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RESEARCH ARTICLE

Investigation of Social Cost of Carbon in the context of environmental sustainability in the housing sector

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Abstract

This research underscores the significance of energy-efficient measures, particularly in the context of an island-based housing project in Antalya, with a focus on diverse glass combinations. Employing Integrated Assessment Models, the study pioneers an examination of the economic dimensions linked to carbon emissions from residential buildings, addressing a critical gap in existing literature. The rapid population growth in the world causes the opening of new settlement areas and the increase in energy use. Since most of the energy needed is met from fossil fuels, the amount of global emissions is increasing day by day. Energy efficient studies are carried out in order to reduce this increase and to eliminate the environmental damages it will cause. In this study, Design Building Models were created by applying 9 scenarios created using three different insulating glass series, four different glass combinations and two different inter-glass filling gases to an island-based housing project in Antalya. The amount of electrical energy consumed annually in the design building models was obtained by performing hourly analyses with the DesignBuilder simulation program. In case the power plant that produces this amount of energy consumed uses seven different energy sources the amount of CO2-eq. emissions it will produce and the costs in 2030, 2040, and 2050 for the elimination of global environmental damages it causes are obtained by using the net present value method with 2.5%, 3%, and 5% discount rates. In our country, there are not many studies analyzing the economic dimension of the environmental damages caused by the emissions of residential buildings. The most distinctive feature that distinguishes this study from other studies is the examination of the energy savings of different glass combinations in an island-based housing project and the analysis of the economic dimension of the environmental impacts of the emission amounts with the help of Integrated Assessment Models. This study aims to contribute to the development of strategies to reduce environmental impacts and to make more informed decisions by governments in the selection of energy resources by determining electricity consumption, carbon emissions, and carbon social cost in a housing model designed with a focus on energy efficiency.

1. Introduction

Today, one out of every two people lives in an urban area. This rate is estimated to be 75% by 2050 [1, 2]. The increase in settlements leads to an increase in energy demand. Approximately 40% of the energy consumed in the world, 32% of the resources and 25% of CO₂ emissions originate from the construction sector [3]. Due to the threat of global climate change, measures have been developed within the framework of international conventions and protocols. The Paris Climate Agreement aims to keep global warming below 2°C compared to the pre-industrial revolution and at 1.5°C levels as much as possible until the end of this century [4]. With the Paris Climate Agreement, to which Turkey became a party in 2015, Turkey declared that it will reduce greenhouse gas emissions by 21 percent by 2030 compared to the business-as-usual scenario by constructing new residential and service buildings in an energy efficient manner [5].

According to the report published by the Organization for Economic Co-operation and Development (OECD) in 2015, if preventive climate policies and carbon economy are not implemented, it is predicted that it will bring economic damage costs in the range of 1%-3.3% of the country's gross domestic product (GDP) by 2060 and 2%-10% by 2100 [6]. In the event that the global temperature targets set out in the Paris Agreement are not achieved, it is estimated that the adaptation financing needs for developing economies will face costs ranging from \$520 billion to \$1.75 trillion annually after 2050 [7]. According to the 2020 data of the Global Adaptation Commission in the world, it is estimated that global emissions have reached 38 billion tonnes CO₂-eq and that 180 billion dollars are needed between 2020 and 2030 to cover the global climate change damages caused by emissions. Turkey, with 31 million tonnes of CO₂-eq emission production, is responsible for approximately 2 billion dollars of the global adaptation financing need [8].

Emission mitigation policies have an important position within the scope of combating climate change. For this reason, there are many different models on emission reduction policies and carbon economy. One of these models, Integrated Assessment Models (IAM), is to prepare the ground for appropriate policy choices by predicting possible economic costs in climate change [9]. In this context, one of the Integrated Assessment become which has Models. increasingly widespread in recent studies, is the Social Cost of Carbon (SCC). SCC is a measure designed to measure climate damages and convert them into monetary values, showing the net economic cost of carbon dioxide emissions [10].

1.1. Research background

Integrated Assessment Models (IAM) are multidisciplinary models used to analyses complex issues such as climate change. These models combine energy, economics, environment, social factors and climate science to assess the long-term impacts of specific policy options or human activities. IAMs are used to understand the impacts of economic activities on climate and the socioeconomic consequences of climate change. They are comprehensive tools used to analyses the causes and impacts of climate change and possible response options. These models are used to study complex interactions between consumption, carbon emissions, economic growth, technological developments, population dynamics and other factors related to climate change. IAMs have a significant impact on the design and implementation of climate policies. They are especially used in the policy-making process in combating climate change [11-14].

In the literature, there are many Integrated Assessment Models such as Finite Amplitude Impulse Response (FAIR), Model for the Assessment of Greenhouse gas Induced Climate Change (MAGICC), MIT Earth System Model (MESM), University of Victoria Earth System Climate Model (UVic ESCM) to be used in SCC calculation [15-18]. Among these models, the Dynamic Integrated Climate and Economy Model (DICE). Framework the for Uncertainty. Negotiation and Distribution (FUND) and the Policy Analysis of the Greenhouse Effect (PAGE), Integrated Model to Assess the Global Environment (IMAGE), Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), Global Change Assessment Model (GCAM) models are widely used in the field of climate economics and policy analysis [15-20].

The DICE is an integrated assessment model used in the field of environmental economics and climate change policy analysis. The DICE model aims to integrate economic and climate systems by considering how economic activities affect greenhouse gas emissions and thus climate change. The DICE model incorporates economic variables consumption, investment, as accumulation, population growth, technological progress and productivity; climate system factors including CO₂ emissions, temperature changes, greenhouse effect and their impacts on the environment and society; policy scenarios addressing climate change such as carbon taxes, emission reduction technological targets. innovation incentives and international agreements such as the Paris Agreement; cost-benefit analysis of different climate policies by estimating the relationship between the change of economic activities and climate change, the costs of policy implementation against the benefits in terms of reduced climate damages [8, 15, 21, 22].

The FUND is designed to analyses the interactions between the economy and the climate system while taking into account uncertainties in various factors affecting climate change. The FUND model incorporates climate impacts such as changes in temperature, sea level rise, agricultural productivity. resources. health water ecosystems; the costs of consumption, investment, technological progress, adaptation measures and implementation of climate policies; the acceptance of uncertainties in the estimation of economic and damages in climate change policies, different climate policies and strategies such as mitigation efforts and adaptation; regional analysis of climate impacts [9, 22-25].

