2012) reported the generation and strength resistance of clay/epoxy composite.

Nanoclay did not advance the tensile and flexural strengths of PC, but increased the compressive strength by 15.2% and fracture toughness by 7.6%. Kinloch et al. (2005) examined the influence of silica and rubber particles on the durability of multiphase epoxy polymers. As the nanosilica volume fraction increased, the compressive modulus and pressure yield stress enhanced monotonically. In this study, the effect of Cr_7C_3 filler percentage on the compression values of epoxy matrix composite was evaluated.

2. RESEARCH AND FINDINGS

2.1. Experimental Studies

Cr_7C_3 filler material was added to the epoxy resin and hardener mixture. Composite sample ratios are indicated in Table 1. Cr_7C_3 particles were selected as 75 µm. Then, wettability was achieved by heating with epoxy at 60 °C for 1 h. The mixture of epoxy and Cr_7C_3 was mechanically mixed at a ratio of 1:10. Composite plates were compressed with a hydraulic press at 100 ºC and under 50 kg pressure for 1 h. Afterwards, the composites were left to cool for 24 h and removed from the mold. The surface structure of the samples was examined with a scanning electron microscope (SEM). Compressive tests were carried out on cube samples of 12.5x12.5x25.4 mm^3 determined according to ASTM standard D695.

Table 1. Composite ratios of samples (wt.%).

Sample no	Composite ratios
S-Ref	Epoxy resin
S1	%65 Cr_7C_3 + %35 epoxy resin
S2	%70 Cr_7C_3 + %30 epoxy resin
S3	%75 Cr_7C_3 + %25 epoxy resin
S4	%80 Cr_7C_3 + %20 epoxy resin

2.2. Experimental results

The surface SEM photograph of sample S3 is presented in Figure 1. Cr_7C_3 was evenly dispersed in the epoxy matrix.

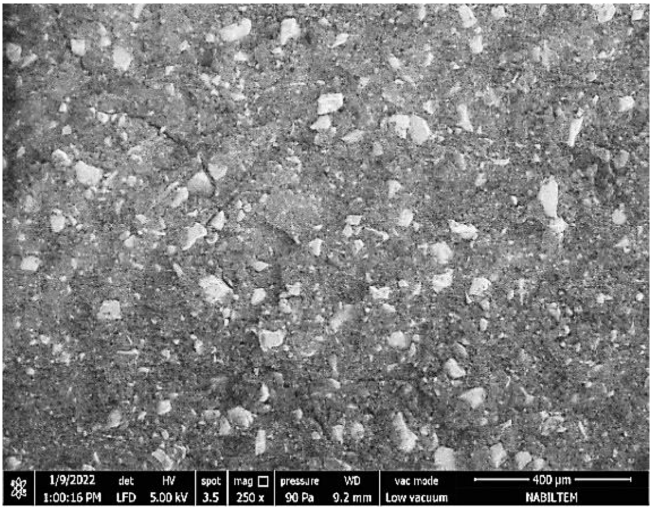
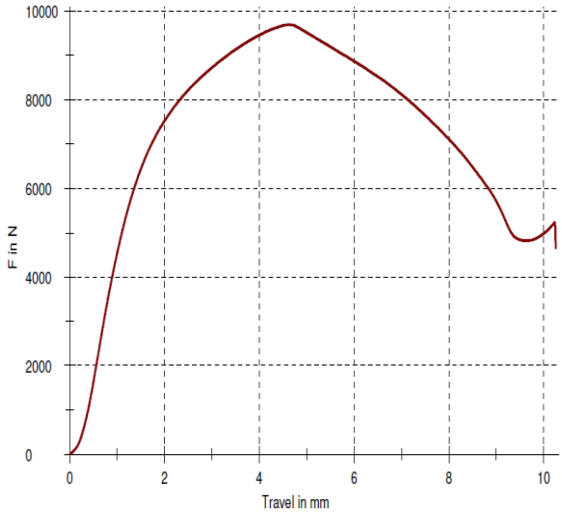


Figure 1. The surface SEM micrographs of sample S3.

Compressive test graphs of samples are given in Figure 2a-e. In graph 2a, the yield point of the S-Ref material was around 6300 N and the strength (F_{max}) was 9800 N. In graph 2b, the yield point of the S1 material was around 9300 N and the strength (F_{max}) was 12584 N. In graph 2c, the yield point of the S2 material was around 8800 N and (F_{max}) was 11308 N. In graph 2d, the yield point of the S3 material was around 8100 N and (F_{max}) was 10714 N. In graph 2e, the yield point of the S4 material was around 8000 N and (F_{max}) was 10395 N. Cr_7C_3 enhanced the compressive stress-strain behavior of epoxy polymers. The addition of hard fillers or agglomerated nano-fillers to epoxy resins increases the stiffness but negatively affects the fracture stress (Abenojar et al., 2009).

The strength of the composite decreased as the amount of fillers increased. This was due to localized stress concentrations leading to premature fracture. Also, the decrease in strength and failure strain indicates insufficient load transfer and a poor interface between the matrix and particles. The uniform distribution of high hardness nanofillers in the matrix increases the fracture toughness of the system.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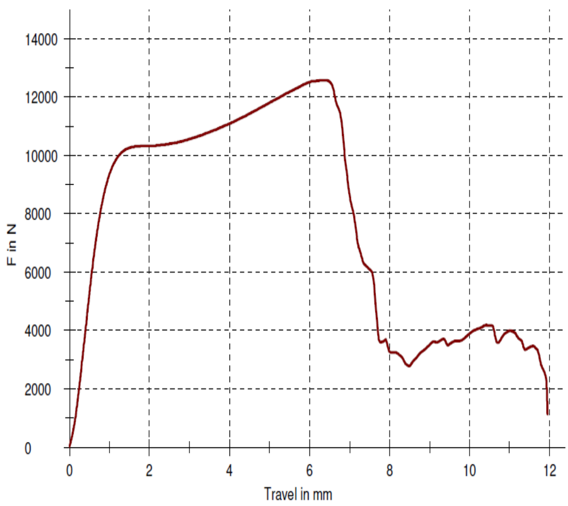
a)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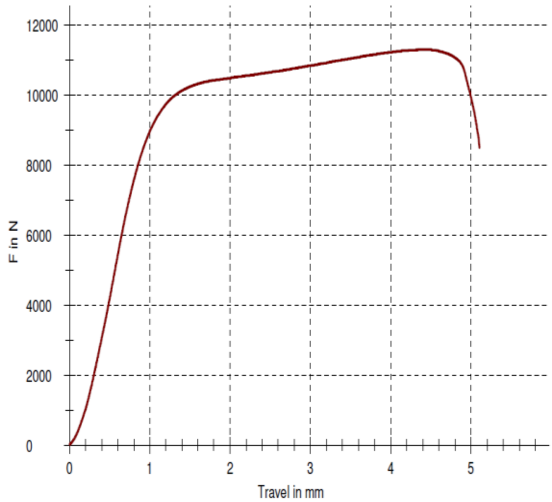

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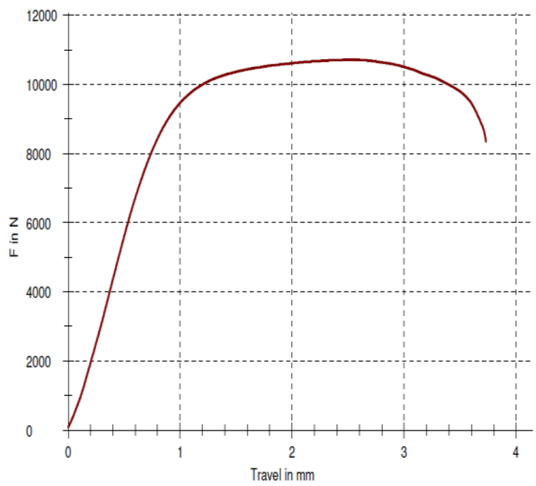

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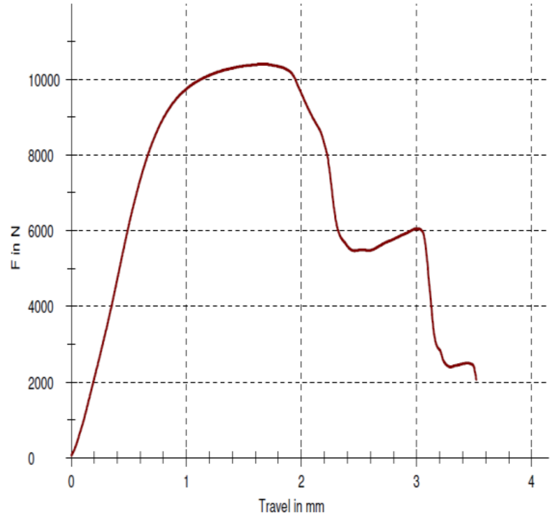

e)

Figure 2. Compression test graphs of samples a) S-Ref, b) S1, c) S2, d) S3, e) S4.

Factors that play an important role in composite performance are particle-matrix interactions and particle-particle interactions. Van der Waals and electrostatic attractions can affect interactions between particles, reducing composite properties (Bhagyashekar & Rao, 2007). Pushing and pulling forces can be detected by particle weight percent, volume percent, and shape (Shi et al., 2004). The improved interface between particles and matrix raised mechanical values. The rise in weight and volume can create a smooth interface with the increase in load. Thus, mechanical performance is advanced. Interface characteristic and adhesion strength determine the load dispersion between the matrix and nanofillers. The maximum compressive strengths (F_{max}) of Cr_7C_3 added samples are compared in Figure 3. At 65% carbide content, the compressive force reached the maximum level, then showed a decreasing trend.

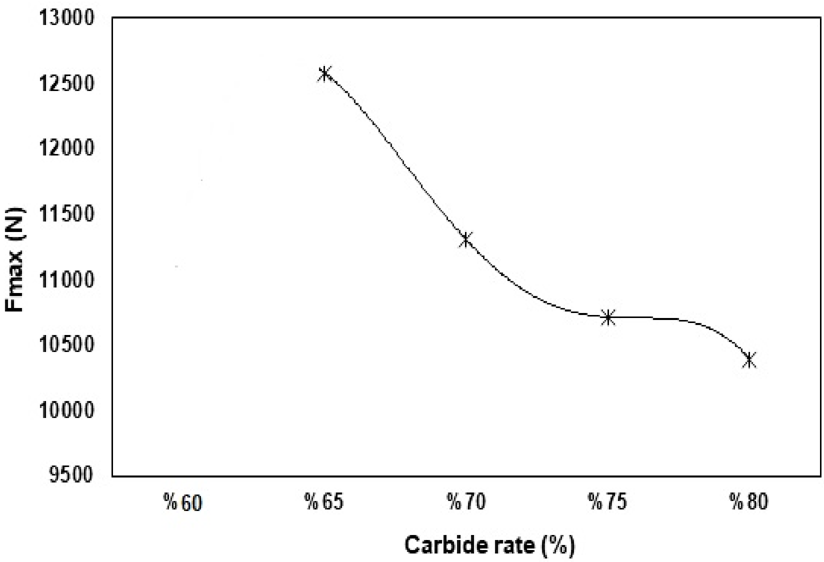

Figure 3. Comparison of compressive strengths of Cr_7C_3 added samples.

Improved the compression properties of Cr_7C_3 epoxy resin. Addition of 65% Cr_7C_3 to the matrix increased the compressive strength without significantly changing the yield stress and fracture stress. The Cr_7C_3 content significantly increased the compressive strength of the epoxy compared to the pure polymer. This showed that the nanofiller interacted very positively with the matrix and was therefore able to effectively transmit stress across the interface. Thus, higher strength was achieved compared to pure polymers.

3. CONCLUSIONS

The influence of Cr_7C_3 filler percentage on the compression values of the epoxy matrix composite was evaluated.

- Cr_7C_3 increased the compression stress-strain behavior of the epoxy polymer.
- The homogeneous distribution of high hardness Cr_7C_3 in the matrix increased the fracture toughness of the system.
- As the amount of Cr_7C_3 increased, the strength of the composites decreased. This was due to high local stress concentration leading to premature fracture.

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CHAPTER 3

LOW-VELOCITY DROP IMPACT BEHAVIOUR S-CORE SANDWICH PANEL COMPOSITES: FEM AND EXPERIMENTAL ANALYSIS*

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INTRODUCTION

The technological industry continues to see an increase in demand for innovative materials with weight reduction and extra capabilities. Due to their high flexural stiffness-to-weight ratio compared to traditional materials, engineers are increasingly using composite sandwich structures in weight-critical applications such as airplane components, aerospace applications, automotive, sports equipment, marine, and so on [1]. These materials are made up of two thin, high-strength skins that are separated by a lightweight core structure. The skins protect the core structure, which gives out-of-plane strength and stiffness, and hence provides in-plane strength and stiffness. It outperforms traditional materials in applications that need high wear, corrosion resistance, resistance to dynamic impact events, low density, and flexibility to generate complex geometries [2-3]. Sandwich composites, for example, are used in airline interiors for floor panels, internal walls, food preparation facilities, and passenger storage racks [4]. In the general preference for sandwich composite panels, improving the material and geometric arrangement in the core structure, compression characteristics (bending and buckling resistance), shear stiffness, high energy absorption capacity [5-8], and lightness are all extremely desirable. The majority of these components (sandwich panels) are constructed of surface materials as well as honeycomb and foam core materials. Polymer or alloy foam cores [9, 10], pyramidal truss cores [11, 12], folded [13], and honeycomb cores [14, 15], are examples of low-density cores. Increased material and geometric arrangement in the core structure, compression characteristics (bending and buckling resistance), shear stiffness, high energy absorption capacity, and lightness are all highly useful in the general preference for sandwich composite panels. The majority of these components (sandwich panels) are constructed from surface materials as well as honeycomb and foam core elements. Sandwich composite panels with open-cell core materials, in particular, give multifunctional benefits to the composite material, such as high stiffness and specific strength [17-18]. The mechanical behavior, performance, and modes of failure of sandwich structures (compression, shear or indentation failures, separation, and crushing) are determined by the material characteristics and geometry of their respective components (surface plates and core topology design). With component geometry, high-performance sandwich composite panels may be produced [19-20]. Surface materials in sandwich composite panels should consist of hard components in the sandwich, be resistant to shear and bending loads, and be resistant to plane separation [21]. Honeycomb sandwich structures are constructed with a substantial core material sandwiched between two thin layers of hard surface. While the honeycomb core material keeps the sandwich panel's stiffness and energy absorption capabilities, its hollow cellular structure provides lightness to the sandwich panel. In industries requiring great strength, such as automotive and aerospace, honeycomb sandwich composite panels are frequently employed instead of conventional materials [22-23]. The honeycomb core chain, pyramid grooved [24], x-type, kagome-type, S-core [25], foam core, pyramidal truss core, folded, hybrid, or unique structural shape can be used. Changes to the core geometry result in improved damage mechanisms [26-28]. The relationships between damaged formations and changes in core and matrix deformations that occur under different energy loads on the composite material are studied, and optimal design parameters are discovered [29]. Chen et al. [30] applied falling weight impact tests and finite element analyses to foam-filled cage sandwich composite samples. The energy absorption ability with foam reinforcement is 110.39% higher than that of unreinforced samples. With their parametric analysis, they expressed the data regarding shell thickness, foam density, and boundary conditions and determined the optimum design values of the studied sandwich composite. This study investigated experimentally and numerically the low-velocity impact tests of different core array variations of S-core sandwich composite panels (SSCP) with a unique core design, and They were evaluated mechanically and compared to finite element analysis investigations made using the package software.

