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LEED-CI v4 Projects in Terms of Life Cycle Assessment in Manhattan, New York City: A Case Study

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Abstract: Over the last decade, it has been clearly shown that the same achievements in Leadership in Energy and Environmental Design (LEED) projects can lead to different life cycle assessments (LCAs). However, the problem of contradictory achievements in LEED and LCA has not yet been resolved. This study aimed to identify and evaluate different strategies for LEED projects using LCAs. Thirty-nine LEED projects with the same characteristics—location and transportation, rating system, rating version, certification level, and space type—were collected and sorted by their energy and atmosphere (EA) category, "optimize energy performance" credit (EAc6) achievement into three equal groups (EA_{Low}, EA_{Medium}, and EA_{High}, where each group includes 13 LEED projects) to minimize the influence of uncontrolled factors on the LEED project strategy. The author focused on two extreme groups with very different EAc6 credit scores: EA_{Low} (13 projects) and EA_{High} (13 projects). The groups were compared across LEED categories and credits. Wilcoxon–Mann–Whitney and Cliff's δ test results showed that the EA_{Low} and EA_{High} groups are associated with high/low achievements in materials-related credits such as "interiors life cycle impact reduction", "building product disclosure and optimization—material ingredients", and "low-emitting materials". As a result, the EA_{Low} and EA_{High} groups were reclassified into $Energy_{Low}$–$Materials_{High}$ and $Energy_{high}$–$Materials_{Low}$ certification strategy groups. In this context, LCAs were used to assess the differences between the two strategies. The results showed that if natural gas was used for operational energy (OE), the $Energy_{High}$–$Materials_{Low}$ strategy showed lower environmental damage compared to the $Energy_{Low}$–$Materials_{High}$ strategy (p = 0.0635); meanwhile, if photovoltaic energy was used for OE, the $Energy_{Low}$–$Materials_{High}$ strategy showed lower environmental damage compared to the $Energy_{High}$–$Materials_{Low}$ strategy (p = 0.0036). The author recommends using the LEED protocol and the LCA method in parallel to better reflect the environmental impact of different certification strategies.

Keywords: LEED-CI v4 gold-certified projects; energy credits; material credits; LCAs; ReCiPe

Citation: Pushkar, S. LEED-CI v4 Projects in Terms of Life Cycle Assessment in Manhattan, New York City: A Case Study. *Sustainability* **2023**, *15*, 2360. https://doi.org/10.3390/su15032360

Academic Editor: Asterios Bakolas

Received: 25 November 2022
Revised: 7 January 2023
Accepted: 16 January 2023
Published: 28 January 2023

1. Introduction

Currently, reducing global climate change and slowing down resource depletion are urgent problems of modern society. The construction sector plays an important role in solving this environmental problem. Ceglia [1] notes that buildings consume over 30% of the world's energy, half of which is used for space heating and cooling (operated energy). The energy consumed by the construction sector is responsible for 50% of global greenhouse gas emissions [2]. In addition, the construction of buildings requires a large amount of building materials, depleting 40% of the world's raw materials [2].

The environmental impact of buildings is usually assessed using environmental rating systems and life cycle assessments (LCAs). The green rating system is one of the generally accepted practices for reducing the harmful environmental impacts associated with the construction industry. The first environmental rating systems, the Building Research Institute Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED), were launched in 1990 in the UK and in 1998 in the US, respectively [3,4]. Since then, due to specific climatic conditions, the availability of natural resources, environmental issues, construction technologies, the needs of the construction market, and the demographic and cultural characteristics of each country, more than 600 such systems have appeared around the world [5]. The rating systems are a list of several environmental categories such as site, energy, water, materials, and wellbeing, with each of these categories including one or more credits with performance requirements and points awarded. In such green systems, points are awarded according to the importance of the credits/categories as determined by a stakeholder group, and are commonly referred to as "points-based" systems [6].

LCAs are a generic cradle-to-grave method (considering the entire life cycle from raw material extraction to final disposal) that focuses on products and services to assess (theoretically) all environmental impacts [7]. The overall structure of an LCA study is prepared by defining the goal and scope. The input and output (interventions) data are then collected in the life cycle inventory (LCI) phase. The contribution of the LCI to various environmental impact categories, such as climate change, human toxicity, and acidification, is assessed during the life cycle impact assessment (LCIA) phase. The completeness and consistency of the results, in relation to the goal and scope, are verified at the interpretation phase. The conversion of LCI to LCIA is accomplished through the use of applied scientific models [7].