The PAGE is designed to assess the economic impacts of climate change and to evaluate the costs and benefits of different policy responses to reduce

greenhouse gas emissions. The PAGE model includes climate impact assessment such as changes in temperature, sea level rise, extreme weather events, impacts on agriculture, health, ecosystems and infrastructure; economic variables, discount rates, technological progress and assumptions on future economic development, costs of mitigation efforts and adaptation measures; uncertainties in economic parameters and valuation of damages, the effects of uncertain factors on policy outcomes, emission reduction targets; carbon pricing mechanisms and adaptation strategies; regional impacts of climate change and policies, how different regions may be affected differently, and costs and benefits [22, 26].

When the models are examined in detail, we can state that they are tools used to understand the social cost of carbon and to predict future climate change scenarios, and each model has its own characteristics and different aspects. We can say that the common features of the models are designed to analyse the interactions between climate change and economic activity, the effects of climate change on the economy, and the effects of the economy on climate change in order to make predictions for future years. In addition, the models make analyses using different emission levels, policy options and climate change scenarios. The different features of the models are that they perform analyses using different modelling techniques, different climate and economic parameters such as economic growth rates, energy demand, carbon emissions, climate sensitivity.

SCC estimates provide guidance in guiding the climate change policies to be taken by governments as a result of carbon becoming an economic data by pricing [27]. It is a parameter used by countries that do not have a comprehensive policy covering all greenhouse gases to determine laws and regulations. Using the SCC, governments can calculate the social costs and benefits of policies that include regulations affecting energy or climate. For example, the US government uses SCC estimates in determining the amount of subsidies for the installation of low-carbon energy sources, establishing discount rates on building insulation materials, and regulating energy efficiency standards in buildings and motor vehicles [28].

1.2. Literature review

There are many studies on the SCC calculated using different theoretical assessment models in different climate zones [29-37]. Heyes et al. [29] argue that there are parameters that are not taken into account in the SCC calculations by the Canadian government and suggest different methods by stating that various factors should be taken into account. Nordhaus [30] developed alternatives to the DICE-2013R Model by comparing the Policy Analysis of the Greenhouse Effect (PAGE), Framework for Uncertainty, Negotiation and Distribution (FUND), Reach, Impact, Confidence, and Effort (RICE), Dynamic Integrated model of Climate and Economy (DICE) Models used in Social Cost of Carbon calculations. Also; Nordhaus [31] presented Social Cost of Carbon estimates for the USA using the revised DICE model DICE-2016R. Thompson [32] compared 10 global Carbon Social Cost calculation models, such as DICE, PAGE, FUND, Finite Amplitude Impulse Response (FAIR), Model for the Assessment of Greenhouse gas Induced Climate Change (MAGICC), MIT Earth System Model (MESM) and University of Victoria Earth System Climate Model (UVic ESCM), to investigate to what extent they met the criteria recommended by the National Academy of Sciences, Engineering and Medicine Committee. Dayaratna et al. [33] analysed the FUND model used in Social Cost of Carbon calculations. It was shown that Monte Carlo analyses in the Social Cost of Carbon calculations do not reflect the findings of the literature sufficiently, and the effect of the determination of the discount rate in agricultural productivity parameters on the Social Cost of Carbon calculation was shown. Withagen [34] presents alternative methods by stating that the assumption of a balanced growth of the economy in the theoretical models based on the Social Cost of Carbon calculations, the assumptions regarding the marginal damages of high temperature or increased atmospheric phenomena in some cases, and the inaccuracy of the calculations made on the basis of the GDP of that year based on one year. Bijgaart et al. [27] obtained an equation for estimating the Social Cost of Carbon using different parameter sets and different analysis methods for the Integrated Assessment Model. Sohn [35] calculated Korea's long-term carbon dioxide social discount rate and social cost of carbon dioxide using various functions and analyses. Sarkar et al. [36] estimated the Social Cost of Carbon for Malaysia for 2030 and 2050 using various scenarios. They presented the optimum scenario for Malaysia to reach its targeted emission amount in 2050. Tol [37] in his Social Cost of Carbon calculation for 30 countries, revealed that India, China, Ethiopia, Bangladesh, Pakistan and Indonesia have the highest Social Cost of Carbon, followed by the European Union and the United States of America. Wang et al. [38] analyzed the impact of socioeconomic factors and climate on the social cost of carbon. A social cost of carbon forecasting model was constructed, and the social cost of carbon was calculated for the provinces of China from 2022 to 2100 under different carbon emission scenarios.

When the literature is examined, it is seen that the Social Cost of Carbon is generally based on calculation methods or economic theorems. In the literature, there are not many studies on the Social Carbon Cost calculated on the energy consumption values of buildings. In this study, the amount of energy consumed by using different glass combinations on transparent surfaces in a selected an island-based housing project in Antalya, located in the Mediterranean Climate Zone, and the CO2eq. amounts of the emissions that will occur in the production of these consumed energy amounts in power plants are calculated. Social Cost of Carbon estimates are presented for the years 2030, 2040 and 2050 according to the type of fuel used to eliminate global environmental damages caused by CO2-eq. emissions.

The study draws attention to the energy and carbon social cost savings resulting from the use of energy efficient glasses. Also, to encourage governments to offer various financial supports such as tax exemptions, tax deductions, favourable loan support, subsidies in proportion to the carbon

social cost values in case of using energy efficient glasses in buildings. In addition, the study intends to spotlight the SCC generated by the amount of emissions produced by power plants using different fuel types and to create an impact that will accelerate the orientation of governments towards renewable energy sources.

1.3. Research objective

This study aims to guide governments in determining policies such as carbon taxes, emission trading and green energy incentives by providing concrete evidence on the need to promote environmentally friendly policies and energy efficiency by drawing attention to carbon emissions, environmental and social costs. In order to achieve sustainable development goals, it is aimed to contribute to the formulation of strategies such as energy efficient construction of houses, renovation of existing buildings, use of energy sources with less carbon emissions, and adoption of environmentally friendly technologies.