EXPERIMENTAL METHOD

In this experiment, the surface layer was 1 mm thick 170x100 mm stainless steel-316, while the core material was aluminum 1050A-0 alloy. DP-8405 acrylic adhesive was used to connect the bottom-upper plate to the core. The dimension of distance between the cores of all samples was taken as 25 mm.

	Aluminum 1050A ,O	316-Stainless Steel
Density	2710kg/m³	7800kg/m³
Tensile Yield Strenght	37,94 MPa	200 MPa
Tensile Ultimate Strenght	80 MPa	515 MPa
Modulus of Elasticity	69 GPa	200 GPa
Elongation (%)	40	40
Shear Modules	50 MPa	82 GPa
Poisson Ratio	0,33	0,275

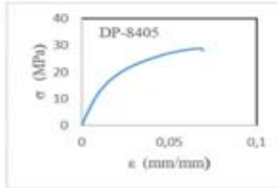

Figure 1. Mechanical properties and production stages of SSCP

As seen in Figure 1, sandwich composites were obtained by applying DP-8405 acrylic adhesive to S-cores prepared on the hand-bending machine for appropriate measurement values.

Table 1. Dimensions of Sandwich Composite Panel Variations

Core array	Group code	Core wall thickneses t, (mm)	Core height (mm)	Core radius (mm)	Weight (gr)	Density (kg/m3)
S	S1	0.6	50	R7.5	12,40	14,0271
	S2	0.7	50	R7.5	12,60	14,2534
	S3	0.8	50	R7.5	13,35	15,1018
	S4	0.6	50	R10	13,10	14,8190
	S5	0.7	50	R10	13,35	15,1018
	S6	0.8	50	R10	14,30	16,1764
	S7	0.6	50	R12.5	13,45	15,2149
	S8	0.7	50	R12.5	13,60	15,3846
	S9	0.8	50	R12.5	14,85	16,7986
	S10	0.7	60	R10	13,60	12,9032
	S11	0.7	70	R10	14,70	12,0098
S-R	S12	0.7	50	R10	13,35	15,1018
3S-3R	S13	0.7	50	R10	13,35	15,1018

The dimensions of sandwich composite variants are depicted in Table 1. In this work, testing and analyses were done for samples with distinct core sequences in meridian wall thickness values, in addition to variable core wall thickness and radius values. (Core array Straight: S, Straight-reverse: S-R, three straight-three reverse: 3S-3R)

Low-velocity impact test

Low-velocity impact test is performed by dropping a given weight from a predetermined height on the sample. Drop-weight tests are classified as either with or without instrumentation. The instrumented drop-weight impact test method is used to evaluate the dynamic properties of the material. Unlike earlier techniques, using different weights and changing different heights may provide the necessary energy, and the impact test system can perform the sticking, piercing, and repeated impact tests on the sample [33-34]. ACI 544.2R-89 [35] instrumented and conducted drop-weight impact tests on an Instron Ceast 9350 testing machine.

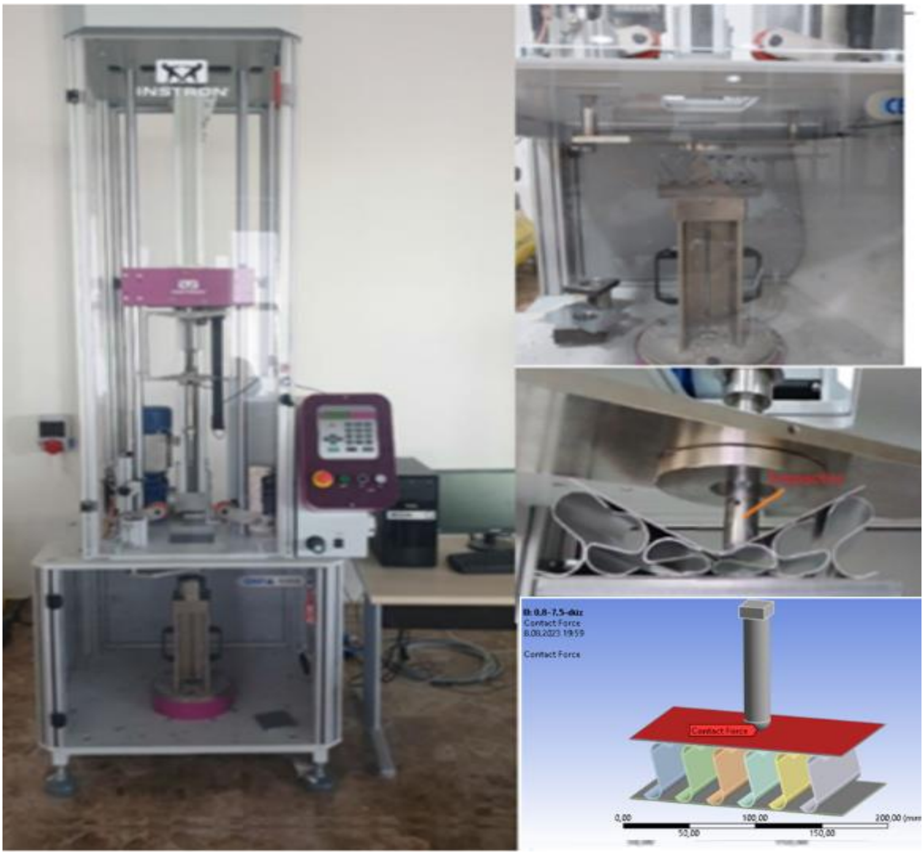

Figure 2. Instrumented drop-weight test machine. (a) Instron 9350, (b) Test setup for the composite plate, (c) Test finished for composite plate, (d) ANSYS drop-weight analysis model

The drop-weight test apparatus is depicted in full in Figure 2.

RESULTS AND DISCUSSIONS

The following study results were gathered as a consequence of the drop-weight impact analysis and experimental application. The low-velocity drop impact test is 10.5kg, and the analysis and testing were performed with 40J energy obtained from a height of 0.388m, the ambient temperature was 23.8C, and the relative humidity was 46%. The test operations were repeated four times, and the average data were collected.

Figure 3. Low-velocity drop impact testing specimens[36]

SSCP specimens low-velocity impact testing images are illustrated in fig 3.

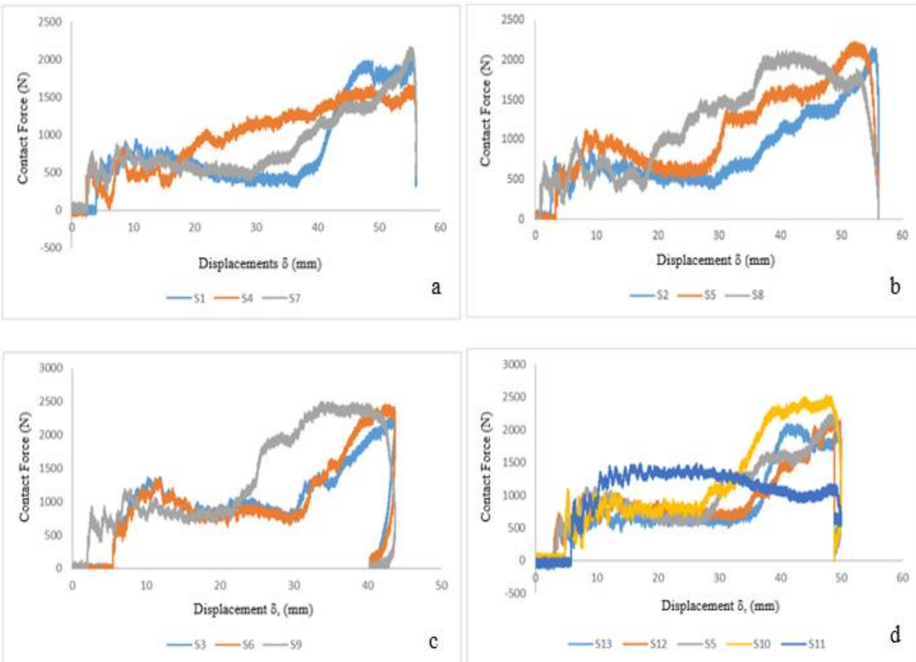

Figure 4 Specimens contact force- displacement graphs. [36]

As seen in Figure 4. The contact force rose as the material wall thickness decreased in Figures 4 a, b, and c. Figure 3.d depicts the impact force fluctuation with different core arrays and core heights. While S5 and S10 responded equally, the nuclear alignment modification in S12 had the greatest effect value. The striker in Figures 7a and b damaged the top layer and core material and made contact with the bottom layer. When the rebound force occurred after the bottom layer contact, the curve on the force axis could not reach zero in Figure 4. a. The bottom layer is not damaged. Figure 4. b shows that the rebound on the contact force axis was tolerated and the curve fell to zero, as well as no damage to the bottom layer. This circumstance is connected to the investigated core shape. Impact resistance and damping capabilities improved as core wall thickness rose. In Figure 4. c, the collapse caused permanent damage after causing temporary damage, and because the displacement value was less than the height value of the sandwich samples, the impact could not reach the substrate. The contact force values of the S12 and S13 samples, which were formed with modifications in the core arrangement, were extremely close to the S5 sample in Figure 4.d, indicating that there was no substantial difference in the samples made with changes in the core arrangement. It was discovered in the S10 and S11 samples generated by adjusting the core height that increasing the core height offered access to high contact forces up to a specific limit value and thereafter tended to decline. Excessive height growth is caused by a reduction in core inertia forces, which causes fast damage to the core. In the samples examined, there was no material loss owing to puncture or rupture.

Specimens	Test	Analysis	% Difference
S1	1941,39	1625,7	-0,19419
S2	1398,265	1421,3	0,016207
S3	1363,598	1370,6	0,005109
S4	1490,71	1557,8	0,043067
S5	1548,49	1319,2	-0,17381
S6	1340,486	1195,6	-0,12118
S7	1560,048	1355,5	-0,1509
S8	1444,48	1355,5	-0,06564
S9	1190,26	1215,9	0,021087
S10	2472,96	2102,1	-0,17642
S11	1935,615	2105,1	0,080512
S12	2288,07	2203,8	-0,03824
S13	2530,74	2109,3	-0,1998

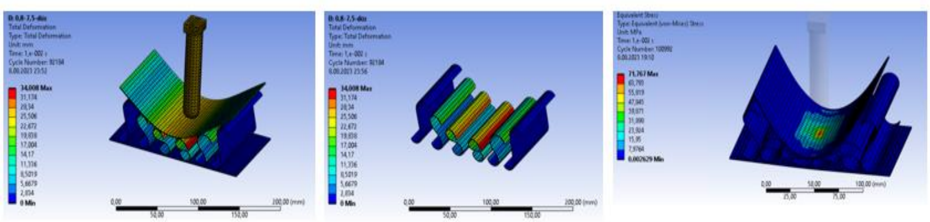

Figure 5. Contact force data for samples subjected to drop weight impact testing and analysis [36]

Fig 5. displays the contact force data, as well as the proportional differences between these data, for a variety of factors utilizing the falling weight impact test and analysis process. Proportional differences between the study groups vary between 0.5109 and 19%. In general, the test and analysis results are compatible with each other.

CONCLUSIONS

In summary, the numerical analysis and test results of an S-shaped sandwich panel exposed to a falling weight impact test with various core radii, heights, and wall thicknesses produced the findings shown below. When the impact loads were evaluated, it was discovered that as the core thicknesses grew, so did the impact loads. This is because the moment of inertia increases as the thickness of the core materials grows.

The impact load-carrying ability increased when the core sequence of the examined samples was changed. (The impact load-bearing capability of the S12 sample is 47.76% more than that of the S5.) The impact load capacity of the S10 and S11 samples, which were created by a change in core height compared to the S5 sample, has increased to values ranging from 59.7 to 25% due to their high moment of inertia.

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CHAPTER 4

A CASE STUDY IN WATER FOOTPRINT ASSESSMENT: AMBARLI ADVANCED BİOLOGİCAL WASTEWATER TREATMENT PLANT

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INTRODUCTION

Our country is located in a region of the Middle East where water resources are scarce. While it could be considered water rich before the 2000s, it is now in the group of countries experiencing water shortages. Climate change, drought, wrong water policies, increasing water demand in all sectors with the increasing population, and global climate change are among the main reasons for today's water problem. Increasing population and limited clean water resources may cause an increase in water needs and cause water shortage for humanity in the future. The annual amount of usable water per person in our country was 1,652 m^3 in 2000, 1,544 m^3 in 2009, and 1,346 m^3 in 2020. 39% of the water potential of 112 billion m^3 is used, 73% of which is for agricultural irrigation, 16% for drinking and use, and 12% for industrial use (Nas and Yılmaz, 2019).

With increasing agricultural areas, the need for agricultural irrigation water also increases. In addition, it is aimed to reduce the agricultural water usage rate of 72 billion m^3 by 64%. It is estimated that Turkey's population will reach 100 million in 2030 and that it will be among the countries experiencing water stress with a usable water potential of 1100 m^3 per capita in 2030. The decrease in water quantity is expected to be around 40% between 1990 and 2025.

Due to the increasing water shortage and drought both on a global scale and in our country, the search for alternative water gradually increases the importance of more efficient and effective use of our existing water resources. With the opening of new agricultural areas for irrigation in our country and the increasing demand for industrial water, the demand for water will increase and the reuse of treated wastewater will become even more important. Developing recycling technologies also make the reuse of wastewater attractive. In order for our clean water resources to be sufficient for future generations, to be used more efficiently and to be protected against pollution, the effective operation of wastewater treatment facilities and the reuse of purified water from these facilities will become an increasingly important issue in the future, ensuring environmental sustainability. New projects are carried out every year all over the world for the treatment and reuse of wastewater, and although treated wastewater is considered as an extra water source for rural areas, there are only a few countries that implement it on a real scale. For this reason, water footprint studies to be carried out in countries will shed light on future studies and will be an example and guide.

1.WATER FOOTPRINT

Water footprint is an alternative indicator of water use. The concept of “Water Footprint” was first introduced by UNESCO-(IHE Delft Institute for Water Education) Arjen Y. Hoekstra in 2002 (Hoekstra and Chapagain, 2007). Water footprint is a globally accepted alternative indicator of water use used to calculate direct and indirect water use. (Hoekstra, 2003).

1.1.Water Footprint Concept

Clean water is a local but also global resource. It is a misconception that although water demand is a local resource, it is still met locally. A product's water footprint is defined as the volume of clean water used to produce the product, measured across the entire supply chain. It is a multidimensional indicator that shows water consumption volumes by source and polluted water volumes by pollution type; All components of the total water footprint are determined geographically and temporally. Figure 1 shows water footprint components by watershed.