In 2002, Scheuer and Keoleanin [8] first noted the environmental inconsistency between score-based environmental rating systems and their LCAs. The authors evaluated three material and resource (MR) credits and three energy and atmosphere (EA) credits on a University of Michigan campus that achieved LEED-NC Silver (New Construction) Version 2 (v2) certification. They concluded that, in contrast to the LEED certification, in which each of the credits had a score of 1, the LCAs of the credits assessed were very different. Humbert [9] later assessed the LCAs of 45 credits from the following categories: sustainable sites (SS), water efficiency (WE), EA, and MR in the LEED-NC v2.2 silver-certified building. The authors found significant discrepancies between the LEED scores awarded and the LCA results: low-scoring credits had high environmental benefits, while high-scoring credits had low environmental benefits.

These first studies generated significant interest in integrating LCAs into the green rating system. For example, Suh et al. [10] studied the environmental impacts of an office building certified with LEED-NC v3. The authors analyzed 38 credits of the SS, WE, EA, and MR categories and concluded that the application of these credits led to different results in terms of environmental impacts. In particular, acidification, human health, respiratory disease, and global warming were decreased, whereas no decrease was noticed for ozone layer depletion and land use.

Al-Ghamdi and Bilek [11] analyzed CO_2 emissions associated with the operational energy consumption of a typical office building. The building was designed according to the energy credit requirement of LEED-NC v3 for 400 sites located worldwide. The author reported that CO_2 emissions had a wide range, from 394 to 911 tons of CO_2. It was concluded that the rewarding of EA points for operational energy need to be reanalyzed to take into account the environmental consequences of the decreased energy use.

As a result of extensive research on the relationship between LCAs and the green rating system, Al-Ghamdi and Bilek [12] noted that several systems, such as BREEAM, LEED, and Green Globes, have already included LCAs in MR credit requirements. For example, the MR LEED Building life cycle impact mitigation credit under the whole building life cycle assessment option requires that the design components of a building be assessed against six environmental impacts: global warming potential, depletion of the stratospheric ozone layer, acidification of land and water sources, eutrophication, formation of tropospheric ozone, and depletion of nonrenewable energy resources [13].

Lessard et al. [14] examined the other side of LCA application in environmental rating systems. The authors have criticized LEED-NC v4, which gives EA categories a higher priority than MR categories, i.e., 30% and 12% of total LEED credits, respectively. The authors argued that such a high priority for EA was based on fossil fuels for power generation in the past, and they proposed changing these two LEED categories to reflect the rapid development of renewables in the near future. To support this argument, Lessard et al. [14] assessed the stages of material production and operational energy using the LCAs of office buildings that use renewable energy sources. They reported that the material production phase accounts for more than 50% of the total impacts associated with the sum of material production and operational energy.

Ismaeel and Ali [15] used an LCA to evaluate two MR credits (building reuse and construction waste management) for rehabilitation of the Richordi Berchet gold project, certified with the LEED-C&S (core and shell) v3 system in January 2014. The authors showed how the environmentally preferable scenarios of demolishing/reusing and waste management practices for walls and floor slab components obtain points in the two MR credits. The authors noted that some construction waste is associated with high LEED scores and high environmental impact, while other construction waste is associated with low LEED scores and low environmental impact.

Greer et al. [16] noted that the same achievement in LEED scores can lead to different results in LCAs. The authors performed LCAs of WE and EA credits for LEED BC + D v4 (building construction and design) certified projects in Californian cities. Greer et al. [16] reported high variability in CO_2 production with the same WE and EA credits in different cities of California. The authors concluded that the same LEED points had different LCAs due to different electricity sources and water infrastructure used in the analyzed cities.

Pushkar [17] studied LEED-CI v4 (commercial interiors) gold-certified office-space projects in Californian cities and identified two main certification strategies: (1) the location and transportation (LT) category with high achievement and the EA category with low achievement (LT_{high} and EA_{Low}); and (2) LT with low achievement and EA with high achievement (LT_{Low} and EA_{High}). Then, the author analyzed the LCA results of these two different certification strategies and concluded that the LT_{Low} and EA_{High} achievement strategy was more environmentally damaging than the LT_{High} and low EA_{Low} strategy. The author concluded that, despite the same level of LEED (gold) certification, the two identified certification strategies resulted in significantly different environmental impacts as assessed using LCAs. To overcome this problem, LCAs should be used to decide whether a particular LEED certification strategy is preferable.