2. Methodology

In the study, four basic steps were followed one after the other (Fig. 1). Firstly, the electrical energy

consumption of the design buildings created with the use of different glass combinations was determined (Determining Energy Consumption). Then, the CO₂ equivalent emission amounts arising from the energy consumption of the Design Buildings were calculated and the global environmental damages of these emissions associated with the use of different energy sources in power plants were determined (Assessment of Environmental Impacts). Then, the dimensions of the cost to society of carbon emissions associated with the use of different energy sources in power plants were calculated for the years 2030, 2040 and 2050 using the Dynamic Integrated model of Climate and Economy (DICE), Framework for Uncertainty, Negotiation and Distribution (FUND) and Policy Analysis of the Greenhouse Effect (PAGE) Integrated Assessment Models (Social Cost of Carbon (SCC) Calculation). Finally, it is concluded that the data and results obtained will provide basic information for developing more sustainable strategies in energy efficiency-oriented housing design and selection of energy sources, and guide decision-makers to promote environmentally friendly practices and more efficient energy use (Providing Baseline Information for Future Strategies).

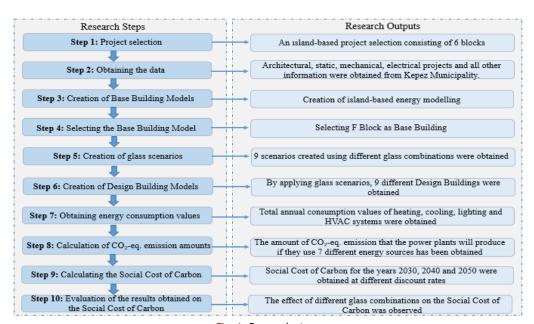


Fig. 1. Research steps

In the study, Design Building Models were created by applying 9 scenarios separately to an island-based housing project in Antalya, which is located in Antalya, which is located in the Mediterranean Climate Zone and classified in the 1st Degree Day Zone according to the Turkish Thermal Insulation Standard-TS 825, with a hothumid climate, using three different insulating glass series (C, K, K3+), four different glass combinations (4mm+12+4mm, 4mm+16+4mm, 4mm+16+4mm) and two different inter-glass filling gases (air, argon) on transparent surfaces.

The amount of electrical energy consumed annually in the design building models was obtained. Since the heating needs of the buildings in the Mediterranean Climate Region are widely met with electrical energy, scenarios in which electrical energy is used in both heating and cooling are produced and analyzed within the scope of the study. The analyses were calculated using the meteorological database, which is a dynamic thermal simulation programme, and DesignBuilder and EnergyPlus dynamic simulation tools with 3D modelling capability.

In case the power plant producing this amount of energy consumed uses seven different energy sources (lignite, hard coal, asphaltite, imported coal, natural gas, fuel oil, diesel oil), the amount of CO₂-eq. emission to be produced is calculated separately. In order to eliminate the social, economic and global environmental damages

caused by these emissions, the present economic values of the costs in 2030, 2040 and 2050 were obtained by using the net present value method with discount rates of 2.5%, 3% and 5%.

2.1. Analysis of the study area

The study area was selected as an island-based housing project consisting of 6 blocks, 317 dependent units, with a total construction area of 37.647 m² (Fig. 2). Considering factors such as the facade area and transparent surface ratio of the buildings in the settlement, Block F was preferred as the "Base Building". Block F has 9 floors, 51 independent sections and a total net usage area of 5201 m².

C class, PVC framed, double glazing with 4mm+12+4mm combination is used in the Block F. The optical design parameters of Block F are presented in Table 1. Block F has an east-west orientation. In Block F, the roof slab (ceiling-open) with an area of 596 m² is designed as a terrace (Fig. 3). The 3D image and photograph of the study area are presented in Figure 4 and Figure 5.

2.2. Analysis of base building model

In the study, the heating and cooling load calculations for Antalya province, where the Base Building is located, are based on the measured climate data for Antalya province according to the ASHRAE 90.1-2010 standard recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

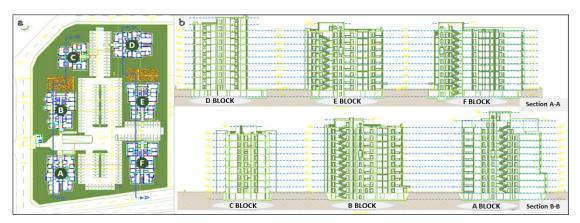


Fig. 2. Island-based housing project (a) layout plan, (b) sections

Table 1. Optical design parameters of base buildings

Parameters		
	South Facade	193,80
	North Facade	24,05
Window Area (m²)	East Facade	402,10
	West Facade	402,10
	Total	1022,05
Transparency Ratio (T	ransparent/Opaque surface area)	0,39
A/V Ratio (Total exter	rnal surface area/Building volume)	0,16



Fig. 3. Block B and its appearance (a) south front, (b) western front, (c) eastern front, (d) north front, (e) regular floor plan



Fig. 4. 3D image of the block-based compound study area (a) Block F south facade south facade, (b) Block F south facade east facade



Fig. 5. Photograph of the block-based compound study area (a) Block F south facade, (b) Block F south facade east facade

Heating and cooling in Block F is done by split air conditioner (7100W, EER: 3.00). The indoor air temperature comfort value is taken as 22°C for the heating period and 25°C for the cooling period. Natural ventilation is designed by taking the air change per hour (ACH) 0.5 (1/h) in the building. The number of people using the building is taken as 20 m²/person and working hours/days are taken as continuous, 7/24. The energy efficiency index of the building is C type building (normal energy efficient building) category.

Considering criteria such as the location, orientation and number of storeys of the buildings in the study area, a block-based composite

representing the energy consumption behavior of the buildings was modelled (Fig. 6). The energy modelling was performed for Block F, which was selected as the base building and shown in Figure 7 and Figure 8.

2.3. Glass combinations used in building envelope

In Block F, 9 Scenarios(S) were created using three different insulating glass series (C, K, K3+), four different glass combinations (4mm+12+4mm, 4mm+16+4mm, 4mm+12+4mm+12+4mm, 4mm+16+4mm+16+4mm) and two different interglass filling gases (air, argon).