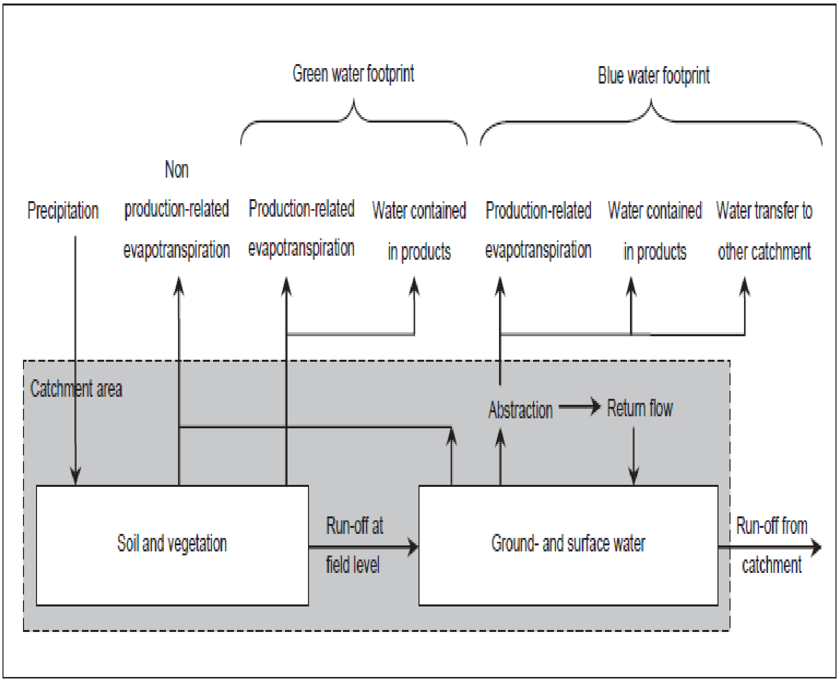


Figure 1: Water Balance Sheet Created by Green and Blue Water Footprints in the Water Basin (Hoekstra, 2009)

There are three components in the water footprint that represent water use and quality. Water footprint can be grouped and calculated on the basis of individual/community/product/nation/basin. The total water footprint (WF) of an individual or community is divided into three components: blue, green and gray water footprint (Figure 2).

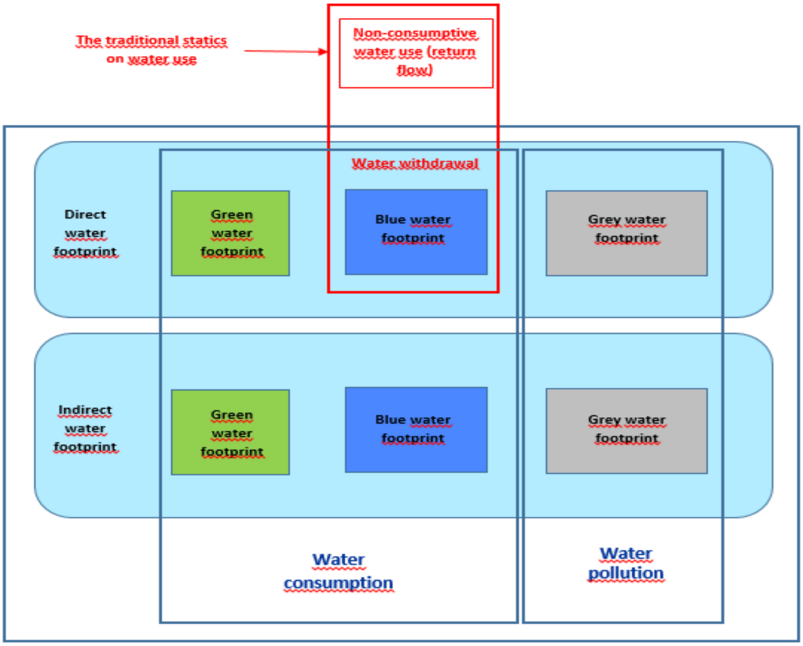


Figure 2: Components of Water Footprint (Hoekstra et al., 2011)

Blue water footprint is the volume of clean water evaporated from global blue water resources (surface water and groundwater) to produce goods and services consumed by an individual or community. Excludes the portion of water withdrawn from a ground or surface water system that returns to that system through seepage immediately after or before use. Blue water footprint is used for the total volume of surface and underground clean water resources needed to produce a good and are traditionally the water resources that come to mind when clean water is mentioned. It is also defined as the amount of surface and ground water that enters the product, evaporates or returns to the basin and the sea.

When evaluated in terms of production consumption chains; Blue water footprint refers to the consumption or evaporation of surface and groundwater resources throughout the supply chain of goods and services. The blue water footprint includes a wide range of «water consumption» patterns. For example, when water footprints are evaluated on a water basin basis; Blue water is water that enters the contents of products and evaporates, as well as water that does not return to the same water basin (e.g., returns to another catchment or to the sea) and is recycled within the same water cycle (e.g., withdrawn from the environment during a dry period and returned to a wet period). It also includes non-spinning water. Losses occur when water evaporates, returns to another collection area or marine environment, or joins the structure of a product. Although water is a renewable resource and therefore does not generally suffer losses, it is present in groundwater resources at certain periods and always in limited quantities (Hoekstra 2009).

Green WF is the volume of water evaporated from global green water resources (rainwater stored as moisture in the soil). Green water can be defined as rainwater in the terrestrial environment that does not flow or reach groundwater but is stored in the soil. However, the rainwater mentioned in the green water footprint does not disappear or mix with groundwater; It is stored in the soil or above the ground for a while. Because rainfall affects green water supply and demand, climate change and variability must be taken into account when assessing a region's green water needs. The green water footprint is particularly relevant to agricultural and forestry products and refers to the total rainwater discharged from plants and soil, as well as the water incorporated into the harvested crop/product. When considered on a production basis, it is rainwater that enters or evaporates into a product (Figure 1). (Hoekstra 2009).

Gray Water Footprint is an indicator of pollution. Gray WF is the volume of polluted water associated with the production of all goods and services for the individual or community (Ozkoc and Taylan, 2016). It is defined as the volume of clean water required to assimilate the load of pollutants to such an extent that the (“polluted”) water remains above current water quality standards. The gray water footprint measures only the pollutant load that actually reaches surface or groundwater. Therefore, the concept of gray water is discussed in relation to population and industrial growth (Mekonnen and Hoekstra, 2011; WWF-Turkey's Water Footprint Report, 2014).

1.2. Water Footprint Assessment

"Water footprint assessment",

(i) Measure and locate the water footprint of a process, product, producer or consumer, or quantify the water footprint in time and space in a specific geographical area;

(ii) (ii) assess the environmental, social and economic sustainability of the water footprint; And It can be evaluated in three stages:

(iii) (iii) formulating a response strategy. In general, the purpose of assessing water footprints is to analyze how human activities or specific products are related to water scarcity and pollution problems to see how production activities and products can become more sustainable from a water perspective.

What a water footprint assessment looks like depends largely on the perspective/focus of interest. One may be interested in the water footprint of a particular process step in the entire production chain or the water footprint of the final product. Alternatively, it can be formed by the water footprint of a consumer or group of consumers, or the water footprint of a producer or the entire economic sector (Mekonnen and Hoestra, 2011; Borgensten et al., 2010).

The total water footprint is the sum of the water footprints of many separate processes occurring in the area. A complete water footprint assessment consists of four different stages/steps (Figure 3). These steps are respectively; It has been tried to be followed as 1-Purpose and Scope, 2-Water Footprint Calculation, 3- Water Footprint Sustainable Assessment, 4-Water Footprint Solution Formulation and Recommendations (Figure 3).

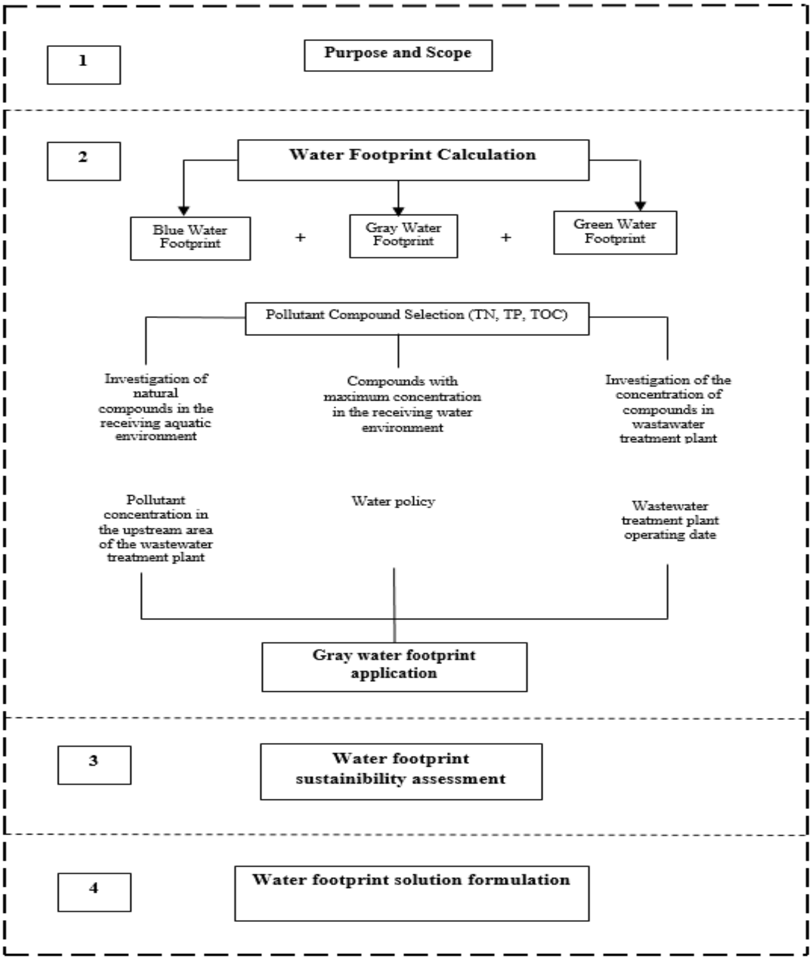


Figure 3: Stages of Water Footprint Assessment of Wastewater Treatment Facilities (Morera et al., 2016)

In order to be transparent about the choices made when undertaking a water footprint assessment study, it is necessary to start by clearly defining the objectives and scope of the study. Because the purpose/target is the element that will direct the work. Water footprint studies can be done for many different reasons. For example, a national government may want to know its dependence on foreign water resources, or it may want to determine how much water is used in the production of products it imports or exports and evaluate the sustainability of that use. At the scale of a river basin, one may want to know whether the total water footprint caused by human activities in the basin violates environmental discharge conditions or water quality standards at any time. At a river basin level, one may want to know the extent of scarce water resources in the basin and the rate of use of these water resources in export crops. A company may want to know its dependence on scarce water resources in its supply chain or how its own operations and throughout the supply chain can contribute to reducing impacts on aquatic environments (receiving environment).

The water footprint calculation phase is the phase where data is collected and calculations are developed. The scope and level of detail in the calculation depends on the decisions taken in the previous stage (objective and target setting). After the calculation phase, comes the sustainability phase, where the water footprint is also evaluated in environmental, social and economic terms. While evaluating the environmental impact of the water footprint calculated in this section, whether the prudent use of natural resources and effective protection of the environment is ensured, whether it meets the needs of all segments in social terms, its economic feasibility and sustainability are questioned by evaluating its contributions to economic growth. In the final stage, intervention options, strategies or policies are formulated. In this way, alternative suggestions are produced by evaluating different options that may be an alternative to the current result or further reduce the environmental impacts of the water footprint. It is not necessary to include all steps in a single study (Figure 3). In practice, this model, consisting of four successive stages, is more of a guide than a strict directive. It may often be necessary to return to previous steps and repeat stages (Hoekstra et al., 2011). In addition, the water footprint assessment study can be examined not only from an environmental perspective, but also in terms of economic and social contributions, and its sustainability can be examined.

2. WATER FOOTPRINT AT AMBARLI WASTEWATER TREATMENT PLANT

The world population is increasing at a rate that cannot meet its needs with existing environmental resources, making it difficult to implement sustainable development. Wastes in solid, liquid and gaseous form resulting from residential areas, residences and industrial facilities that increase with population growth have reached levels that threaten human life by disrupting the balance of nature. Increasing population, industrialization, agricultural practices and urbanization increase the need for water and thus the amount of wastewater generated increases. For these reasons, the treatment, recovery and reuse of wastewater is becoming increasingly important. Recovery of wastewater, including treatment, reuse and recycling, is seen as one of the possible tools contributing to better management and sustainability of water resources. For this reason, the water footprint of an Ambarlı Advanced Biological Wastewater Treatment Facility located within the borders of Istanbul province was determined.

The facility has the capacity to serve a daily population of 1,600,000 and to treat an average of 400,000 m^3/day of wastewater. It was designed to meet a peak flow rate of 520,000 m^3/day and was put into operation in 2012. Ambarlı Advanced Biological Wastewater Treatment Plant with a daily treatment capacity of 400,000 m^3; By treating the wastewater of approximately 1,600,000 people originating from the entire Esenyurt and Beylikduzu districts, the Ambarlı basin, a part of Bahcesehir and Avcilar, Arnavutkoy, Basaksehir districts, to prevent the pollution caused by the wastewater flowing into the Marmara Sea and Kucukcekmece Lake, and to protect these basins and receiving environments. It was established for the purpose of Ambarlı Advanced Biological Wastewater Treatment Plant, which has a basin area of approximately 438 km^2 served by the facility, is an investment that will end the wastewater treatment problem of the Ambarlı Basin and save the region's seas, streams and Küçükçekmece Lake from the wastewater threat. The regions covered by the basin area; Part of Avcilar, Esenyurt, Kiraç, Hadimkoy, Sazlidere, Bahcesehir, Altinsehir, Arnavutkoy, Imrahor, Bogazkoy, Firuzkoy, Beylikduzu, Gurpinar, Yakuplu, Kavaklı, settlement areas in the Haramidere basins and the northern and western region of Kuçukcekmece Lake. With the facility, 54,750 tons of sludge is prevented from being dumped into the sea annually, and 146,000,000 m^3 of wastewater is purified annually.

In the second phase, the facility will serve approximately 3.2 million Istanbulites with an average flow rate of 800,000 m^3/day. After the treated wastewater is rendered harmless to the environment, it is discharged into the

Marmara Sea, which is the final receiving environment. Thus, thanks to the Ambarlı Advanced Biological Wastewater Treatment Plant, Sazlidere Basin, Ambarlı Coasts and Kucukcekmece Lake were freed from the wastewater threat. After purifying the wastewater with advanced treatment methods such as nitrogen and phosphorus removal, some of the treated water can be disinfected and used in environmental irrigation and industry as needed. This also means a new water source. Moreover; The solid material from the facility can be used as secondary fuel in industrial facilities after dewatering and drying, and the energy needs of the facility are met thanks to the cogeneration unit. Wastewater coming to the facility is passed through coarse, fine screens and sand and oil traps, which are the primary physical treatment. Then, primary waste sludge is removed from the wastewater by subjecting it to primary sedimentation in preliminary sedimentation ponds. After preliminary sedimentation, phosphorus, nitrogen and carbon are treated together by aerobic-anoxic-oxic treatment, which includes advanced biological treatment stages, and the wastewater is taken to the final sedimentation tanks and the biomass that can settle is removed from the wastewater. The sludge coming from the preliminary and final settling tanks is passed through the thickening, digestion, dewatering, deodorization and drying units, respectively. The final dry product obtained can be used as secondary fuel in industrial facilities and cement factories, and the energy needs of the facility are also met thanks to the cogeneration unit. Thanks to the facility, which will prevent 54,750 tons of sludge from being dumped into the sea annually, 146,000,000 m^3 of wastewater will be treated annually. After purifying the wastewater with advanced treatment methods such as nitrogen and phosphorus removal, some of the treated water can be disinfected and used in environmental irrigation and industry as needed (Ambarlı Advanced Biological Wastewater Treatment Plant Introduction Booklet, ISKI). This also means a new water source (Figure 4).