This question is important because, as reported in many previous empirical certification studies of environmental ranking projects, different countries prefer very different certification strategies to achieve the same level of certification. For example, Wu et al. [18] compared the certification strategies of LEED-NC v3 certified, silver, gold, and platinum projects in the US and China, and concluded that US projects based their strategy on high achievement in the EA category, whereas Chinese projects preferred high achievements in the SS and WE categories. Pushkar [19] compared certification strategies of LEED-NC v3 gold projects in northern Europe (Finland and Sweden) and southern Europe (Turkey and Spain), revealing that the countries of northern Europe prioritized high performance in EA compared to the countries of southern Europe.

It is clear that the selected certification strategies match the available resources and building technologies in a particular country. However, when building practitioners select different certification strategies within the same country (as demonstrated in Pushkar's study [17]), they need to be aware of the different environmental impacts of alternative certification strategies.

Therefore, the present article continues the study of LEED-LCA certification strategies by analyzing LEED-CI v4 gold-certified office-space projects in Manhattan, New York City. The two goals of the study were (i) to reveal and compare strategies of LEED-CI v4 gold-certified office-spaces and (ii) to conduct LCAs of the revealed strategies. The results of this study can help LEED stakeholders improve the certification system to better reflect the environmental impacts of various certification strategies.

2. Materials and Methods

This section includes two types of structure designs: (1) LEED-CI v4 gold-certified office space structure designs and (2) LEED-LCA (LEED certification strategies converted to LCAs) structure designs. Each structure design includes data collection, data sorting, and statistical analysis. The two-tailed p-value classification applies to both types of structure designs.

2.1. LEED-CI v4 Gold-Certified Office Space Structure Design

2.1.1. LEED Data Collection

Based on the US Green Building Council (USGBC) website [20] and the Green Building Information Gateway (GBIG) website [21], 39 LEED-CIv4 gold-certified office-space projects in Manhattan, New York City were collected. The author sought to ensure that all projects were within the framework of a single green policy. It should be noted that the regulation of "green" policy in the United States is carried out at the state level [22]. It has previously been shown that the analysis of LEED strategies is more accurate when looking at the impact of green policies across the various US states [23].

2.1.2. LEED Data Sorting

The 39 LEED-CIv4 gold-certified office-space projects were sorted by their "optimize energy performance" credit achievements from the energy and atmosphere (EA) category. These 39 LEED projects were divided into three equal groups with sample size (n) $n_1 = n_2 = n_3 = 13$. As a result, the groups EA_{Low}, EA_{Medium}, and EA_{High} were obtained, with low, medium, and high achievements in the EAc6 credit, respectively. However, in the present study, the author focused on two extreme groups with very different EAc6 credit scores: EA_{Low} and EA_{High}. As noted in [24], if the data contain "discrete interval variables with relatively few values", then a sample size of $n \geq 12$ is acceptable for using the nonparametric exact Wilcoxon–Mann–Whitney (WMW) test.

To determine the certification strategies, the EA_{Low} and EA_{High} groups were compared across categories and credits. In the first stage, achievements in the categories IP, LT, WE, EA, MR, EQ, IO, and RP were compared between the two groups. Then, the categories with different achievements in the two groups were compared at the credit level. The credits with high achievements were considered as those that present the applied certification strategies in the EA_{Low} and EA_{High} groups. Statistical analyses (described in Section 2.1.3) were used to compare the groups at both the category and credit levels.

2.1.3. LEED Data Statistical Analysis

It is well known that if two independent groups of indicators are compared, then it is necessary to first check the assumptions about the normality of the data [25]. If the sample size is small, the Shapiro–Wilk test can be used to test for normal distribution. If the LEED data were normally distributed, the author used parametric statistics: mean $\pm$ standard deviation (SD), Cohen's d effect size, and unpaired t-test. If distribution normality was not met for the LEED data, the author used non-parametric statistics: the median and 25th–75th percentiles, interquartile range (IQR), Cliff's δ effect size, and the exact WMW test. In all comparisons, two-tailed p-values were used.

Cohen's d test with bias correction [26] or Cliff's δ test [27] was used to determine the substantive significance between the EA_{Low} and EA_{High} groups. For both tests, positive (+) values indicated that the EA_{Low} group was larger than the EA_{High} group, 0 indicated equality, and negative (–) values indicated that the EA_{High} group was larger than the EA_{Low} group.