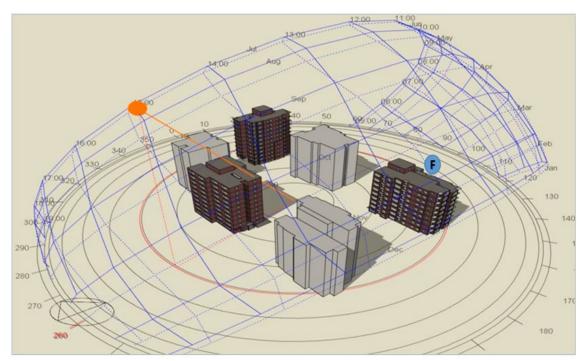


Fig. 6. Model image of the block-based compound

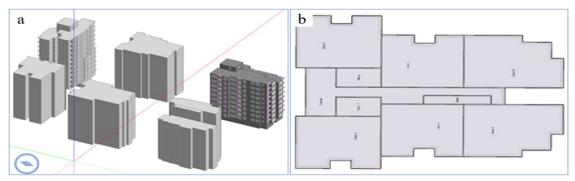


Fig. 7. Block F model image (a) layout plan, (b) floor plan

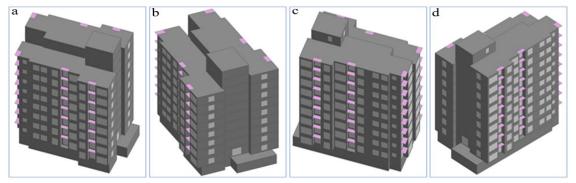


Fig. 8. Block F model image (a) south facade, (b) west facade, (c) north facade, (d) east facade

The properties of the scenarios and glass combinations are presented in Table 2. Design building energy models were created by applying the glazing combination scenarios separately to the Block F base building model. The energy performances of the design buildings were obtained with DesignBuilder, a dynamic thermal simulation programme. EnergyPlus, an integrated simulation programme, was used as the simulation engine of DesignBuilder.

2.4. Social Cost of Carbon (SCC)

The Social Cost of Carbon is defined as the cost of economic damage caused by each tonne of CO₂ emissions added to the atmosphere [16, 17, 39, 40]. The economic damage cost of a unit emission increase expresses the present value of possible economic damage today and in the future. Estimates of the SCC are basically produced by utilising the target country's economy, the amount of emissions to the atmosphere and global warming parameters [27, 41].

There are many different models for calculating the social cost of carbon. Due to the different models used, different analyses made, different data sets taken as basis, the predicted values of the Social Cost of Carbon are different. In this study, the Social Cost of Carbon was calculated based on the data obtained as a result of the combination of Dynamic Integrated Climate and Economy Model (DICE), Framework for Uncertainty, Negotiation and Distribution (FUND) and Policy Analysis of Greenhouse Effect (PAGE) Integrated Assessment Models. In addition to DICE, FUND, PAGE, the use of models such as FAIR, MAGICC, MESM, UVic, IMAGE, MESSAGE, GCAM in the literature will yield different Social Cost of Carbon results despite the same energy consumption in buildings. While some models (DICE, FUND, PAGE) focus only on the fundamental relationships between climate and economy, some models (IMAGE, MESSAGE, GCAM) address social, political and environmental factors as well as the fundamental relationships between climate and economy.

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	Series		Daylight (EN 410)			Power 410)	Heat Permeability Coefficient (U) (EN 673)		
Scenarios	Glass	Window combinations	Permeability %	Projection %	Total Permeability %	Shading Coefficient	Air	Argon	
S-1	С	4mm+12+4mm	80	14	75	0,86	2,9	X	
S-2	K	4mm+12+4mm	71	10	44	0,51	1,6	X	
S-3	K	4mm+12+4mm	71	10	44	0,51	X	1,3	
S-4	K	4mm+16+4mm	71	10	44	0,51	1,3	X	
S-5	K	4mm+16+4mm	71	10	44	0,51	X	1,1	
S-6	K3+	4mm+12+4mm+12+4mm	63	12	39	0,44	0,9	X	
S-7	K3+	4mm+12+4mm+12+4mm	63	12	39	0,44	X	0,7	
S-8	K3+	4mm+16+4mm+16+4mm	63	12	39	0,44	0,7	X	
S-9	K3+	4mm+16+4mm+16+4mm	63	12	39	0,44	X	0,6	

The differences between the models arise from the methods used, the choice of parameters and what is intended. These differences determine the specific aspects and limitations of the models. Each model provides forecasts using various scenarios to serve a specific purpose. This situation constitutes the biggest limitation of the study.

In this study; data obtained by combining the Dynamic Integrated model of Climate and Economy (DICE), Framework for Uncertainty, Negotiation and Distribution (FUND) and Policy Analysis of the Greenhouse Effect (PAGE) Integrated Assessment Models published in Technical Support Document 2016 were used. In the combined model; social cost values calculated by using the net present value method for the past base year (2017) and the targeted years (2030, 2040, 2050) using discount rates of 2.5%, 3% and 5% were used (Table 3). All carbon social cost values produced are estimated based on the \$ price of 2017. The study applied all economic and geo-

physical processes at global level based on 2017 data.

DICE, which is used in the calculation of cost values, is a calculation model using a global damage function that does not differentiate the impact of heat on the global economy according to specific sectors. PAGE is a calculation model based on economic, non-economic and catastrophic damages. FUND is an accounting model that considers a range of specific market and non-market sectors, including agriculture, forestry, water, energy use, sea level rise, ecosystems, human health and extreme weather [17].

Using the 2017 economic and 2020 emission parameters, the social costs of carbon for the years 2030, 2040 and 2050 were predicted for Turkey. The total amount of greenhouse gas emissions in terms of CO₂-eq. of the emissions that will occur in electricity generation according to the fuels for the power plants of the energy consumed in Turkey is presented in Table 4.

Table 3. Discount rate, social cost values(\$) of emissions depending on the projected years [10, 17]

Years	2030			2040		2050			
Discount Rate (%)	5%	3%	2,5%	5%	3%	2,5%	5%	3%	2,5%
Social cost values (\$/tonne)	19	60	88	25	72	101	31	83	114

Table 4. Fuels used in power plants generating electricity in Turkey and the amount of emissions to the atmosphere
caused by fuels [42, 43]

Fuel type	Lignite	Hard Coal	Asphaltite	Imported Coal	Natural Gas	Fuel Oil	Diesel Oil
Usage Rate (%)	38,07	1,25	0,65	21,23	38,52	0,28	0,00
Emission Amount (kgCO ₂ -eq/kWh)	1,279	1,100	1,177	0,872	0,376	0,644	0,645

When Table 4 is observed; 38.07% of the electrical energy produced in thermal power plants in Turkey is obtained from power plants using lignite and 38.52% is obtained from power plants using natural gas. Although the use of lignite and natural gas in power plants is approximately the same amount, it is seen that the amount of emission that will occur as a result of the use of lignite is approximately 240% more than the amount of emission that will occur as a result of the use of natural gas.