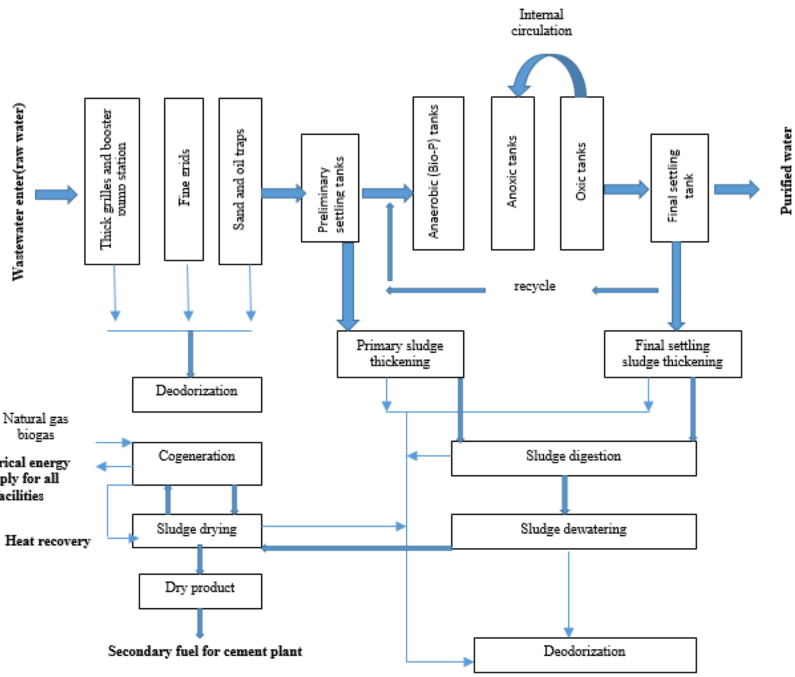


Figure 4: Ambarlı Advanced Biological Wastewater Treatment Plant Flow Chart.

2.1. Water Footprint Assessment

Gray water and blue water footprints were determined in the light of data and literature acceptance at Ambarlı Advanced Biological Wastewater Treatment Facility, located within the borders of Istanbul province. Three different scenarios were evaluated in gray water footprint calculations;

- Advanced biological treatment (Scenario-1),
- Biological treatment only (Scenario-2),
- Direct discharge without treatment (Scenario-3) (Figure 5).

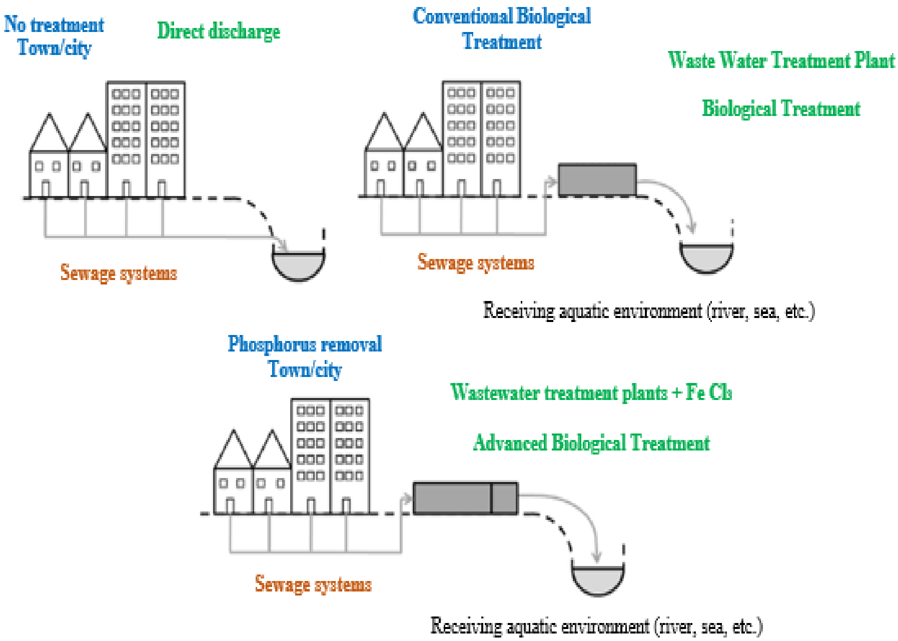


Figure 5: Treatment Scenarios in the Study.

The receiving environment where the treated wastewater is discharged is the Marmara Sea, and assumptions were made according to the domestic wastewater discharge standard and the deep sea discharge standard, and the reductions/changes in the gray water footprint were tried to be evaluated in terms of TN and TP parameters. (Llanos et al., 2018; Morera et al., 2016; Hoekstra et al., 2011). While applying the scenarios in gray water footprint calculations, 4 steps were followed respectively. These steps are respectively;

1. Purpose and Scope,
2. Water Footprint Calculation,
3. Water Footprint Sustainable Assessment,
4. Water Footprint Solution Formulation and Recommendations.

2.1.1. Purpose and Scope

The aim of this study is to evaluate the reuse options of treated wastewater due to the rapid decrease in clean water resources as a result of climate change, drought and water scarcity, which are among the biggest problems of today and the future. Based on this idea, it is aimed to evaluate the reuse options after purification of the wastewater of the Ambarli Advanced Biological Wastewater Treatment Facility within the borders of Istanbul province, instead of discharging it to the receiving environment, to examine the suitability of the quantity and quality of the purified water for agricultural and/or urban use purposes, and therefore to evaluate its sustainability potential. . For the study, first of all, gray water footprints were calculated in terms of TN (total nitrogen), TP (total phosphorus) and pollutant types according to three different scenarios (1- Advanced Biological Treatment, 2- Only Biological Treatment, 3- Direct Discharge) (Morera et al., 2016). The effect of advanced biological treatment (additional treatment) on gray water footprint reduction and its contribution to the sustainability of treated wastewater was tried to be examined.

2.2. Calculation of Water Footprint Components in a Wastewater Treatment Plant

General equation (1) for calculating the water footprint of wastewater treatment facilities is given below. In general terms, it is a multidimensional indicator that is evaluated in three aspects. The total water footprint is the sum of blue, green and gray water footprints (Hoekstra et al., 2011).

$$WFtotal=WF(blue)+WF(gray)+WF(green) \quad (1)$$

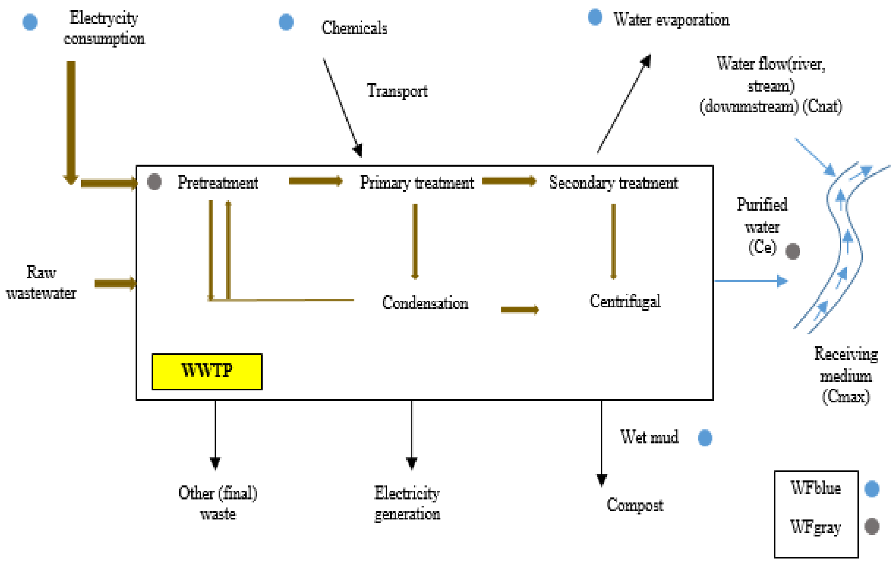


Figure 5. Identification of Water Footprint Components in a Wastewater Treatment Plant (Llanos et al., 2018; Morera et al., 2016).

2.2.1. Green Water Footprint

Green WF is defined as the consumption of water that is stored in the soil by precipitation, does not flow or feed groundwater and is therefore available for evaporation. Since the combination of WFgreen, purified water and soil water does not support each other and does not contribute to the evaporation of water from plants and soil, the green water footprint is not taken into account in classical wastewater treatment plants (Morera et al., 2016). The green water footprint is related to the amount of rainfall in the area. However, in units open to the atmosphere, rainwater has been neglected because it enters the wastewater and therefore the gray water footprint (Morera et al., 2016).

2.2.2. Blue Water Footprint

Blue WF is an indicator of surface water or groundwater consumption. It is defined as the clean water consumption required for all processes related to unit operations of the wastewater treatment plant. WFblue is an indicator of surface water or groundwater consumption. Evaporated water includes water incorporated into the product and the return water stream. WFblue takes into account the water used for all relevant processes in the different units of wastewater treatment plants (chemicals, energy consumption, management of residues, losses in sludge treatment and transportation, etc.) (Hoekstra et al., 2011; Morera et al., 2016). It also includes the calculation of water used in all processes and water evaporated from units open to the atmosphere during wastewater treatment. For example; Due to the water added to the system during the production of chemicals and energy; chemical and energy consumption have a common blue water footprint. It may join the structure of the final product, evaporate during the process, and be lost with the return flow.

Blue Water Footprint (WFblue) includes the part of the wastewater in the system that does not reach the receiving environment and the direct and indirect water flows used within the wastewater treatment plant. It also includes wastewater flows recycled from the treatment plant, reused water flows, and filtrate flow rate. During the operation of the wastewater treatment system, the direct water footprint describes the amount of water evaporated from the treatment units (WFeva) and present in the structure of the treatment sludge and removed by dewatering, and can be calculated based on equation (2) (Risch et al., 2014). Equation (3) is used to estimate the amount of water evaporating from open water surfaces (Cankaya, 2023).

$$\mathrm{WF(blue-direct)} = \mathrm{WF(eva)} + \mathrm{WF(SI)} \quad (2)$$

$$\mathrm{WF(eva)} = (2{,}36 + 1{,}67\mathrm{U_2}).\mathrm{A}^{-0{,}05}(\mathrm{V_W} - \mathrm{V_a}) \quad (3)$$

In this equation;

WF(eva): Amount of Water Evaporated from Surfaces Open to the Atmosphere (mm/day)

A: Surface Area of Surfaces Open to the Atmosphere (m^2)

U_2: Wind Speed at 2m Height Above the Water Surface (m/s)

V_W: Saturated Vapor Pressure (kPa) at the Temperature at the Surface of the Existing Water Body

V_a: Vapor Pressure at Current Air Temperature (kPa)

It is expressed as the amount of water removed from the sewage sludge (WF_{SI}). The standard dry matter content of the examined sludge was accepted as 25% according to the data in the treatment facilities introduction booklets. Indirect blue water use includes the water footprint from chemical consumption (WF_c), the water footprint from electricity consumption (WF_e), and the water footprint from sludge transportation and management (WF_t). Therefore, the total blue water footprint is the sum of direct and indirect blue water footprints and can be calculated as written in equation (4).

$$WF_{blue} = WF_{blue-direct}\,(WF_{eva} + WF_{SI})WF_{blue-indirect}(WF_C + WF_e + WF_t) \tag{4}$$

Data of Ambarlı advanced biological wastewater treatment plant are given in Table 1. According to equation (4), Total Blue Water Footprint is 539506,19 (m^3/day).

2.2.3. Gray Water Footprint

The greywater footprint calculation proposed in the assessment is adapted to a specific domain of wastewater treatment plants. According to the new equation, WWTP is based on mass balance at the discharge point. In this approach; gray water footprint is defined as the minimum volume of freshwater (clean water) required to assimilate the pollutant concentration at the wastewater treatment plant effluent to natural environment concentrations and current ambient water quality standards (Hoekstra et al., 2011). The following equations are used for this:

$$Q_e .\, C_{e(p)} + WF_{gray} .\, C_{nat(p)} = (Q_e + WF_{gray(p)}) .\, C_{max(p)} \tag{5}$$

Equation (5) is also the pollutant mass balance at the discharge point of the wastewater treatment plant.

$$WF_{gray} = \max [\, WF_{gray(p)} .\, (Q_e.(C_{e(p)} - C_{max(p)})) / (C_{max(p)} - C_{nat(p)})) \,] \tag{6}$$

(Unit = volume/time; p=1 p_{end}=p)

$$WFgray = Qe.\frac{Ce - Cmax}{Cmax - Cnat} \quad (7)$$

Qe: Flow rate (output flow) of wastewater (volume/time)

Ce(p): Concentration of pollutant p at the outlet of the Wastewater Treatment plant (mass/volume)

Cmax(p): Maximum p pollutant concentration allowed by the receiving water environment

Cnat(p): Natural concentration of pollutant p in the receiving water environment (before discharge)

Table 1: Ambarlı Advanced Biological Wastewater Treatment Plant Blue Water Footprints.