Cohen's $|d|$ can take on any number between 0 and infinity. The effect size of Cohen's d is considered to be negligible if $|d| < 0.20$, small if $0.20 \leq |d| < 0.50$, medium if $0.50 \leq d < 0.80$, and large if $|d| \geq 0.80$ [28].

Cliff's δ ranges between -1 and +1. The effect size of Cliff's δ is negligible if $|\delta| < 0.147$, small if $0.147 \leq |\delta| < 0.33$, medium if $0.33 \leq |\delta| < 0.474$, and large if $|\delta| \geq$

0.474 [29]. However, in green building research, effect size classification is more intuitive than deterministic approaches, as there is still little research in this area [17].

2.2. LEED-LCA Structure Design

2.2.1. EA_{Low} and EA_{High} LCA Data Sorting

LCAs were used to convert EA_{Low} and EA_{High} LEED certification strategies into environmental evaluations. The Ecoinvent database, based on the SimaPro platform [30], was used to describe certification strategies in environmental terms. The ReCiPe2016 Life Cycle Impact Assessment (LCIA) midpoint and endpoint methods were used to compare the different certification strategies in the two groups [31]. In this context, validation of LCA data is not required [30]. The statistical analysis presented in Section 2.2.4 was used to compare the LEED-LCA certification strategies in the two groups.

2.2.2. Functional Unit and Life Cycle Inventory

The functional unit (FU) is the credit performance of the identified LEED certification strategies per 1 m^2 of a building's floor area. The life cycle inventory (LCI) includes the production stage of the building materials and the operational energy needed for heating and cooling the analyzed building. A detailed explanation of the FU and LCI is described in Section 3.2.1.

2.2.3. Life Cycle Impact Assessment: ReCiPe2016

According to ReCiPe2016, based on the SimaPro platform [31], the midpoint evaluation includes global warming, ionizing radiation, water consumption, terrestrial eco-toxicity, human noncarcinogenic effect, and freshwater ecotoxicity, whereas the endpoint evaluation includes a single score of damage to human health, ecosystem quality, and resources. ReCiPe2016 allows us to perform the endpoint evaluation from individualist (I), egalitarian (E), and hierarchist (H) perspectives on environmental problems, and apply perspective-specific and average weightings to human health, ecosystem quality, and resources. As a result, individualist/average (I/A), hierarchist/average (H/A), egalitarian/average (E/A), individualist/individualist (I/I), hierarchist/hierarchist (H/H), and egalitarian/egalitarian (E/E) endpoint single-score evaluations can be obtained. The I/A and I/I evaluations consider only short-term harm, the E/A and E/E evaluations assess long-term harm, and the H/A and H/H evaluations evaluate intermediate-term harm [32]. In this study, both midpoint and endpoint single-score evaluations were used; this is because midpoint evaluation is more robust, but harder to interpret, while endpoint evaluation provides more uncertain analysis, but is easier to interpret.

2.2.4. ReCiPe2016 Single-Score and Analysis of Variance (ANOVA)

A two-stage nested mixed analysis of variance (ANOVA) model was used because the ReCiPe2016 single-score results (i.e., the I/A, H/A, E/A, I/I, H/H, and E/E methodological options) have a two-stage nested structure design, as shown in Figure 1. In order to understand this two-stage nested ANOVA model, the following terms should be explained: sampling frame, primary sampling unit, subunits, and individual subunits. The sampling frame is a collection of all elements (primary sampling units) that are accessible for sampling in the population of interest. A primary sampling unit contains two or more subunits. A subunit contains two or more individual subunits. Measurements were collected from the individual subunits [33].

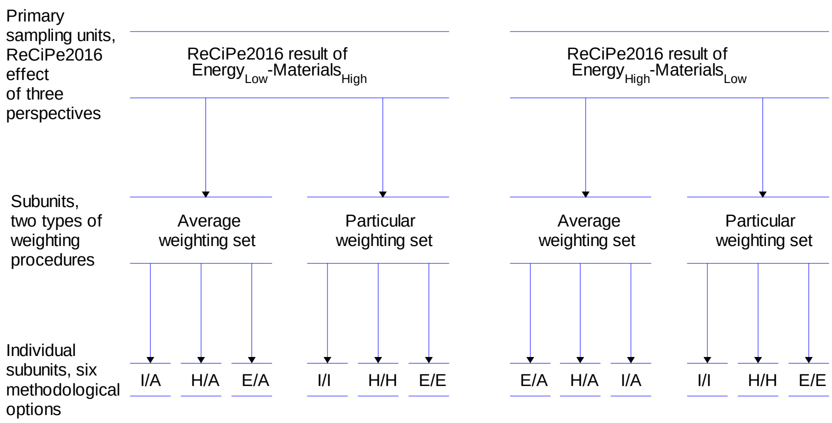

Figure 1. Two-stage nested structure design for environmental assessment.