3. Findings and Discussion

In the study, Design Buildings were created by applying 9 scenarios to the Basic Building using three different insulating glass series (C, K, K3+), four different glass combinations (4mm+12+4mm, 4mm+16+4mm, 4mm+12+4mm+12+4mm, 4mm+

16+4mm+16+4mm) and two different inter-glass filling gases (air, argon). The amounts of electrical energy consumed for heating, cooling, lighting, electrical equipment, common area equipment, fans/HVAC, pumps and domestic water in the design buildings were calculated. In case of using seven different energy sources (lignite, hard coal, asphaltite, imported coal, natural gas, fuel oil, diesel oil), the amount of CO₂-eq. emission to be produced by the power plant producing the energy consumed in the design buildings was calculated and presented in Table 5.

When Table 5 is analyzed; it is determined that the total energy consumption of the buildings decreases as the distance between the glasses increases, the gap distance between the glasses increases and argon is preferred as the filling material between the glasses as C insulating glass series is changed to K3+ insulating glass series.

Table 5. The amount of CO₂-eq. emissions that the glass combinations used will produce in the power plant according to different energy source (tonnes/year)

s		Energy Requirements (kWh)	Emissions(tonne/year)									
Scenarios	Design Buildings		Lignite	Hard Coal	Asphaltite	Imported Coal	Natural Gas	Fuel Oil	Diesel Oil			
S-1	Design Building-1	301847,1	386,1	332,0	355,3	263,2	113,5	194,4	194,7			
S-2	Design Building-2	259881,1	332,4	285,9	305,9	226,6	97,7	167,4	167,6			
S-3	Design Building-3	258226,1	330,3	284,0	303,9	225,2	97,1	166,3	166,6			
S-4	Design Building-4	257288,3	329,1	283,0	302,8	224,4	96,7	165,7	166,0			
S-5	Design Building-5	256385,4	327,9	282,0	301,8	223,6	96,4	165,1	165,4			
S-6	Design Building-6	251916,2	322,2	277,1	296,5	219,7	94,7	162,2	162,5			
S-7	Design Building-7	250134,3	319,9	275,1	294,4	218,1	94,1	161,1	161,3			
S-8	Design Building-8	249716,6	319,4	274,7	293,9	217,8	93,9	160,8	161,1			
S-9	Design Building-9	249310,7	318,9	274,2	293,4	217,4	93,7	160,6	160,8			

Among the Design Buildings for which energy analyses were performed, the building with the highest energy efficiency was found to be Design Building-9 with "K3+/4mm+16+4mm+16+ 4mm +16+4mm-Argon" glass combination. The building with the lowest energy efficiency among the design buildings is Design Building-1 with "C/4mm+12+4mm-Air" glass combination. It was determined that Design Building-1 consumes approximately 21% more energy than Design Building-9.

When Table 5 is analyzed, it is calculated that the minimum amount of CO₂-eq. emission occurs in the power plants using natural gas and the maximum amount of CO2-eq. emission occurs in the power plants using lignite when the amount of CO₂-eq.emission that occurs when the energy required in the design buildings is produced in power plants using different energy sources is compared. It has been determined that the use of lignite during electricity generation in power plants emits CO₂-eq. emissions to the atmosphere at a rate of approximately 240% higher than the use of natural gas. Although the fuels used in power plants vary, the maximum emission amount occurs in the "C/4mm+12+4mm-Air" glass combination used in Scenario-1 (S-1), while the minimum emission amount occurs in the "K3+/4mm+16+4mm+ 16+4mm+16+4mm-Argon" glass combination used in Scenario-9 (S-9).

In order to eliminate the global environmental damages caused by the CO₂-eq. emission amounts produced according to different energy sources in power plants, the present economic values of the costs in 2030, 2040 and 2050 were obtained by using the net present value method with discount rates of 2.5%, 3% and 5% (Table 6).

When Table 6 is examined; the highest SCC is 114\$/t in power plants using lignite for the year 2050 and at a discount rate of 2.5%, in the design building with C insulating glass class/4mm+12+4mm-Air combination; the lowest is 19\$/t in power plants using natural gas for the year 2030 and at a discount rate of 5%, in the design building with K3+ insulating glass class/4mm+16+4mm+16+4mm-Argon combination. Social Cost of

Carbon; it has been observed that it increases as the discount rates increase from 2030 to 2050. When the emission amounts produced by the fuels used in power plants are compared, it is seen that the power plant that produces minimum emissions is the power plant using natural gas, followed by the power plants using fuel oil, diesel oil, imported coal, hard coal, asphaltite and lignite. Accordingly, it has been determined that the Social Cost of Carbon is the lowest in power plants using natural gas and the highest in power plants using lignite. There is a 21% carbon social cost difference between Design Building-9, which has the highest energy efficiency with "K3+/4mm+16+4mm+ 16+4mm-Argon" glass combination, and Design Building-1, which has the lowest energy efficiency with "C/4mm+12+4mm-Air" glass combination.

It has been concluded that the use of a coated glass system with a combination of "K3+/4mm+16+4mm+16+4mm" and using argon gas as the filling material between the glasses will be more appropriate in terms of sustainability and energy efficiency in buildings located in the Mediterranean Climate Zone.

Although lignite and natural gas are used at about the same rate (38%) in thermal power plants in Turkey, the amount of carbon emissions to be produced by the plants using lignite is about 240% higher than the amount of carbon emissions to be produced by the plants using natural gas. In parallel with this situation, power plants using lignite have approximately 240% more SCC. For a sustainable environment, it is thought that it would be appropriate to use natural gas as the energy source of thermal power plants as a priority, and then systematically replace thermal power plants with renewable energy sources. When the calculation results are evaluated, it is seen that in the most optimistic estimation (2030, 5% discount rate, C/4mm+12+4mm-Air combination (widely used in residences), lignite-natural gas) in order to eliminate the damage to the environment as a result of the annual energy consumption of only one residence in Antalya, an average of approximately \$4,746/year SCC is incurred.