BLUE WATER FOOTPRINTS		**Literature**
Recycle Rate (Qr/Q) (m^3/day)	120000	Samsunlu, 2006
Internal Circulation Return Rate (m^3/day)	400000	Samsunlu, 2006
Reused (m^3/day)	5000	Ambarlı ABWTP, Facility introduction booklet
Total Surface Area Evaporation Amount (Average) (m^3/day)	88,19	www.mgm.gov.tr
Filtrate Flow Rate (m^3/day)	13800	Verbal information (question/answer) received from the facility
Amount of water used in dissolving polyelectrolyte (m^3/day)	318	Verbal information (question/answer) received from the facility
Amount of Water Removed from Treatment Sludge (m^3/day)	300	Ambarlı ABWTP, Facility introduction booklet
Virtual Water Contained in Consumed Electricity	neglect	Cankaya, 2023
Water Losses in Transportation Processes	neglect	Cankaya, 2023
Total Blue Water Footprint (m^3/day)	539506,19	

Table 2: Scenarios and Assumptions

SCENARIO-1: ADVANCED BIOLOGİCAL TREATMENT	
Assumption-1 **Cmax:** WPCR-Table:22 **Cnat:** MMUP	**Assumption-2** **Cmax:** Domestic Wastewater Discharge Standards **Cnat:** MMUP
SCENARIO-2:BIOLOGİCAL TREATMENT	
Assumption-1 **Cmax:** WPCR-Table:22 **Cnat:** MMUP	**Assumption-2** **Cmax:** Domestic Wastewater Discharge Standards **Cnat:** MMUP
SCENARIO-3:DIRECT DISCHARGE (NO TREATMENT)	
Assumption-1 **Cmax:** WPCR-Table:22 **Cnat:** MMUP	**Assumption-2** **Cmax:** Domestic Wastewater Discharge Standards **Cnat:** MMUP

WPCR (Water Pollution Control Regulation)

MMUP (Marmara Municipalities Union Publication) (Ozturk and Tanik, 2013)

Table:3 Gray Water Footprints Calculated for Scenario 1 / Assumption-1

Pollutant Type	Purification efficiency (%)	Raw Wastewater Pollutant Concentration (g/m³)	Ce (g/m³)	Cmax (g/m³)	Cnat (g/m³)	WF gray (m³/G)
TN- Total Nitrogen	90	60	6	40	0,05	-340425,5319
TP- Total Phosphorus	90	8	0,8	10	0,01	-368368,3684

Table 4: Gray Water Footprints Calculated for Scenario 1 / Assumption-2

Pollutant Type	Purification efficiency (%)	Raw Wastewater Pollutant Concentration (g/m³)	Ce (g/m³)	Cmax (g/m³)	Cnat (g/m³)	WF gray (m³/G)
TN- Total Nitrogen	90	60	6	15	0,05	-240802,6756
TP- Total Phosphorus	90	8	0,8	2	0,01	-241206,0302

Table 5: Gray Water Footprints Calculated for Scenario 2/ Assumption-1

Pollutant Type	Purification efficiency (%)	Raw Wastewater Pollutant Concentration (g/m3)	Ce (g/m³)	Cmax (g/m³)	Cnat (g/m³)	WF gray (m³/G)
TN- Total Nitrogen	30	60	42	40	0,05	20025,03129
TP- Total Phosphorus	20	8	6,4	10	0,01	-144144,1441

Table 6: Gray Water Footprints Calculated for Scenario 2 / Assumption-2

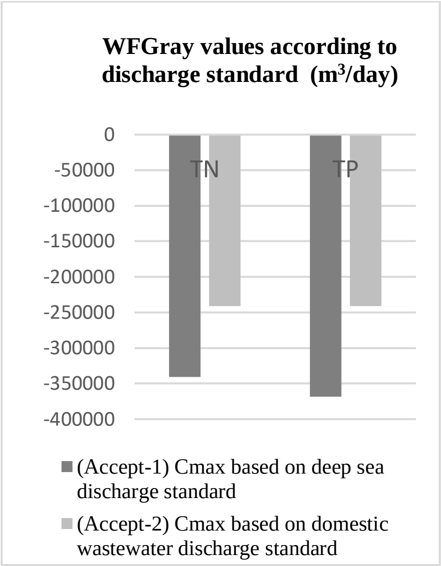
Pollutant Type	Purification efficiency (%)	Raw Wastewater Pollutant Concentration (g/m3)	Ce (g/m^3)	Cmax (g/m^3)	Cnat (g/m^3)	WF gray (m^3/G)
TN- Total Nitrogen	30	60	42	15	0,05	722408,0268
TP- Total Phosphorus	20	8	6,4	2	0,01	884422,1106

Table 7: Gray Water Footprints Calculated for Scenario 3 Assumption-1

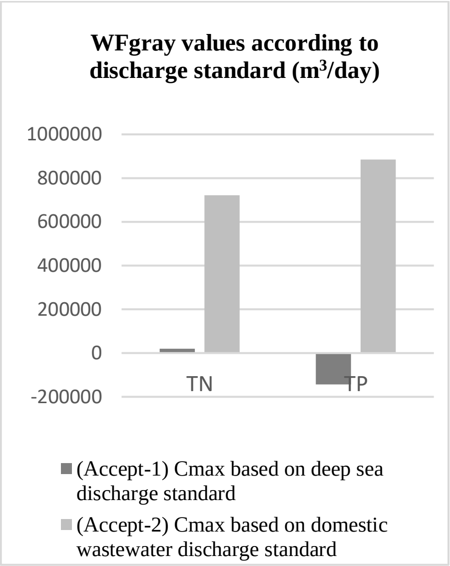
Pollutant Type	Purification efficiency (%)	Raw Wastewater Pollutant Concentration (g/m3)	Ce (g/m^3)	Cmax (g/m^3)	Cnat (g/m^3)	WF gray (m^3/G)
TN- Total Nitrogen	0	60	60	40	0,05	200250,3129
TP- Total Phosphorus	0	8	8	10	0,01	-80080,08008

Table 8: Gray Water Footprints Calculated for Scenario 3 / Assumption-2

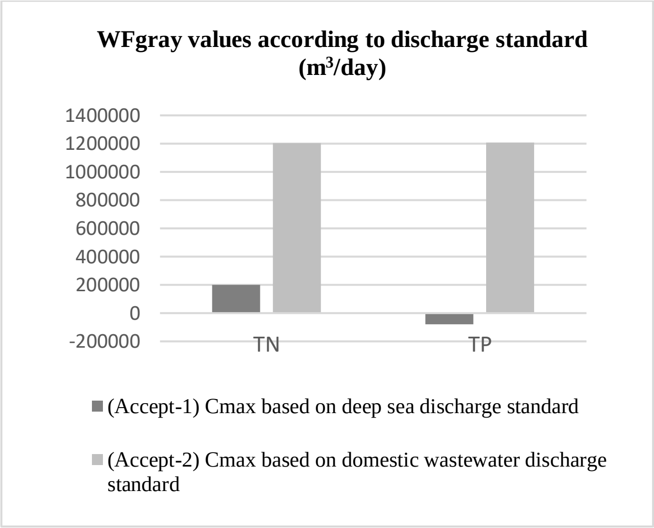
Pollutant Type	Purification efficiency (%)	Raw Wastewater Pollutant Concentration (g/m^3)	Ce (g/m^3)	Cmax (g/m^3)	Cnat (g/m^3)	WF gray (m^3/G)
TN- Total Nitrogen	0	60	60	15	0,05	1204013,378
TP- Total Phosphorus	0	8	8	2	0,01	1206030,151



Scenario 1



Scenario 2



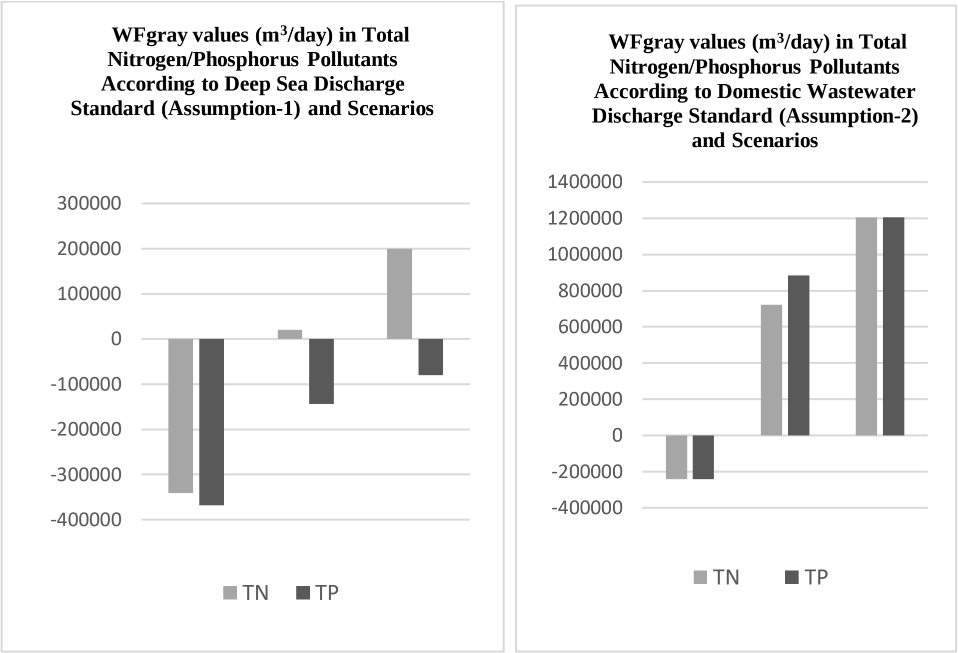
Scenario 3

Figure 6: Gray Water Footprints Calculated According to Discharge Standards in Scenerio-1 (Advanced Biological Treatment), Scenerio-2 (Biological Treatment) and Scenerio-3 (Direct Discharge)

In Figure 6 (Scenario 1), WFgri values are negative because the pollutant concentration (Ce) in the treated water leaving the wastewater treatment plant is lower than the maximum allowable concentration value (Cmax) for the receiving environment. A negative gray water footprint means that the pollutant concentration at the outlet of the treatment plant (in the treated water) is lower than the maximum acceptable pollutant concentration before discharge in the receiving environment. In summary, it means that the effluent of the wastewater treatment plant is cleaner than the receiving environment (Ce<Cmax).

If the maximum acceptance tolerance (or Cmax) of the receiving environment for the pollutant is greater than the pollutant concentration (or Ce) in the treated wastewater, the WFgri (grey water footprint) value is negative. Although this situation is positive for the receiving environment; It is negative in terms of treatment costs. In the wastewater treatment plant, the removal efficiency of the pollutant in question can be kept lower than the current value and treatment costs can be reduced. However, when considering the use of treated wastewater for agricultural or landscape irrigation purposes, both assumption-1 (deep sea discharge standard) and assumption-2 (domestic wastewater discharge standard) can be preferred for the 1st scenario (in the Advanced biological treatment option). Because in advanced biological treatment, the gray water footprint (in terms of TN and TP pollutants) is negative in both standards, meaning that the treated wastewater is cleaner than the receiving environment.

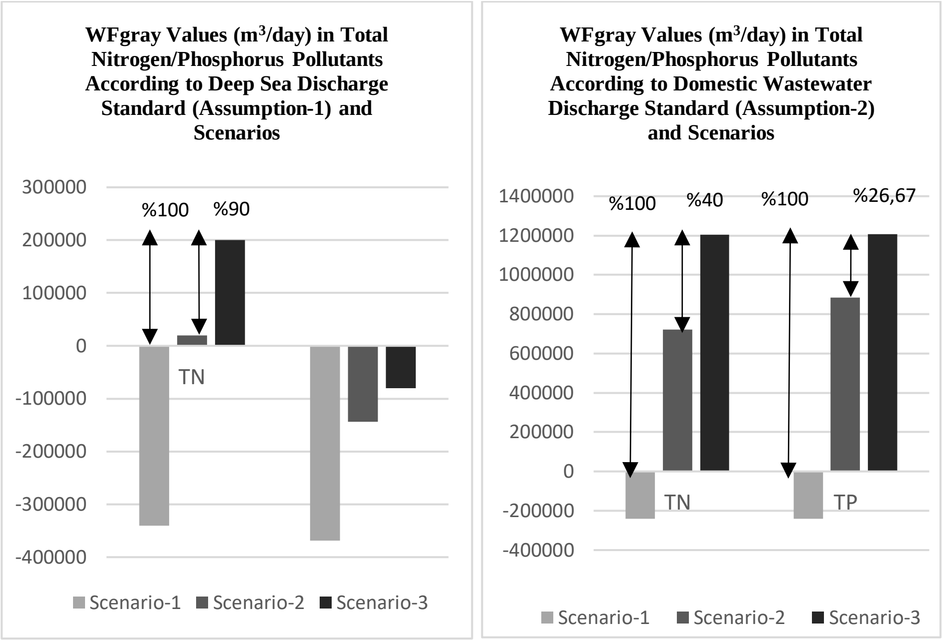
When Cmax is assumed according to the domestic wastewater discharge standard in Figure 6 (Scenario 2), the calculated WFgri (grey water footprint) values are higher than the gray water footprints calculated according to the deep sea discharge standard regulation. Only in Assumption-1, the gray water footprint has a negative value due to the TP (for total phosphorus) Ce<Cmax condition. In Figure 6 (Scenario 3), gray water footprints are generally positive since it is assumed that wastewater is discharged without any treatment (Ce>Cmax). TN and TP pollutant concentrations in wastewater are higher than the maximum concentration acceptable to the receiving environment.



(a) **(b)**

Figure 7: Combined Evaluation of Gray Water Footprint in Scenarios According to Deep Sea Discharge (assumption-1) and Domestic Wastewater Discharge Standards (assumption-2)

When Figures 7 (a) and (b) are examined, it is understood that the scenario with the lowest gray water footprint is scenario 1 (advanced biological treatment). As the treatment level increases, the gray water footprint also decreases. It is desirable for WFgri to be low; Therefore, the receiving environment with high Cmax concentrations should be selected and; Ce concentrations should also be low (purification efficiency is high). When discharging the treated wastewater into the receiving environment, the treatment efficiency should be increased by keeping the treatment efficiency high and decreasing the Ce values. Or, the WFgri value can be reduced by selecting a receiving environment with a high Cmax value (high pollutant concentration capacity).



(a) **(b)**

Figure 8: Combined Evaluation of Gray Water Footprint in Total Nitrogen/Phosphorus Pollutants of Deep Sea Discharge (Assumption-1) and Domestic Wastewater Discharge (Assumption-2) Standards According to Scenarios

In Figure 8 (a), in the deep sea discharge standard; The difference in total nitrogen (TN) removal efficiency is 100% in scenario -1 and 90% in scenario-2 compared to scenario-3 (with no treatment). Total phosphorus removal efficiency is negative in all three scenarios. Because the pollutant concentration of total phosphorus in the treated water leaving the wastewater treatment plant (0.8 mg/L- 6.4 mg/L- 8 mg/L) is lower than the Cmax value (10 mg/L) accepted for the receiving environment in the deep sea discharge. (Ce<Cmax).

In Figure 8 (b), in the domestic wastewater discharge standard; the difference in total nitrogen (TN) removal efficiency is 100% in scenario-1 compared to scenario-3 with no treatment, and 40% in scenario-2. The removal efficiency of total phosphorus is 100% in scenario-1, compared to scenario-3, where there is no treatment, and 26.67% in scenario-2. In scenario-1, where advanced biological treatment takes place for both total nitrogen and total phosphorus, the gray water footprint is negative. Because the Ce values, which are the pollutant concentration in the treated water leaving the wastewater treatment plant, are lower than the Cmax values accepted for the receiving environment (Ce: 6 mg/L, Cmax: 15 mg/L for TN; Ce: 0.8 mg/L for TP, Cmax: 2 mg/L).

The gray water footprint calculated according to the Deep Sea Discharge Standard is lower than the gray water footprint calculated according to the Domestic Wastewater Discharge Standard. For example, when the TN pollutant is treated according to the deep sea discharge standard, the reduction in the gray water footprint in the 2nd scenario (Biological Treatment) is 90% for TN; When treated according to the domestic wastewater discharge standard, it drops to 40% for the same pollutant. For example, when we look at the gray water footprint reductions for the TP pollutant, the gray water footprints in the treatment according to the deep sea discharge standard are negative (no gray water footprint) in all three scenarios (Ce<Cmax); In the domestic wastewater discharge standard, 26.67% gray water reduction could be achieved in the 2nd Scenario (biological treatment) for the same pollutant. Because the Cmax value accepted for the receiving environment in the TP pollutant in deep sea discharge (10 mg/L) is higher than the Cmax value accepted for the receiving environment in the domestic wastewater discharge standard (2 mg/L). In case of TN pollutant, the Cmax value (40 mg/L) accepted for the receiving environment in deep sea discharge is higher than the Cmax value (15 mg/L) accepted for the receiving environment in the domestic wastewater discharge standard. In this case, it is concluded that the domestic wastewater discharge standard criteria are more stringent than the deep sea discharge criteria, and therefore the gray water footprint values calculated according to the domestic wastewater discharge standard are higher than those calculated according to the deep sea discharge standard.

If the Cmax value of a receiving environment close to the wastewater treatment plant is low, choosing a receiving environment with a higher Cmax value or changing the discharge point can reduce the Wfgri value and thus protect our clean water resources and make them last longer. Otherwise, if the conditions are not met, wastewater treatment efficiency should be increased according to the Cmax value that the receiving environment can accept. In addition, reducing the wastewater flow rate (reducing wastewater at its source) is effective in reducing the WFgri value. Again, depending on the intended use of treated wastewater, if the option of using it for irrigation purposes is considered, the most suitable scenario is the advanced biological treatment scenario (scenario 1). The most appropriate one in the 1st scenario is assumption-2 (domestic wastewater discharge standard).