2.3. *p-Value Classification*

Following [34], in the present work, the author replaced the dichotomous fixed α solution (where α is the level of significance, for example, $\alpha = 0.05$; i.e., $p < \alpha$ or $p > \alpha$) with a three-logic-value solution: "seems to be positive" (i.e., there seems to be a difference between the EA_{Low} and EA_{High} groups), "seems to be negative" (i.e., there does not seem to be a difference between the EA_{Low} and EA_{High} groups), and "judgment is suspended" (regarding the difference between the EA_{Low} and EA_{High} groups). This three-logic-value solution corresponds to Fisher's philosophical proposal that "no scientific worker has a fixed level of significance at which, from year to year and in all circumstances, he rejects (null) hypotheses; he rather gives his mind to each particular case in light of his evidence and ideas" (cited by Hurlbert and Lombardi [34], p. 316). The author also took the advice of Gotelli and Ellison [35], who suggested using the exact p-value instead of $p < 0.05$ or "ns" (i.e., non-significance); for example, "in many cases, it may be more important to report the exact p-value and let the readers decide for themselves how important the results are" (cited by Hurlbert and Lombardi [34], p. 318).

3. Results and Discussion

3.1. *LEED Certification Strategies*

3.1.1. At the Category Level

Table 1 shows that the normality assumption was met in four categories (WE, EA, MR, and EQ) in both the EA_{LOW} and EA_{High} groups, while the normality assumption was not met in four categories (IP, LT, IO, and RP) in both or one of the EA_{LOW} and EA_{High} groups. It was concluded that if the normality assumption holds in both groups, then parametric statistics should be used; if the normality assumption does not hold in one of the two groups, then non-parametric statistics should be used [36].

Table 1 also shows that, in the EA category, EA_{Low} underperforms relative to EA_{High} ($d = -2.91$ and $p = 0.000001$). In contrast, EA_{Low} outperforms EA_{High} in the three categories of MR, EQ, and IO ($d = 1.02$ and $p = 0.0112$; $d = 0.96$ and $p = 0.0180$; and $\delta = 0.80$ and $p = 0.0002$, respectively). EA_{Low} and EA_{High} showed equal achievements in the four categories of IP, LT, WE, and RP ($\delta = -0.11$ and $p = 0.7292$; δ= 0.00 and $p = 1.0000$; $d = 037$ and $p = 0.3338$; and $\delta = -0.17$ and $p = 0.5034$, respectively). For the LEED total, EA_{Low} underperforms relative to EA_{High} ($\delta = -0.53$, $p = 0.0212$). Consequently, despite the same gold certification level of the projects in both the EA_{Low} and EA_{High} groups, the EA_{High} certification strategy seems to be "greener" than the EA_{Low} strategy.

Table 1. Categories of the LEED-CI v4 gold-certified office-space projects in Manhattan, New York City: EA_{Low} versus EA_{High}.

Category	Maximum Points	Group	Median, 25–75th Percentiles/ Mean ± STD	Normality Assumption (p-Value) [1]	Cliff's δ [2]/ Cohen's d [3]	Significance Test (p-Value)
Integrative process (IP)	2	EA_{Low} EA_{High}	1.0 0.0–1.0 1.0 0.0–1.3	0.0087 0.0136	–0.11 [2]	0.7292 [a]
Location and transportation (LT)	18	EA_{Low} EA_{High}	17.0 17.0–17.0 17.0 17.0–17.0	NA [4] 0.00004	0.00 [2]	1.0000 [a]
Water efficiency (WE)	12	EA_{Low} EA_{High}	5.85 ± 2.51 4.92 ± 2.25	0.2972 0.1676	0.37 [3]	0.3338 [a]
Energy and atmosphere (EA)	38	EA_{Low} EA_{High}	16.54 ± 2.40 25.54 ± 3.45	0.4577 0.1218	–2.91 [3]	0.000001 [b]
Materials and resources (MR)	13	EA_{Low} EA_{High}	6.38 ± 1.39 4.62 ± 1.89	0.5879 0.6920	1.02 [3]	0.0120 [b]
Indoor environmental quality (EQ)	17	EA_{Low} EA_{High}	7.46 ± 2.44 5.38 ± 1.66	0.0672 0.6321	0.96 [3]	0.0180 [b]
Innovation (IO)	6	EA_{Low} EA_{High}	6.0 5.0–6.0 4.0 4.0–5.0	0.0001 0.0993	0.80 [2]	0.0002 [b]
Regional priority (RP)	4	EA_{Low} EA_{High}	3.0 2.0–3.0 3.0 2.0–3.0	0.0618 0.0027	–0.17 [2]	0.5034 [a]
LEED total	110	EA_{Low} EA_{High}	62.0 60.8–63.3 65.0 62.8–68.0	0.0305 0.5482	–0.53 [2]	0.0212 [b]