Table 6. Social emission cost values for different fuels and discount rates (\$)

0			2030			2040			2050			
Fuel Scenario	Design Buildings	Window Combinations	Discount	Rate		Discount	Discount Rate			Discount Rate		
Fuel Scen			5%	3%	2,5%	5%	3%	2,5%	5%	3%	2,5%	
S-1	Design Building-1	C/4mm+12+4mm-Air	7335,2	23163,7	33973,5	9651,6	27796,5	38992,3	11967,9	32043,2	44011,1	
S-2	Design Building-2	K/4mm+12+4mm-Air	6315,4	19943,3	29250,1	8309,7	23931,9	33571,2	10304,0	27588,2	37892,2	
S-3	Design Building-3	K/4mm+12+4mm-Argon	6275,2	19816,3	29063,9	8256,8	23779,5	33357,4	10238,4	27412,5	37650,9	
S-4	Design Building-4	K/4mm+16+4mm-Air	6252,4	19744,3	28958,3	8226,8	23693,2	33236,2	10201,2	27313,0	37514,2	
S-5	Design Building-5	K/4mm+16+4mm-Argon	6230,4	19675,0	28856,7	8197,9	23610,0	33119,6	10165,4	27217,1	37382,5	
Lignite 9-S	Design Building-6	K3+/4mm+12+4mm+12 +4mm-Air	6121,8	19332,0	28353,7	8055,0	23198,5	32542,3	9988,2	26742,7	36730,9	
_ S-7	Design Building-7	K3+/4mm+12+4mm+12 +4mm-Argon	6078,5	19195,3	28153,1	7998,0	23034,4	32312,1	9917,6	26553,5	36471,1	
S-8	Design Building-8	K3+/4mm+16+4mm+16 +4mm-Air	6068,4	19163,3	28106,1	7984,7	22995,9	32258,1	9901,0	26509,2	36410,2	
S-9	Design Building-9	K3+/4mm+16+4mm+16 +4mm-Argon	6058,5	19132,1	28060,4	7971,7	22958,5	32205,7	9884,9	26466,1	36351,0	
S-1	Design Building-1	C/4mm+12+4mm-Air	6308,6	19921,9	29218,8	8300,8	23906,3	33535,2	10293,0	27558,6	37851,6	
S-2	Design Building-2	K/4mm+12+4mm-Air	5431,5	17152,2	25156,5	7146,7	20582,6	28872,8	8861,9	23727,1	32589,1	
S-3	Design Building-3	K/4mm+12+4mm-Argon	5396,9	17042,9	24996,3	7101,2	20451,5	28688,9	8805,5	23576,0	32381,6	
S-4	Design Building-4	K/4mm+16+4mm-Air	5377,3	16981,0	24905,5	7075,4	20377,2	28584,7	8773,5	23490,4	32264,0	
_ S-5	Design Building-5	K/4mm+16+4mm-Argon	5358,5	16921,4	24818,1	7050,6	20305,7	28484,4	8742,7	23408,0	32150,7	
Hard Coal	Design Building-6	K3+/4mm+12+4mm+12 +4mm-Air	5265,0	16626,5	24385,5	6927,7	19951,8	27987,9	8590,3	22999,9	31590,3	
Ë S-7	Design Building-7	K3+/4mm+12+4mm+12 +4mm-Argon	5227,8	16508,9	24213,0	6878,7	19810,6	27789,9	8529,6	22837,3	31366,8	
S-8	Design Building-8	K3+/4mm+16+4mm+16 +4mm-Air	5219,1	16481,3	24172,6	6867,2	19777,6	27743,5	8515,3	22799,1	31314,5	
S-9	Design Building-9	K3+/4mm+16+4mm+16 +4mm-Argon	5210,6	16454,5	24133,3	6856,0	19745,4	27698,4	8501,5	22762,1	31263,6	

Table 6. 0	Cont'd										
S-1	Design Building-1	C/4mm+12+4mm-Air	6750,2	21316,4	31264,1	8881,9	25579,7	35882,7	11013,5	29487,7	40501,2
S-2	Design Building-2	K/4mm+12+4mm-Air	5811,7	18352,8	26917,4	7647,0	22023,4	30893,9	9482,3	25388,0	34870,3
S-3	Design Building-3	K/4mm+12+4mm-Argon	5774,7	18235,9	26746,0	7598,3	21883,1	30697,1	9421,9	25226,4	34648,3
S-4	Design Building-4	K/4mm+16+4mm-Air	5753,7	18169,7	26648,9	7570,7	21803,6	30585,7	9387,7	25134,8	34522,4
့ S-5	Design Building-5	K/4mm+16+4mm-Argon	5733,5	18105,9	26555,4	7544,1	21727,1	30478,3	9354,7	25046,5	34401,3
Asphaltite	Design Building-6	K3+/4mm+12+4mm+12 +4mm-Air	5633,6	17790,3	26092,5	7412,6	21348,4	29947,0	9191,7	24609,9	33801,6
₹ S-7	Design Building-7	K3+/4mm+12+4mm+12 +4mm-Argon	5593,8	17664,5	25907,9	7360,2	21197,4	29735,2	9126,7	24435,9	33562,5
S-8	Design Building-8	K3+/4mm+16+4mm+16 +4mm-Air	5584,4	17635,0	25864,6	7347,9	21162,0	29685,6	9111,4	24395,1	33506,5
S-9	Design Building-9	K3+/4mm+16+4mm+16 +4mm-Argon	5575,3	17606,3	25822,6	7336,0	21127,6	29637,3	9096,6	24355,4	33452,0
S-1	Design Building-1	C/4mm+12+4mm-Air	5001,0	15792,6	23162,5	6580,3	18951,2	26584,3	8159,5	21846,5	30006,0
S-2	Design Building-2	K/4mm+12+4mm-Air	4305,7	13597,0	19942,2	5665,4	16316,4	22888,2	7025,1	18809,2	25834,3
S-3	Design Building-3	K/4mm+12+4mm-Argon	4278,3	13510,4	19815,2	5629,3	16212,5	22742,5	6980,4	18689,4	25669,7
S-4	Design Building-4	K/4mm+16+4mm-Air	4262,8	13461,3	19743,3	5608,9	16153,6	22659,9	6955,0	18621,5	25576,5
S-5	Design Building-5	K/4mm+16+4mm-Argon	4247,8	13414,1	19674,0	5589,2	16096,9	22580,4	6930,6	18556,1	25486,8
Imported Coal S-2 S-2	Design Building-6	K3+/4mm+12+4mm+12 +4mm-Air	4173,7	13180,3	19331,0	5491,8	15816,3	22186,8	6809,8	18232,7	25042,5
<u>ब</u> S-7	Design Building-7	K3+/4mm+12+4mm+12 +4mm-Argon	4144,2	13087,0	19194,3	5452,9	15704,4	22029,8	6761,6	18103,7	24865,4
S-8	Design Building-8	K3+/4mm+16+4mm+16 +4mm-Air	4137,3	13065,2	19162,3	5443,8	15678,2	21993,0	6750,3	18073,5	24823,8
S-9	Design Building-9	K3+/4mm+16+4mm+16 +4mm-Argon	4130,6	13043,9	19131,1	5435,0	15652,7	21957,3	6739,4	18044,1	24783,5