3. RESULTS AND DISCUSSION

In the study, a 90% gray water footprint reduction was achieved in the classical biological treatment process in terms of TN (total nitrogen) in deep sea discharge, and a 100% gray water footprint reduction was achieved with additional treatment (advanced biological treatment). In terms of TP, treatment beyond discharge standards has been achieved and the gray water footprint is negative in all three scenarios.

In the domestic wastewater discharge standard, conventional treatment provided a 40% reduction in gray water footprint in terms of TN (total nitrogen), and additional treatment (advanced biological treatment) provided a 100% gray water footprint reduction. Therefore, advanced treatment reduced the gray water footprint by 60% compared to classical treatment. In terms of TP (total phosphorus), classical treatment reduced the gray water footprint by 26.67%, while advanced treatment reduced the gray water footprint by 100%. As a result, the effect of the additional treatment process (advanced treatment) on the reduction in gray water footprint compared to the classical biological treatment option is 73.33% in terms of TP (total phosphorus); It was obtained as 60% in terms of TN (total nitrogen). This decrease shows that it significantly affects the sustainability of the gray water footprint. In short, water footprint studies carried out in wastewater treatment facilities have an important role in the urban water cycle.

In addition, some studies in the literature, Morera et al., 2016, stated that a 51.5% and 72.4% reduction in water footprint was achieved, respectively, by using secondary treatment (classical biological treatment) and chemical phosphorus removal in order to meet legal limits. Çankaya 2023 emphasized that, unlike conventional treatment, after the additional treatment process applied to treated wastewater, the gray water footprint decreases by 44% and this decrease significantly affects the sustainability of the gray water footprint. In summary, advanced biological treatment methods in wastewater treatment plants are important for the management and sustainability of gray water and the protection of natural water resources.

In order to protect natural water resources and prevent their waste, the first practice that comes to mind is the option of reusing treated wastewater. In this case, instead of discharging treated wastewater, usage options should be considered in situations that require irrigation of agricultural products in rural areas, vehicle washing in urban areas, irrigation of gardens, parks, golf courses and other landscape areas, feeding of groundwater, etc., and their advantages and disadvantages should be evaluated. The next step should be to investigate the flow rate of treated wastewater, the quality of exit from the facility, whether it can meet the need in terms of quantity and quality, transportation and storage of treated wastewater to usage areas, and whether there will be additional treatment costs accordingly. As a result of the research, the reuse of treated wastewater will contribute to the sustainability of clean water resources by preserving the quantity and quality.

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CHAPTER 5

COMPARATIVE ANALYSIS OF GREEN BUILDING CERTIFICATES AND ASSESSMENT OF TURKEY IN THE CONTEXT OF B.E.S.T. AND YES-TR

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INTRODUCTION

The construction industry and its most important output, buildings, have profound economic, environmental, and social effects on society during their life cycle. While construction activities have positive impacts, such as providing buildings and facilities to meet people's needs, generating employment opportunities, and providing a contribution to the national economy, they also have negative effects, as large quantities of human and natural resources are depleted during the construction phase and impact on the environment persist after construction is completed (Zuo and Zhao, 2014). The impacts that this sector is responsible for involve energy usage, greenhouse gas emissions, waste generation, and unsustainable consumption of non-renewable natural resources (IEA, 2024). Recognized as the largest user of energy and natural resources, the construction industry consumes about 40% of the total flow of raw materials entering the world economy yearly (Mazur et al., 2023), generates about 26% of global waste, and ranks among the main GHG emitters worldwide (Reidy et al., 2011). Thus, the construction industry must cope with the pressure to increase stringent measures, such as the production of environmental assessment methods, to prevent the mentioned negative situations (Alyami et al., 2014). Therefore, people need to reshape the way they grow and build in a way that enables them to thrive both today and in the future. For this reason, the concept of sustainable/green building is of global importance (Lazar and Chithara, 2020).

A green building is recognized as a building that responds to building performance needs while optimizing the workings of global, regional, and local ecosystems during construction and throughout its defined service life (Sev, 2011; Li et al., 2017). Systems called green rating tools have been developed to estimate the degree of sustainability of buildings. These rating tools have been introduced to provide a benchmark for quantifying green building performance, taking into account the distinct objectives, characteristics, and standard requirements of different countries in the world (Illankoon et al., 2017; Mattoni et al., 2018). The performance assessment of green buildings is an important challenge as different rating tools highlight different dimensions of building performance, and nowadays this issue has attracted a lot of attention from researchers (Nilashi et al., 2015).

Researchers have conducted many academic studies in the literature related to green building certification systems. There are researches such as Nilashi et al. (2015), and Abdul-Rahman et al. (2015) that focus on certification systems that can be evaluated at the global level. Researchers in the literature, especially in the last 15 years, have also conducted various studies on the development of a rating tool for each country. Ali and Al Nsairad (2009) in Jordan, Namini et al. (2014) and Shad et al. (2017) in Iran, Medineckiene et al. (2015) in Sweden, Alyami et al. (2015) in Saudi Arabia, Vyas and Jha (2016) in India, Zhang and Yi (2017) and Shao et al. (2018) in China, Al-Jebouri et al. (2017) in Oman, Akhanova et al. (2020) in Kazakhstan, Anshebo et al. (2022) in Ethiopia, reveal the characteristics of green building certification systems that should be implemented.

In this study, research was conducted on the evaluation of B.E.S.T. and YeS-TR certificates developed in Turkey. In the study, the comparison of B.E.S.T. and YeS-TR certificates with globally accepted green building certificates and the evaluation of their qualifications were carried out. The study followed the data collection method from qualitative research methods. The study compared LEED, BREEAM, CASBEE, and DGNB certificates, which are widely used and accepted globally. The two certification systems in Turkey have also emerged by examining and evaluating other certificates, but their suitability for the country's context is the crucial question of the study.

In the research, data was first collected by examining 6 green building certification systems, and data analysis was carried out on the sub-assessment criteria under the main assessment criteria of these certificates. The comparisons were analyzed in the evaluation table and radar diagrams. In light of all these evaluations, recommendations have been made for B.E.S.T. and YeS-TR systems. The processes carried out in the study are given in Figure 1.

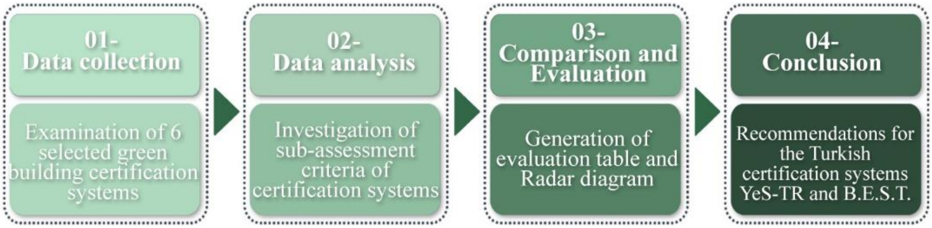

Figure 1: Stages followed in the study

1. GREEN BUILDING CERTIFICATION SYSTEMS

Green buildings are defined as wholesome facilities that are constructed and designed in a resource-efficient somehow using ecologically fundamental principles (Kibert, 2008). Green buildings are intended to minimize environmental impacts, improve the health circumstances of their residents, ensure a return on investment for the local community and developers, and consider the life cycle in the planning and improvement process (Robichaud and Anantatmula, 2010). Green building is the application of standards to decrease the important effect of buildings on the society, environment and economy (Zuo and Zhao, 2014). With the increase in the number of green buildings, there is a need for a measurement to value the performance of green buildings, and many evaluation tools and green building value systems have been introduced worldwide. Green building rating tools are a benchmark that gauges the coverage to which buildings meet green building deficiencies (Illankoon et al. 2017). These systems measure the sustainability of a building by implementing a set of criteria that are organized into distinct classifications and classify factors that need to be executed a performance assessment of buildings (Nilashi et al., 2015). After detailed assessments, it gives a ranking to the building. It also serves as a guide to contextualize environmental issues throughout the design, building, and operation stages. Therefore, these assessment tools promote sustainable practices (Li et al., 2017).

Green Building Councils (GBC) mainly improved green building scoring system around the world under the mandate of the World Green Building Council (WGBC) (Lazar and Chithara, 2020). GBC has implemented several Green Building Rating Systems around the world (Lazar and Chithara, 2018). The improvement of these grading tools started several decades ago and the initial building performance evaluation method was BREEAM, founded in 1990 by the Building Research Establishment in the UK. Subsequently, LEED was introduced in the US between 1993-1998. Afterwards, different organizations in developed countries started setting their own green standards (Akhanova, 2020).

Each certification system has its own methodologies and comprise of distinct parts and criteria that define distinct parts of the building's life cycle. Among the protocols used for labeling, some provide centages, some use scores, and some use alphabetic letters or stars. Some have very detailed and lengthy assessment methodologies, while others have a simpler and clearer methodology (Medeineckie et al., 2015).

Although hundreds of rating systems exist today, implementers and academics are still interested in developing new tools to bear specific needs (Lazar and Chithara, 2020). This is because different countries have different climatic conditions and cultures, and it makes more sense to produce separate rating systems for each climatic region, including contextual requirements (Lazar and Chithara, 2020). Countries' legal regulations, climates, geographical conditions, current status in technological innovations, differences in the labor force and local materials, etc. are the criteria for evaluation. Such country-specific studies are mostly carried out in developing countries (Serbest Yenidünya and Limoncu, 2024). In this study, evaluations will be made in the context of B.E.S.T., a recently produced certification system for Turkey, a developing country, and the recently announced YESTR, and comparisons will be made over the widely accepted BREEAM, LEED, CASBEE, DGNB.

1.1. BREEAM

BREEAM certificate is the first green building certification system developed by the Building Research Establishment in the UK in 1990. BREEAM is an evaluation system that establishes sustainability criteria and evaluates the environmental impact of buildings (Cole, 2013). The BREEAM certification system aims to ensure that buildings are recognized for their environmental benefits, decrease environmental impact during the lifecycle, and provide a reliable environmental label by promoting sustainable building design. The BREEAM certification system aims to create the criteria above regulations by integrating innovative sustainable solutions into the design, implementation, and use of the building (Ürük and İslamoğlu, 2019). BREEAM has an understanding that can be adapted to current changes, renewed according to environmental policies, and adapted to local conditions. This system is organized in various categories according to the function and country of the building. The classification of the certification system in various categories according to countries aims to ensure adaptation to local changing conditions and standards. In addition, BREEAM has facilitated the standardization and adaptation of other countries by organizing its criteria in the energy field according to energy performance measurements in European norms (Roderick et al., 2009; Awadh, 2017).

The assessment of the BREEAM certification system includes various classifications such as existing buildings, newly constructed buildings, additions to available buildings, a combination of newly constructed buildings and available buildings, and the fine structural reinforcement of available buildings. There are also many certification categories according to their functions, such as residential, industrial, educational, and healthcare buildings (Roderick et al., 2009; Awadh, 2017).

The BREEAM certification system evaluates buildings according to ten headings and sub-criteria: Water, Energy, Materials, Land Use and Ecology, Innovation, Waste, Pollution, Health and Wellbeing, Management and Transportation. A total of 110 points can be obtained provided that the required points are obtained according to these ten criteria and sub-criteria. There are five different certification scales according to the score of the building. According to the BREEAM certification system, the 30-44 point range is Pass, the 45-54 point range is Good, the 55-69 point range is Very Good, the 70-84 point range is Excellent, and the 85 to 110 point range is Outstanding. After the building is certified according to its score, this certificate is valid for 3 years and must be updated again at the end of 3 years. The certification process takes place in two stages. First, the building is evaluated at the design stage according to its environmental impacts and completed with an interim certificate. The second stage is evaluated after construction and the final certificate can be awarded (Yetkin, 2014). The BREEAM certification process is shown in Figure 2.

Figure 2: BREEAM Certification Process (prepared by the authors)

1.2. LEED

LEED is a certification system for rating environmentally friendly buildings created by the US Green Building Council (USGBC) in 1998. The certificate is issued by GBCI (Green Business Certification Body). LEED, the most preferred certification system in Turkey and in the world, is successfully implemented in 165 countries. The aim of the LEED certification System is to create a basis for creating highly efficient, healthy and cost-effective environmentally friendly buildings. It aims to save water, natural resources and energy in buildings and to produce as little waste as possible. It was created for the planning, reconstruction, and running of buildings suitable for human health (URL-1).

LEED green building certification system can be awarded to existing buildings (O+M) and new projects (BD+C). It covers all processes from the selection of the project site to the final completion of construction in many new construction projects (BD+C) and commercial interior projects (ID+C) with different functions such as Office, Hotel, School, Core and Shell, Data Center, Hospital Warehouse. To be certified in existing buildings (O+M), the building must be used for at least 1 year. While LEED certificate is given to existing buildings, it includes a process in which planning is made and implemented by examining the criteria in the certification system (URL-2). Prior to registration in the LEED certification system, projects are required to meet all Minimum Program Requirements (MPR). The minimum program requirements have three main purposes. These are to protect the integrity of the LEED certification program, to reduce complications that may arise in the LEED certification process and to provide guidance to clients. According to the Minimum Program Requirements, MPR1: The Building to be certified must not move, MPR2: It must have an acceptable project area and boundary, and MPR3: The project must comply with dimensional requirements (LEED BD+C and O+M Certification Systems and LEED ID+C Certification Systems) (URL-3) (Figure 3).

The LEED certification system examines the performance of buildings for seven sections: Water efficiency, Location and transportation, Indoor environmental quality, Sustainable landscapes, Integrative Process, Materials and resources, Innovation, Regional Priority and Energy and atmosphere. There are sub-headings for each category. For each sub-heading there are some credits in the LEED scoring system. Credits measure some environmental impacts and give certain points to the building to be certified. There are some prerequisites for categories in the scoring system. Buildings that do not meet the prerequisites cannot qualify for certification (URL-4). In order for the building to be eligible for certification, all prerequisites must be met and a minimum of 40 points must be obtained. The required score will vary according to the level of certification (URL-3). There are four different certification levels according to the score of the building. According to the LEED certification system, 40-49 point out is Lean Certificate, 50-59 point out is Silver, 60-79 point out is Gold, and 80-110 point out is Platinum. As a result of the scores given by the authorized organization GBCI, the building that meets all the prerequisites is entitled to the certificate at the level corresponding to the score it receives (URL-4).

Figure 3: LEED Certification Process (prepared by the author)

1.3. CASBEE

Developed in 2001 through the collaboration of the Japan Sustainable Building Consortium (JSBC) and the Japan Green Building Council (JaGBC), CASBEE (Comprehensive Assessment System for Built Environment Efficiency) is rooted in the sustainability principles of Japan and other Asian nations. The certificate is designed to serve as a method for assessing and rating the environmental performance of buildings and the built environment. CASBEE's certificate aims to encourage the usage of energy-efficient materials and equipment that reduce environmental impact, while also evaluating the overall quality of buildings by considering factors like indoor comfort and landscape aesthetics.