Notes: [1] the Shapiro–Wilk test was used to estimate the normality assumption; [2] Cliff's δ is non-parametric effect size; [3] Cohen's d is parametric size effect; [4] p-value not available (NA) due to the EA_{Low} group including the same number; [a] the difference between the two groups seems to be negative; [b] the difference between the two groups seems to be positive.

3.1.2. At the Credit Level

Table 2 shows EA, MR, and EQ credits in which the difference between EA_{Low} and EA_{High} seems to be positive. The credits of IO and RP were excluded from the consideration because they cannot be accounted with LCAs, due to their undocumented diversification in the evaluated projects. This means that IO practices were not documented at the US Green Building Council website and the Green Building Information Gateway website, and RP credits differed for the considered projects [20,21].

Table 2. The credits of the LEED-CI v4 gold-certified office-space projects in Manhattan, New York City in which the difference between EA_{Low} and EA_{High} seems to be positive.

Credit	Maximum Points	Group	Median, 25–75th Percentiles	Normality Assumption (p-Value) [1]	Cliff's δ	Significance Test (p-Value)
Optimize energy performance (EAc6)	25	EA_{Low} EA_{High}	11.0 7.0–13.0 21.0 19.0–25.0	0.0505 0.0348	–1.00	0.0000001 [b]
Interiors life cycle impact reduction (MRc2)	4	EA_{Low} EA_{High}	1.0 0.0–1.5 0.0 0.0–0.0	0.0030 0.00001	0.47	0.0212 [b]
Building product disclosure and optimization—material ingredients (MRc5)	2	EA_{Low} EA_{High}	1.0 1.0–2.0 1.0 0.8–1.0	0.0001 0.0013	0.45	0.0389 [b]
Low-emitting materials (EQc2)	3	EA_{Low} EA_{High}	3.0 2.0–3.0 1.0 0.0–3.0	0.0003 0.0113	0.47	0.0336 [b]

Notes: [1] the Shapiro–Wilk test was used to estimate the normality assumption; [b] the difference between the two groups seems to be positive.

Table 2 shows that the normal assumption was not met for all EA_{Low} and EA_{High} groups. Therefore, non-parametric statistics should be used. Table 2 also shows that, as expected, in the EAc6 credit, EA_{Low} underperforms relative to EA_{High} (δ = −1.00 and

p = 0.000001). In contrast, EA_{Low} outperforms EA_{High} in the three credits of MRc2, MRc5, and EQc2 (δ = 0.47 and p = 0.0212; δ = 0.45 and p = 0.0389; and δ = 0.47 and p = 0.0336, respectively). This means that there are two different certification strategies: EA_{high}-group projects used a high energy and low materials ($Energy_{high}$–$Materials_{Low}$) strategy, whereas EA_{Low}-group projects used a low energy and high materials ($Energy_{Low}$–$Materials_{High}$) strategy.

A similar tendency of using two completely different certification strategies was previously uncovered by Pushkar for LEED-CI v4 gold-certified office projects in Californian cities [17]. The author noticed that one group of projects preferred high achievements in location and transportation credits and low achievements in energy and atmosphere credits, whereas another group of projects preferred low achievements in location and transportation credits and high achievements in energy and atmosphere credits.

3.1.3. Choosing LEED Projects for the LCA Procedure

Tables 3 and 4 show the points awarded in the EAc6, MRc2, MRc6, and EQc2 credits for projects belonging to the $Energy_{Low}$–$Materials_{High}$ and $Energy_{high}$–$Materials_{Low}$ groups, respectively.

Table 3. The $Energy_{Low}$–$Materials_{High}$ strategy: energy and materials credit achievements.