Table 6.	Cont'd										
S-1	Design Building-1	C/4mm+12+4mm-Air	2156,4	6809,7	9987,5	2837,4	8171,6	11462,9	3518,3	9420,0	12938,4
S-2	Design Building-2	K/4mm+12+4mm-Air	1856,6	5862,9	8598,9	2442,9	7035,5	9869,2	3029,2	8110,4	11139,5
S-3	Design Building-3	K/4mm+12+4mm-Argon	1844,8	5825,6	8544,2	2427,3	6990,7	9806,4	3009,9	8058,7	11068,6
S-4	Design Building-4	K/4mm+16+4mm-Air	1838,1	5804,4	8513,2	2418,5	6965,3	9770,8	2999,0	8029,5	11028,4
g S-5	Design Building-5	K/4mm+16+4mm-Argon	1831,6	5784,1	8483,3	2410,0	6940,9	9736,5	2988,4	8001,3	10989,7
Natural Gas S-6 S-7	Design Building-6	K3+/4mm+12+4mm+12 +4mm-Air	1799,7	5683,2	8335,4	2368,0	6819,9	9566,8	2936,3	7861,8	10798,1
z S-7	Design Building-7	K3+/4mm+12+4mm+12 +4mm-Argon	1787,0	5643,0	8276,4	2351,3	6771,6	9499,1	2915,6	7806,2	10721,8
S-8	Design Building-8	K3+/4mm+16+4mm+16 +4mm-Air	1784,0	5633,6	8262,6	2347,3	6760,3	9483,2	2910,7	7793,2	10703,9
S-9	Design Building-9	K3+/4mm+16+4mm+16 +4mm-Argon	1781,1	5624,4	8249,2	2343,5	6749,3	9467,8	2906,0	7780,5	10686,5
S-1	Design Building-1	C/4mm+12+4mm-Air	3693,4	11663,4	17106,3	4859,7	13996,0	19633,3	6026,1	16134,3	22160,4
S-2	Design Building-2	K/4mm+12+4mm-Air	3179,9	10041,8	14728,0	4184,1	12050,2	16903,7	5188,3	13891,2	19079,4
S-3	Design Building-3	K/4mm+12+4mm-Argon	3159,7	9977,9	14634,2	4157,4	11973,4	16796,1	5155,2	13802,7	18957,9
S-4	Design Building-4	K/4mm+16+4mm-Air	3148,2	9941,6	14581,0	4142,3	11929,9	16735,1	5136,5	13752,6	18889,1
_ S-5	Design Building-5	K/4mm+16+4mm-Argon	3137,1	9906,7	14529,9	4127,8	11888,1	16676,3	5118,5	13704,3	18822,8
Fuel Oil	Design Building-6	K3+/4mm+12+4mm+12 +4mm-Air	3082,4	9734,0	14276,6	4055,9	11680,9	16385,6	5029,3	13465,4	18494,7
S-7	Design Building-7	K3+/4mm+12+4mm+12 +4mm-Argon	3060,6	9665,2	14175,6	4027,2	11598,2	16269,7	4993,7	13370,2	18363,9
S-8	Design Building-8	K3+/4mm+16+4mm+16 +4mm-Air	3055,5	9649,0	14151,9	4020,4	11578,9	16242,6	4985,3	13347,9	18333,2
S-9	Design Building-9	K3+/4mm+16+4mm+16 +4mm-Argon	3050,6	9633,4	14128,9	4013,9	11560,0	16216,2	4977,2	13326,2	18303,4

-	Гable 6. С	Cont'd										
	S-1	Design Building-1	C/4mm+12+4mm-Air	3699,1	11681,5	17132,8	4867,3	14017,8	19663,8	6035,4	16159,4	22194,8
	S-2	Design Building-2	K/4mm+12+4mm-Air	3184,8	10057,4	14750,9	4190,6	12068,9	16930,0	5196,3	13912,7	19109,1
	S-3	Design Building-3	K/4mm+12+4mm-Argon	3164,6	9993,4	14656,9	4163,9	11992,0	16822,1	5163,2	13824,1	18987,4
	S-4	Design Building-4	K/4mm+16+4mm-Air	3153,1	9957,1	14603,7	4148,8	11948,5	16761,0	5144,5	13773,9	18918,4
	. _ S-5	Design Building-5	K/4mm+16+4mm-Argon	3142,0	9922,1	14552,4	4134,2	11906,5	16702,2	5126,4	13725,6	18852,0
	Diesel O	Design Building-6	K3+/4mm+12+4mm+12 +4mm-Air	3087,2	9749,2	14298,8	4062,1	11699,0	16411,1	5037,1	13486,3	18523,4
	ʿ□ _{S-7}	Design Building-7	K3+/4mm+12+4mm+12 +4mm-Argon	3065,4	9680,2	14197,6	4033,4	11616,2	16295,0	5001,4	13390,9	18392,4
	S-8	Design Building-8	K3+/4mm+16+4mm+16 +4mm-Air	3060,3	9664,0	14173,9	4026,7	11596,8	16267,8	4993,1	13368,6	18361,7
	S-9	Design Building-9	K3+/4mm+16+4mm+16 +4mm-Argon	3055,3	9648,3	14150,9	4020,1	11578,0	16241,3	4985,0	13346,8	18331,8

How significant this number is becomes clear when one considers the immense number of structures that exist in Turkey.