CASBEE certificate has assessment criteria adapted to different scales. These criteria are construction (houses and buildings), urban (city development), and city management. CASBEE-Residential and CASBEE-Building have been applied to homes and buildings to examine their environmental performance. CASBEE-Urban Development is used to examine the environmental performance of urban islands and city development. CASBEE-City assesses environmental performance at the local government scale. These are assessed by CASBEE according to BEE indicators. CASBEE assessment criteria follow three rules: Building Life Cycle Assessment, Built Environment Quality and Built Environment Burden Assessment, and the newly developed Built Environment Efficiency (BEE) assessments (Figure 4). At the building scale, the tools vary according to the stage of the buildings. In other words, different assessment tools are used for preliminary design, new buildings, existing buildings, and renovation phases, regardless of the function of the building (URL-5).

The CASBEE certificate assessment process is based on two rules. One is the environmental quality and performance of the building (expressed as “Q”) and the second is its environmental loads of the building (expressed as “L”). The Q/L ratio refers BEE of the building. The “Q” value is the sum of the points provided by the building in the criteria of Service Quality, Indoor Environment, Outdoor Environment on Site. The “L” value is the sum of the points earned in the categories Energy, Resources and Materials, and Environment Outside the Site. The Q and L values are calculated automatically by entering the required performance values into Excel tables obtained from CASBEE's website. The environmental efficiency criterion is then written graphically, and the sustainability level of the building is determined. The sustainability level of the building increases as the value of Q to L increases.

At the end of the evaluation, the building is ranked according to five ratings: Superior (S), Very Good (A), Good (B+), Somewhat Poor (B-), and Poor (C) (URL-5). Compared to other systems, CASBEE is considered highly complex, and since much of its methodology and documentation is in Japanese, its implementation in countries outside of Japan is less likely.

Figure 4: CASBEE Certification Process (prepared by the author)

1.4. DGNB

DGNB was established in 2007 as a non-gain, efficient organization. The DGNB was launched energy certification system for general office use and administrative use in 2009, and in 2010 it further developed this system and became an international system. The aim of the DGNB energy certification system is to develop innovative materials for sustainability, manage the built-up and operative process of the construction, solve problems, provide a quality label for buildings, use resources efficiently and create infrastructure suitable for user comfort and welfare (DGNB, 2011).

There are various versions of the DGNB energy certification system, depending on the phase of the building's lifetime, the classification of construction, and the district scheme. For example, it has up to 37 sub-criteria under six headings for new buildings and nine sub-criteria under three headings for buildings in use. This system covers various categories of existing buildings, new buildings, educational buildings and commercial buildings. In this system, buildings are evaluated in ten categories: From new building types to office and administrative buildings, shopping centers, industrial buildings, educational, residential and hotel structures. In addition, the repair and modernization of existing office and administrative buildings in urban areas is included. As the DGNB system can be easily applied to the climatic, cultural and regulatory features of other countries, it can provide certification worldwide. The important features that distinguish this system from other international certification systems are its emphasis on life cycle assessment, holistic approach and performance orientation (URL-6).

The DGNB certificate is issued in two stages. First, a preliminary certificate is issued during the design phase, while the final certificate is issued after the building is finished. Thus, it ensures that sustainability-oriented optimization is optimized from the design stage and that official records of this process are created (Doğan & Seçme, 2018) (Figure 5). The DGNB certification system has high quality standards consisting of six headings. It is required to meet the minimum performance of these six evaluation criteria. However, no minimum performance level is required for new buildings. These criteria are classified under environmental, technical, process, sociocultural, economic, functional and land/zone/region titles in the context of quality. Buildings evaluated according to these criteria are graded according to four different certification levels. In the DGNB certification system, the 35–49 point range is Bronze, the 50-64 point range is Silver, the 65-79 point range is Gold and the score above 80 is Platinum (Doğan and Seçme, 2018).

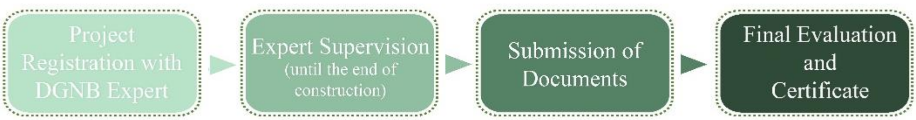

Figure 5: DGNB Certification Process (prepared by the author)

1.5. B.E.S.T.

Environmentally Friendly Green Buildings Association (ÇEDBİK) was established to contribute for the improvement of the construction industry in Turkey in the framework of green and environmental policies in 2007. In 2013, within the scope of the "Green Housing Certification Guide" introduced at the International Green Building Summit and the protocol signed, it was accepted to take the "Green Housing Certification Guide" as a reference for the houses to be built and to carry out certification studies for greenhouses built in Turkey with ÇEDBİK (ÇEDBİK, 2016).

In 2015, the Environmentally Friendly Green Buildings Association (ÇEDBİK), which continues its studies and researches in the context of green buildings, created B.E.S.T-Housing and Commercial, a certification system suitable for Turkish conditions to be applied in new housing projects (URL-7). The goal of BEST energy certification is to create a better place to live, healthy communities, and a thriving economy. The aim is to increase existing building regulations with this certificate. It also aims to provide the best conditions for assessing the sustainability of the constructed environment (URL-7).

All organizations can apply for green building certification for their newly constructed projects. The project is designed and constructed in accordance with local regulations (Regulation on Fire Protection of Buildings, Regulation on Buildings to be Built in Earthquake Zones, etc.), Zoning Regulations and Zoning Plans of the relevant municipalities. It is possible to obtain a "Design Conformity Letter" for projects during the design phase. "BEST - Housing Certificate" evaluation criteria are determined by 'BEST - Housing Certificate Regulation'. Organizations that have completed the pre-application process to obtain a certificate make their certificate applications based on the BEST-Housing Certificate Guide.

The evaluation is carried out with a scoring systematic within the framework of basic criteria and sub-criteria under them. The evaluation process is carried out by scoring by expert evaluators within the scope of nine evaluation criteria and 44 sub-criteria. For the BEST Commercial Buildings Certificate, the evaluation process is carried out by scoring by expert evaluators within the scope of 9 upper categories and 6 prerequisites and 40 criteria under them (B.E.S.T, 2019) (Figure 6).

In the BEST Housing Certificate System, there are 6 different housing typologies for newly built residences: Single-family dwelling, Basic dwelling ≤ 2,000 m², 2,000 m² < Basic dwelling ≤ 20,000 m², 20,000 m² < Basic dwelling ≤ 50,000 m², 50,000 m² < Basic dwelling, Residence-Luxury residential building. As for new commercial buildings and large-scale renovation works in existing buildings, there are 3 different commercial building typologies within the framework of BEST- Commercial Buildings Certificate; Standard small commercial buildings ≤ 2,000 m², Standard commercial buildings > 2,000 m², Luxury commercial buildings (B.E.S.T, 2019).

In the context of the BEST certificate for the assessment of residential/commercial buildings, buildings are assessed in 9 categories: Water, land, energy, material, and resource use assessment, integral green project management, operation and servicing, innovation, residential/commercial, health, and comfort. There are detailed explanations about each heading and sub-categories in residential/commercial certification guides. Criteria of the evaluation systems are very comprehensive; they cover all construction operations (planning, construction, operation, and usage of the design and transformation phases after usage) as well as the measurement and certification system (B.E.S.T, 2019). Projects are assessed according to the strategies under the categories with a maximum score of 110 points and are certified with one of four different certification levels. According to the Best-tr certification system, a score of 46-64 is considered Approved, 65-79 is Good, 80-99 is Very Good, 100-110 is Excellent (URL-7).

Figure 6: B.E.S.T. Certification Process (prepared by the author)

1.6. YeS-TR

Green Certificate (YeS-TR) is a national certification system that provides assessment and certification of buildings for sustainability. This system was initiated in 2014 with the publication of the ‘Regulation on the Certification of Sustainable Green Buildings and Sustainability Settlements’ in the Official Gazette numbered 29199 (Kılınçaslan et al., 2019). ‘‘The Communiqué on the Implementation of the Green Certificate Regulation’’ was published in the Official Gazette numbered 31506 and the evaluation criteria and information on the certificate system were presented in the communiqué in 2021 (Özaydın & Baz, 2021). The purpose of the YeS-TR certification system is to minimize the adverse effect on the natural surroundings by insuring to make effective use of natural sources and energy at the scale of buildings/settlements and to evaluate this by creating certification systems. In this process, the objectives of the certification system are stated with the guideline that determines the duties and qualifications of the responsible green certification experts and presents the performance criteria and percentages for the certification of buildings (Ministry of Environment, Urbanization and Climate Change, 2021).

According to YeS-TR certification system, the evaluation of the buildings is completed in three steps. The first step, Planning and Design, is the preliminary step where the necessary permits and procedures for grading are completed before construction starts. Construction/Development Sequence is the second phase, which is completed by proving that 50-75% of the development area has been completed and fulfillment of permits. The final stage, Construction / Post Development, can be qualified upon 100% completion of the construction. There is a certain process operation for the buildings to be rated with YeS-TR certificate (Ministry of Environment, Urbanization and Climate Change, 2021). This process is carried out by registering to the system, uploading the necessary information and documents, and evaluating them by experts (Figure 7).

Buildings can be assessed in two modules, as existing buildings and new buildings, according to the guidelines published in the YeS-TR certificate. In both modules, buildings are classified based on their typologies as residential, hotel, shopping, commercial, office, health care and educational buildings. The certification assessment criteria consist of six modules: Energy efficiency, interior environmental quality, building materials and lifetime assessment, water and wastes management, innovation, integral building design and construction process and management. Green Certificate degrees are determined according to the total amount of credits. The maximum credit score for each module is 100. The credits achieved in each module are multiplied by the weighting coefficients of their respective modules to arrive at the total weighted credits. The total amount of weighted credits required for grading is obtained by summing the weighted credit amounts obtained for the modules. Weight coefficients differ according to building types. The weight coefficients and total weighted credits of the modules for new and existing buildings differ. A four-stage certification process has been developed, which is determined separately for new and current buildings depending on the building score evaluated in the YeS-TR certification system within the framework of all calculations and scores. According to the score, 32-39 is Pass, 40-54 is Good, 55-74 is Very Good, 75 and above is National Superior (Ministry of Environment, Urbanization and Climate Change, 2021).

Figure 7: YeS-TR Certification Process (prepared by the author)

2. COMPARISON AND EVALUATION

In this part of the study, the twelve evaluation criteria of the certification systems determined by the authors are presented with their scores in Table 1 and Figure 8. In Table 2, the titles of the sub-evaluation criteria of the certificates are given together with their scores and the table is colored according to the twelve criteria. Each certificate was first evaluated individually and then a general evaluation was made by comparing all certificates.

When the CASBEE certificate is examined through Table 1; it is seen that transportation, cost, process, and biodiversity criteria are not included and the largest share is allocated to land and regional use. The certification system, which also emphasizes energy and interior space criteria, evaluates buildings by considering functionality, water, waste and pollution, materials and resources, and innovation criteria. Unlike other certification systems, transportation and process criteria are not evaluated in this certificate. When the LEED certificate is examined through Tables 1-2; it is seen that the cost, biodiversity and functionality criteria are not included and the energy criterion has the largest share. The certification system, which also attaches importance to transportation and interior space criteria, evaluates buildings by considering water, materials and resources, process and innovation criteria. Although waste and pollution, one of the criteria examined, is seen as zero in the table, it is considered as a prerequisite for the sustainable sites criterion in the certification system. When the BREEAM certificate is analyzed through

Table 1; it is seen that the functionality criteria are not included and the energy criterion has the largest share. The certification system, which also attaches importance to waste and pollution, interior space and materials, resources criteria, evaluates buildings by considering transportation, land and land use, water, process, innovation criteria. Unlike other certification systems, this certificate also includes cost and biodiversity criteria.

When the DGNB certificate is analyzed through the Table 1, it is seen that waste and pollution criteria are not included and the largest share is taken by the interior space criterion. The certification system, which also attaches importance to process and innovation criteria, evaluates buildings by considering transportation, land, and regional use, materials and resources, and functionality criteria. Unlike other certification systems, the certificate gives more importance to cost, process, and biodiversity, and much less importance to energy. When the YeS-TR certificate is examined through Table 1; transportation, land and regional use, cost, biodiversity, and functionality pollution criteria are not included and the energy criterion has the largest share. The certification system, which also attaches importance to interior space and process criteria, evaluates buildings by considering water, waste and pollution, materials and resources, and innovation criteria. Unlike other certification systems, land and land use criteria are not included in the evaluation. When the BEST certificate is examined through Table 1, it is seen that the cost and biodiversity criteria are not included and the energy criterion has the largest share. The certificate system, which also attaches importance to materials and resources and water criteria, evaluates buildings by considering transportation, land and regional use, waste and pollution, process, interior space, innovation and functionality criteria. Unlike other certification systems, the certificate gives less importance to the innovation criterion.

When all the analyzed certificates are compared, it is determined which certification system stands out in which criteria, as shown in Figure 8. LEED certificate in transportation criterion, CASBEE certificate in land and land use, LEED and YeS-TR certificates in energy criterion, BEST certificate in water criterion, BREEAM certificate in waste and pollution criterion, DGNB certificate in cost criterion, YeS-TR and BEST certificates in materials and resources criterion, and CASBEE and BEST certificates in functional criterion received the highest score. In addition, the DGNB certificate stood out with the highest score in the process criterion, interior space criterion, innovation criterion and biodiversity criterion.

Table 1: Comparison of the analyzed certificates

Parameter	Transportation	Land and Territory Use	Energy	Water	Waste and Pollution	Cost	Materials and Resources	Process	Indoor	Innovation	Biodiversity	Functional
CASBEE	0	30	20	5	5	0	5	0	20	5	0	10
LEED	15	12	30	10	0	0	10	3	15	5	0	0
BREEAM	7	7	17	5	16	3	12	8	14	9	2	0
DGNB	5	10	2	4	0	7	8	15	21	16	6	6
YESTR	0	0	30	8	10	0	12	14	16	10	0	0
ÇEDBİK	6	10	24	11	9	0	12	6	10	2	0	10

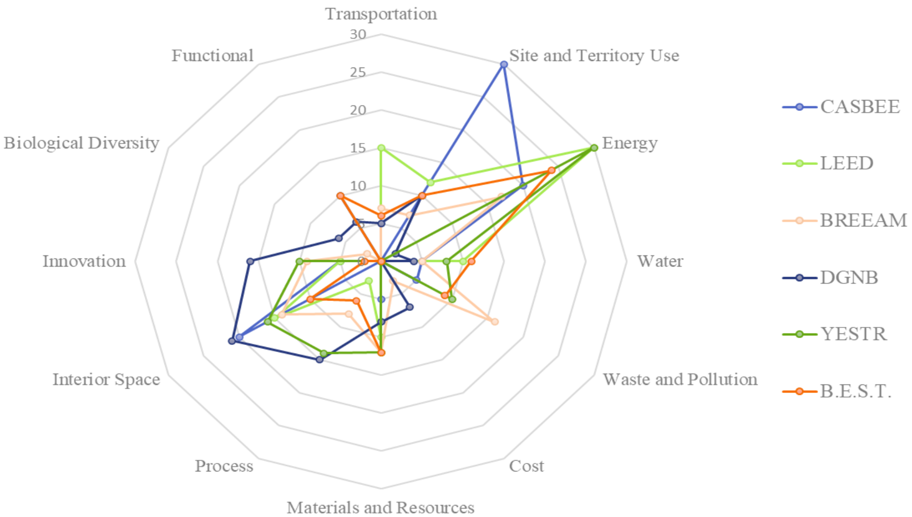

Figure 8: Comparison of the analyzed certificates (Prepared by the authors)

As a result of these evaluations, it was seen that each certificate prioritizes various criteria and the buildings are evaluated with the scoring system created accordingly. During this evaluation process, some questions and deficiencies were identified during the creation of the tables and research on BEST and YeS-TR certification systems. The most striking of these questions is why there is a need for a second certification system, Yes-TR, when there is already a certification system called BEST in Turkey. The most striking of the identified gaps is the difficulty in finding data on the two certification systems. Although both certification systems have their own websites, experts and training platforms, detailed information about the certified buildings is not shared and it is difficult to access this information.