Project			EAc6	MRc2	MRc5	EQc2
No	**Name**	**Address**				
1	***Schrodinger NYC Floors 21–24***	***1540 Broadway***	***6***	***3***	***2***	***3***
2	Mohawk Industries New York Showroom	125 West 25th Street	7	0	1	2
3	Oak Hill Advisors	1 Vanderbilt Ave	7	1	1	3
4	Thornton Tomasetti—NYC Office	120 Broadway	7	3	1	3
5	HLW New York	5 Pennsylvania Plaza	10	1	2	3
6	JPMC 5 Manhattan West FL 14, 15, 16, 16M	450 W 33rd St	10	1	1	0
7	One Deutsche Bank Center	1 Columbus Cir	11	0	2	3
8	Accenture NYC Headquarters	401 9th Ave	12	0	1	3
9	NLGIA 101 Park Ave NYC	101 Park Ave	13	0	1	3
10	Celonis NYC	1 World Trade Center	13	3	2	3
11	Morgan Stanley 11th Floor Renovation	1 New York Plaza, 1 FDR Drive	13	1	2	1
12	Guardian Life Ins. Co., 10 Hudson Yards	10 Hudson Yards	13	0	1	3
13	EDF Park Ave 11th Floor	257 Park Ave	14	1	1	2

Notes: EAc6, optimize energy performance; MRc2, interiors life cycle impact reduction; MRc5, building product disclosure and optimization—material ingredients; EQc2, low-emitting materials; bold italic font, data evaluated in the LCA of LEED certification strategies.

Table 4. The $Energy_{high}$–$Materials_{Low}$ strategy: energy and materials credit achievements.

Project			EAc6	MRc2	MRc5	EQc2
No	**Name**	**Address**				
1	Syska Hennessy at 1185 AoA	1185 6th Avenue	18	0	1	1
2	Durst 1WTC 84K	285 Fulton Street	19	0	1	3
3	IPG Momentum New York	300 Vesey Street	19	1	1	1
4	Cosentini Associates	498 7th Avenue	19	0	1	2
5	Nasdaq Project Tomorrow	4 Times Square	20	0	1	0
6	Durst 1WTC 77, & Partial 86th floor	72 Vesey Street	21	0	1	1
7	Swiss Re- 1301 AOA	1301 Avenue of the Americas	21	0	0	1
8	SOM NYC Fit-Out	250 Greenwich Street	23	2	1	0
9	Surdna Foundation	200 Madison Avenue	24	0	0	0
10	***Bank of America—One Bryant Park Fl34***	***Bank of America Tower***	***25***	***0***	***0***	***0***
11	Bank of America—One Bryant Park Fl3	1 Bryant Park	25	0	2	3
12	Bank of America—One Bryant Park Fl 35 + 36	1 Bryant Park	25	0	1	3
13	Bank of America–One Bryant Park FL4 + 37	1 Bryant Park	25	0	1	3

Notes: EAc6, optimize energy performance; MRc2, interiors life cycle impact reduction; MRc5, building product disclosure and optimization—material ingredients; EQc2, low-emitting materials; bold italic font, data evaluated in the LCA of LEED certification strategies.

3.2. LCA of LEED Certification Strategies

3.2.1. Preliminary Results: Energy and Materials Input

Two projects, Schrodinger NYC Floors 21–24 (Table 3) and Bank of America—One Bryant Park Fl34 (Table 4), were selected as representative projects for evaluating $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ and $\text{Energy}_{\text{high}}$–$\text{Materials}_{\text{Low}}$ certification strategies, respectively. To compare the LCAs of these certification strategies, the functional unit (FU) needs to be related to the LCA of the combination of the energy and material components for 1 m^2 of building floor.

The energy component of the FU is the LCA of operational energy (OE) needed for 50 years of the building's heating, cooling, and lighting (EAc6). The material component of the FU is the LCA of partitions, floor covering, furniture production (MRc2); paint production (EQc2); and partitions, floor covering, furniture, and paint transportation (MRc5).

Li [37] studied energy consumption in Manhattan and concluded the following: that "Specifically, the highest electricity-use intensity is located in the center and southern corner of Manhattan, which are mainly composed of large offices with an annual electricity-use intensity over 200 kWh/m^2". Thus, based on this high annual electricity-use intensity [37], in the present study, a base annual OE intensity of 210 kWh/m^2 was assumed for large office buildings in New York City.