This data can guide governments and encourage the creation and implementation of policies such as carbon taxes, emission trading systems, energy efficiency incentives to reduce carbon emissions. This study has shown that the social cost of carbon can be reduced and the housing sector can be made more sustainable and the negative environmental impacts of cities can be minimized if housing is built energy efficiently. In particular, it can contribute to promoting practices such as the use of renewable energy sources and the preference for environmentally friendly building materials to reduce the carbon impact in the housing sector.

Since this study provides information on the social cost of carbon, it is thought that it can help the society to be more aware of environmental impacts and to adopt more sustainable consumption and production habits. By implementing policies based on the social cost of carbon, cleaner air, healthier living conditions and a more economically sustainable future can be achieved. It is concluded that economic and social benefits can be achieved in the long run by considering the social cost of carbon. In this study, it is concluded that the concept of social cost of carbon plays an important role in promoting environmental sustainability and in policy making and sectoral practices for a healthier future.

4. Conclusions

This research investigates the impact of energy-efficient measures, specifically focusing on different glass combinations, in an island-based housing project in Antalya. By creating Design Building Models and analyzing nine scenarios, the study evaluates the annual electrical energy consumption. Additionally, it assesses the environmental consequences, particularly carbon emissions, associated with the production of this energy from seven different sources. The economic dimensions of these emissions are explored using the net present value method at various discount rates for the years 2030, 2040, and 2050. This

unique study contributes to the limited research on the economic aspects of residential building emissions in the country. The findings aim to inform strategies for reducing environmental impacts, guiding governments in making more sustainable decisions in energy resource selection, and promoting energy-efficient practices in housing design. It was observed that the total energy and emission savings reached 17.40% with the use of maximum energy efficient glasses in the buildings. It is calculated that if the energy used in the buildings is produced in the power plant using lignite instead of being produced in the power plant using natural gas, 70.60% more SCC will occur.

The study revealed that SCC studies in the literature are generally conducted to obtain the unit social cost value with various theoretical economic models developed. The feature that distinguishes this study from other studies is the calculation of SCC by using the unit social cost value determined by various economic models in the literature and applying it to the amount of energy consumed by using energy efficient glasses in a housing project. This type of analysis is a unique approach that is not very common in the literature. It is thought that such analyses will provide guidance for the development and implementation environmentally friendly practices and sustainable solutions in the field of energy efficiency, especially in the housing sector.

The study concluded that as a result of energy efficiency designs in buildings, economic benefits can be achieved by reducing the energy needed individually, and environmental impacts can be minimized by reducing emission values globally. In order to realize the 2053 net zero commitment in the Paris Climate Agreement, to which Turkey is a party within the scope of combating climate change, greenhouse gas emissions must be reset. For this reason, first, it is necessary to apply energy efficient building criteria to keep the energy used in buildings at a minimum level and to provide the energy needed from renewable energy sources. For this purpose, getting out of coal and coal-based energy policies is not a choice but a necessity. Unless radical decisions are taken, it is thought that the amount Turkey will have to pay within the scope of global harmonization arising from international agreements to which Turkey is committed will be well over \$2 billion.

Since there are many different models that make analyses using different data sets to calculate the social cost of carbon, only the values obtained as a result of an integrated approach of models based on the relationship between climate and economy (DICE, FUND, PAGE) are used in this study. It is thought that optimum values are obtained by limiting the scope with both the relationship between climate and economy and an integrated approach.

It is necessary to develop more sensitive models with a holistic approach that will bring together climate change, ecosystem impacts, health consequences and economic impacts to determine the social cost of carbon. It is foreseen that an optimum model can be created by meta-heuristic analysis of different models in future studies and this limitation can be eliminated. In addition, with this optimum model, it is thought that by minimizing the uncertainties in the process of determining the social cost of carbon, it can help us better understand the effects of carbon emissions on different sectors and regions.

By using different policy instruments such as carbon tax, emission trading, incentives, as well as technological developments such as renewable energy, carbon capture and storage, studies comparing the effects of carbon on the social cost of carbon can be conducted to determine which policy instruments provide the most effective results. In order to raise awareness on the social cost of carbon, co-operation between policy makers and the public should be ensured. Studies can be carried out to develop communication strategies to encourage social participation. These recommendations can form a basis for future studies to better understand the social cost of carbon and make more effective decisions in policy making.

The study can be extended to different cities representing different climate zones by comparing carbon social costs between regions. Instead of the data obtained with the DesignBuilder simulation programme, the study can be renewed with the data obtained by field studies and real-time data collection methods to obtain more realistic results. Although this study focuses on energy efficient glass parameters, the scope of the study can be expanded to include other energy efficient building design parameters. In addition to the residential sector, a new study can be conducted by creating a wider scope to include the effects of other sectors such as industrial sectors or commercial buildings on energy consumption and carbon emissions.

In the study, it is shown that energy efficiency can be achieved and SCC can be reduced by applying different glass combinations in buildings. It is thought that the SCC results calculated according to different fuel types used in power plants will be an important guide in determining climate change policies and will accelerate the studies planned to switch to renewable energy. An important result of the study is that different glass combinations are associated with different SCC values when different energy sources such as lignite and natural gas are used. These results show how the environmental impacts of different energy change different sources can with glass combinations used in residential buildings.

This research underscores the significance of energy-efficient measures, particularly in the context of an island-based housing project in Antalya, with a focus on diverse glass combinations. Employing Integrated Assessment Models, the study pioneers an examination of the economic dimensions linked to carbon emissions from residential buildings, addressing a critical gap in existing literature. While providing valuable insights into sustainable housing practices, the research recommends the widespread adoption of energy-efficient technologies and calls for the integration of findings into building codes and government policies to incentivize environmentally conscious construction. However, the study has limitations, including its contextual specificity to simplified Antalya, reliance on modeling assumptions, and the need for more comprehensive socio-economic analysis. Despite these limitations,

the research contributes essential knowledge to guide governmental decision-making and encourages further interdisciplinary exploration to

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Author Contributions

A. Kazaz: Conceptualization, Methodology, Investigation, Resources, Supervision, Validation, Writing- Reviewing and Editing; E. Yetim: Methodology, Formal Analysis, Investigation, Data curation, Writing- Original draft, Visualization, Simulation.

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Not applicable.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Ethics Committee Permission

Not applicable.

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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foster a more sustainable future in residential construction.

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