When the green building certificates used in Turkey are analyzed, it is seen that there are some differences between the criteria. While land and regional use, transportation and functionality are given importance in the BEST certification system, these criteria are not included in the YeS-TR certificate. While material and resource utilization, interior space and innovation criteria are given importance in the YeS-TR certification system, these criteria are less important in the BEST certification system. When the deficiencies in these two certification systems are evaluated as common; it is seen that BEST and YeS-TR certificates do not have evaluation criteria in terms of cost and biodiversity.

Table 2: Comparison of criteria and scores of the analyzed certificates

CASBEE											
Interior Environment	Pt	**Service Quality**	Pt	**Outdoor Environment on Land**	Pt	**Energy**	Pt	**Materials and Resources**	Pt	**Land Environment**	Pt
Sound and Acoustics	5	Service Capability	5	Conservation and Creation Biotope	5	Thermal Load of the Building	5	Water Resources	5	Caring about Global Warming	5
Thermal Comfort	5	Durability and Reliability	5	Cityscape and Landscape	5	Natural Energy Use	5	Reducing the Use of Non-Renewable Resources	5	Caring for the Local Environment	5
Lighting and Lighting	5	Relevance and Adaptability	5	Local Characteristics and Outdoor Quality	5	Efficiency in Building Service Systems	5	Avoiding the Use of Polluting Materials	5	Caring for the immediate surroundings of the building	5
Air Quality	5					Productivity Practices	5				
DGNB											
Environmental Quality	Pt	**Economic Quality**	Pt	**Sociocultural and Functional**	Pt	**Technical Quality**	Pt	**Process Quality**	Pt	**Land/Region/Field Quality**	Pt
Building Life Cycle Quality		Life Cycle Cost		Thermal Comfort		Fire Safety		Comprehensive Project Summary		Local Environment	
Biodiversity on Site		Flexibility and Adaptability	22.5	Indoor Air Quality		Sound Insulation		Sustainability Aspects in the Tender Phase		Impact on the Region	
Sustainable Resource Extraction		Commercial Adaptability		Acoustic Comfort		Building Envelope Quality		Certification for Sustainable Management		Transportation Access	5
Potable Water Demand and Wastewater Volume	22.5			Visual Comfort	22.5	Use and Integration of Building Technology	15	City Planning and Design Process		Access to Opportunities	
Land Use				User Control		Ease of Cleaning of Building Components		Construction Area and Construction Process	12.5		
Local Environmental Impact				Indoor and Outdoor Quality		Ease of Recycling and Recovery		Quality Assurance of Construction			
				Safety and reliability		Emission Control		Systematic Applications			
				Design for Everyone		Mobility Infrastructure (transportation)		User Communication			
								Planning in accordance with FM Standards			
YES-TR											
Integrated Building Design, Construction Mgmt.	Pt	**Indoor Environment Quality**	Pt	**Building Material and Life Cycle Assessment**	Pt	**Energy Use and Efficiency**	Pt	**Water and Waste Mgmt.**	Pt	**Building Innovation**	Pt
Project Planning		Visual Comfort		Building Material Life Cycle Assessment and Environmental Product Declaration		Building Energy Performance	30	Water Management	20	Engineering and Engineering that Improves Quality of Life	10
Integrated Design		Auditory Comfort	16	Healthy Product Declaration		Renewable Energy Technologies		Waste Management		Design Solutions	
Preparation of Construction Related Documents	14	Thermal Comfort		Radiation Release	20						
Production		Air quality		Responsible Sourcing							
Control, Commissioning and Acceptance				Local Sourcing							
Operation, Maintenance, Measurement and Facility Management				Use of Reused, Reclaimed or Recyclable Materials							
				Use of Durable Materials							

Transportation | Land and Territory Use | Energy | Water | Waste and Pollution | Cost | Materials and Resources | Process | Indoor | Innovation | Biodiversity | Functional

LEED

Location and Transportation	Pt	Sustainable Sites	Pt	Water Efficiency	Pt	Energy and Atmosphere	Pt	Materials and Resources	Pt	Indoor Environment Quality	Pt	Integrated Process	Pt	Innovation	Pt	Regional Priority	Pt
Hassa Site Protection	1	Prevention of Pollution from Construction	Prereq. (0)	Reducing Outdoor Water Use	Prereq. (0)	Basic Testing and Commissioning Verification	Prereq. (0)	Collection of Recyclable Waste	Prereq. (0)	Minimum Indoor Air Quality	Prereq. (0)	Integrated Process	1	Innovation	1-5	Regional Priority	1-4
High Priority Site Selection	1-2	Field Assessment	1	Reducing Indoor Water Use	Prereq. (0)	Minimum Energy Performance	Prereq. (0)	Construction / Demolition - Waste Management Plan	Prereq. (1-2)	Cigarette Smoke Control	Prereq. (0)			LEED Expert	1		
Settlement Density and Essential Services	1-5	Site Development - Protected or Reconstructed Habitat	1-2	Building Based Water Measurement	Prereq. (0)	Optimizing Energy Performance	Prereq. (0)	Building Life Cycle Analysis	2-5	Improved Indoor Air Quality	1-2						
Proximity to Public Transportation	1-5	Open Spaces	1	Savings in Outdoor Water Use	1-2	Basic Refrigerant Management	Prereq. (0)	Environmental Product Declarations	1-2	Low Emissivity Interior Material	1-3						
Bicycle Facilities	1	Rainwater Management	1-3	Savings in Indoor Water Use	1-6	Advanced Testing and Commissioning	2-6	Resource Utilization	1-2	Indoor Air Quality Management Plan in Construction	1						
Reducing Parking Space	1	Reducing the Heat Island Effect	1-2	Cooling Tower Water Usage	1-2	Building Energy Measurement	1-18	Material Content	1-2	Indoor Air Quality Assessment	1-2						
Green Vehicle	1	Reducing Light Pollution	1	Advanced Water Metering	1	Advanced Energy Metering	1			Basic (Heat) Comfort	1						
						Demand Response	1-2			Interior Lighting	1-2						
						Renewable Energy Production	1-3			Sunshine	1-3						
						Advanced Refrigerant Management	1			Qualified Landscape	1						
						Green Power and Carbon Offset	1-2			Acoustic Performance	1						

BREEAM

Energy	Pt	Governance	Pt	Health Comfort	Pt	Transportation	Pt	Water	Pt	Material	Pt	Waste	Pt	Land Use and Ecology	Pt	Pollution	Pt
Reducing CO2 Emissions	11	Commissioning	3	Daylight	4	Predisposition to urban facilities	1,5	Water Consumption	1	Material Specifications	1	Construction site waste management	1	Land reuse	3	Impact of refrigerants used in buildings on global warming	2
Submetering of Current Energy Use	1	Environmental and Social Business Rules for Contractors	3	Lighting zones and controls	2	Lack of public transportation	1,5	Water Meter	1	Durability - Designing for continuity	1	Recycled aggregates	1	Land contaminated with infectious agents	1	Prevention of refrigerant leaks	2
Outdoor Lighting	1	Life Cycle Cost Analysis	3	Glare Control	2	Transportation alternatives	1	Detection of main water leaks	1	Reuse of the facade	3	Storage of recycled waste	1,5	Protecting the ecological value and ecological characteristics of the land	2	Global warming potential of fluids used in cold storage	1
Low and Zero Carbon Technologies	3	Construction Site Impacts	3	High Frequency Lighting	1	Pedestrian and cyclist safety	1	Shutdown of Plumbing Water	1	Reuse of the structural system	3	Waste compaction/baling press	1	Reducing the impacts of construction on ecology	2	NOx emissions from heat sources	1
Energy Efficient Equipment Procurement	2			Indoor and outdoor lighting levels	1	Maximum parking capacity	1	Irrigation Systems	1	Obtaining materials from responsible sources	1	Composite	1	Reducing the long-term impacts of development on biodiversity	2	Reducing water bed pollution	1
Free Ventilation	1			Field of View	1	Transportation information point	1	On-site Water treatment	1	Insulation	2	Floor coverings	2	**Innovation**		Flood risk	1
				Natural ventilation facilities	1	Deployment and maneuvering	1			Hard Landscaping and Perimeter Walls	1,5			Innovation	10	Reducing light pollution at night	1
				Indoor air quality	1											Noise reduction	1
				Thermal Comfort	1												

B.E.S.T.

Integrated Green Project Mgmt.	Pt	Land Use	Pt	Water Use	Pt	Energy Use	Pt	Health and Comfort	Pt	Material and Resource Utilization	Pt	Life in Housing	Pt	Operation and Maintenance	Pt	Innovation	Pt
Integrated Design	Prereq. (1-2)	Land settlement	1-3	Reducing water use	Prereq. (1-6)	Commissioning	Prereq. (0)	Thermal comfort	3	Use of environmentally friendly materials	3	Universal and inclusive design	1-2	On-site waste separation and user access	2	Innovation	1
Environmentally Responsible Contractor	2	Disaster risk	3	Preventing water losses	2	Energy efficiency	Prereq. (1-15)	Visual comfort	3	Utilization of existing building elements	1-3	Security	1-2	Waste technologies	1	Approved Counselor	1
Construction waste reduction and waste management	3	Density and housing structure	2	Wastewater treatment and utilization	1-2	Use of renewable energy	1-7	Fresh air	3	Material reuse	1-3	Sports and recreation areas	2	Building operation and maintenance manual	1		
Noise Pollution	2	Land reuse	3	Surface water flow	2	Outdoor lighting	1	Control of Pollutants	2	Use of local materials	1-3	Art	1	Monitoring of consumption values	2		
		Proximity to urban facilities	1-2			Energy efficient white goods	1	Auditory Comfort	2	Durable material	1-2	Transportation	3				
						Elevators	2					Parking lot	2				
												Working from home	2				

Transportation | Land and Territory Use | Energy | Water | Waste and Pollution | Cost | Materials and Resources | Process | Indoor | Innovation | Biodiversity | Functional

It is known that biodiversity in Turkey, which has seven different climate zones, is quite high. Despite this, it has been observed that biodiversity is ignored in two different certificates. In the context of both global climate change and the limitation of natural resources, it is extremely important for both certificates to develop evaluation criteria for green areas and biodiversity. Another deficiency in the certificates is the need to consider the cost criterion. It is very important to encourage quality at every stage from design to construction and use of buildings to make cost-effective decisions. In addition to these deficiencies, it is noteworthy that the YeS-TR certificate does not include transportation, land and regional use and functional criteria. Turkey has a topography with hilly, mountainous areas and these physical conditions constitute the most important design inputs affecting green building design. For this reason, land and land use and transportation criteria should be established in more detail and awareness on this issue should be raised by determining new criteria.

Although different criteria are prioritized in these two certificates prepared for Turkey and two different certificates are created, neither of them is widely used. The biggest reason for this is that the criteria in widely used certificates such as LEED and BREEAM are tried to be applied directly without making them suitable for Turkey. When trying to create a certificate for Turkey, natural and human conditions such as the country's climatic conditions, topography, cultural living conditions, economic situation, biodiversity, and its location in an earthquake zone should be evaluated and a green building certification system should be created accordingly. For example, Turkey is located in an earthquake zone and resilience in design should be an important criterion for certificates, but when BEST and YeS-TR are examined, it is seen that there is no upper criterion and sub-criteria in this context, and the disaster is evaluated very superficially. In addition, there are five different climate zones in Turkey and each climate zone needs different design parameters for design, but it is seen that there are no criteria for this in the certificates used. In addition to this, it is thought that BEST and YeS-TR certificates are not well known and considering the economic conditions, institutions and organizations should play an active role in this process for information and cost support.

3. CONCLUSION AND RECOMMENDATIONS

The global warming effects caused by the building sector, carbon dioxide emissions, increase in fossil fuel use and environmental pollution have increased the interest in environmentally friendly and green building concepts. Green buildings are a design concept that is a reaction to the negative conditions triggered by human activity and practices that threaten human health. Green building is a concept that is handled in a comprehensive process from the decisions in the planning stage of the design to the environmental effects in the life cycle process. In this process, sensitive and sustainable targets are carried out that propose renewable energy sources, emphasize waste utilization, offer efficient and productive energy use, have a design specific to its location and have minimal impact on the environment. Green Build Certifications has been designed to define, evaluate, rate these designed buildings according to certain standards. Internationally recognized certification systems have evaluation criteria that are sensitive to human health and the environment, and emphasize ecological design.

Certification systems have been developed in Turkey by determining criteria that attach importance to environmentally friendly and ecological design, just like other international certification systems. Firstly established by ÇEDBİK, BEST was designed by taking other international certification systems as an example. The other system developed in Turkey is the YeS-TR system, which was started in 2014. This system, unlike other international certification systems, has developed criteria and criteria according to various building types by taking into consideration the local conditions of our country.

This study compares and analyses the internationally developed certification systems with the national BEST and YeS-TR certification systems. In the analysis made by examining the main headings and subheadings of these certification systems, 12 criteria were determined as transportation, land and regional use, energy, water, waste and pollution, cost, materials and resources, process, interior, innovation, biodiversity and functionality. Within the scope of the study, 6 certification systems were evaluated according to 12 criteria. According to the evaluations made, it was seen that CASBEE certificate should develop criteria for transport, cost, process and biodiversity issues. In the LEED certification system, it was revealed that it could not score points on waste and pollution, cost, biodiversity and functional criteria and lagged behind in these issues. In the BREEAM certification system, since there is no evaluation criterion for functional design, the event could not receive points from this criterion. The DGNB certification system was found to need to develop criteria for waste and pollution management. In the YeS-TR certification system, improvements should be made on transport, land regional use, cost, biodiversity and functional criteria. It was also observed that the BEST certification system should take into account the criteria of cost and biodiversity.

As a result, it is very important that the certification systems developed in Turkey are intended to develop criteria according to the purpose of establishment and local characteristics. However, these systems are lagging behind in terms of planning according to the criteria set. In particular, it is seen that studies should be carried out on five criteria in the YeS-TR system and 2 criteria in the BEST system, which are not addressed at all in the criteria. It is also recommended that the YeS-TR and BEST certificates should be more open and easier to access their data. It is essential that the information about the buildings rated in these certification systems is accessible by the researchers. It is also expected that the two certification systems developed in Turkey can be translated into other languages and the use of the system, which started nationally, can be adapted to the climate and region in the international arena. It is very significant that these systems should be developed and evaluated according to various types of buildings, both existing and new, and that buildings in our country should be evaluated according to these national systems. In addition, the concept of green building needs to be incentivized, and awareness raised on a global scale.

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