Analyzing EAc6, the Schrodinger NYC Floors 21–24 and Bank of America—One Bryant Park Fl34 projects were awarded 6 and 25 points, respectively (Tables 3 and 4). These points correspond to savings of 5% and 28%, with respect to a base annual OE intensity [38]. This means that the OE needs of the Schrodinger NYC Floors 21–24 project, which used an $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ certification strategy, are 9975 $kWh/m^2 \cdot 50$ years, whereas the OE needs of the Bank of America—One Bryant Park Fl34 project, which used an $\text{Energy}_{\text{high}}$–$\text{Materials}_{\text{Low}}$ certification strategy, are 7560 $kWh/m^2 \cdot 50$ years.

Analyzing MRc2, the Schrodinger NYC Floors 21–24 and Bank of America—One Bryant Park Fl34 projects were awarded 3 and 0 points, respectively (Tables 3 and 4). It was assumed that in a typical office, the area of the partitions is 88% of the floor area [39] and 18.6 m^2 per person, while each person has one desk and chair [37]. MRc2 requires reused partitions and floor coverings for at least 50% of the surface area and reused furniture for at least 30% of the total furniture [38]. Thus, for FU = 1m^2 of office building, the Schrodinger NYC Floors 21–24 project used 0.44 m^2 of newly produced partitions, 1 m^2 of newly produced floor covering, and 0.15% newly produced furniture, whereas the Bank of America—One Bryant Park Fl34 project used 0.88 m^2 of newly produced partitions, 2 m^2 of newly produced floor covering, and 0.22% newly produced furniture. Note that this assumes that floor coverings are replaced twice and that furniture is replaced four times during 50 years of office life.

According to Hischier et al. [40], 0.35 kg of paint was assumed to cover 1 m^2 of wall. EQc2 assesses volatile organic compound (VOC) emissions in the building's internal space [38]. Analyzing EQc2, the Schrodinger NYC Floors 21–24 and Bank of America—One Bryant Park Fl34 projects were awarded 3 and 0 points, respectively (Tables 3 and 4). This means that per FU, the Schrodinger NYC Floors 21–24 project used 1.3 kg of eco-friendly paint, whereas the Bank of America—One Bryant Park Fl34 project used 2.6 kg of typical paint. Note that this assumes that paint is replaced four times on both sides of the partitions during 50 years of office life.

Analyzing MRc5, the Schrodinger NYC Floors 21–24 and Bank of America—One Bryant Park Fl34 projects were awarded 2 and 0 points, respectively (Tables 3 and 4). MRc5 requires materials/products to be transported within 160 km from the producer to the building site [38]. Thus, for the transportation of partition material, floor covering material, paint, and furniture, 150 km and 300 km transportation distances were assumed for the Schrodinger NYC Floors 21–24 and Bank of America—One Bryant Park Fl34 projects, respectively.

Table 5 sums the respective input, energy, and material quantities, as well as their LCI sources, for LCA evaluations of the $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ and $\text{Energy}_{\text{high}}$–$\text{Materials}_{\text{Low}}$

certification strategies applied in the Schrodinger NYC Floors 21–24 and Bank of America—One Bryant Park Fl34 projects.

Table 5. The input data (quantities and sources) for converting the credit achievements into LCAs.

Credit	Input	$Energy_{Low}$–$Materials_{High}$	$Energy_{High}$–$Materials_{Low}$	Ecoinvent v3.2 Data Source [30]
EAc6	OE: natural gas (kWh/m^2·50 years) OE: photovoltaic (kWh/m^2·50 years)	9975	7560	Electricity, natural gas/US Electricity, mix photovoltaic/US
MRc2	Partitions: concrete (kg)	158	316	Concrete, exacting, at plant/CH
	Floor covering: ceramic tile (kg)	20	40	Ceramic tiles/CH
	Furniture: wood (kg)	15	22	Glued laminated timber/RER
EQc2	Paint: eco-friendly (kg) Paint: typical (kg)	1.3	2.6	Alkyd paint, without water/RER Alkyd paint, without solvent/RER
MRc5	Transportation (tkm)	72.4	269	Lorry transport, 22 t/RER

Notes: US, the United States; CH, Switzerland; RER, France.

3.2.2. The Environmental Impacts of the Certification Strategies

Figure 2 shows the global warming potential, ionizing radiation, water consumption, and terrestrial ecotoxicity impacts of the $Energy_{Low}$–$Materials_{High}$ and $Energy_{High}$–$Materials_{Low}$ certification strategies when a natural gas fuel source is used for OE production. As expected, using an $Energy_{Low}$–$Materials_{High}$ strategy led to a high contribution of the energy component and low contribution of the material component, whereas $Energy_{High}$–$Materials_{Low}$ led to a relatively low contribution of the energy component and relatively high contribution of the material component.

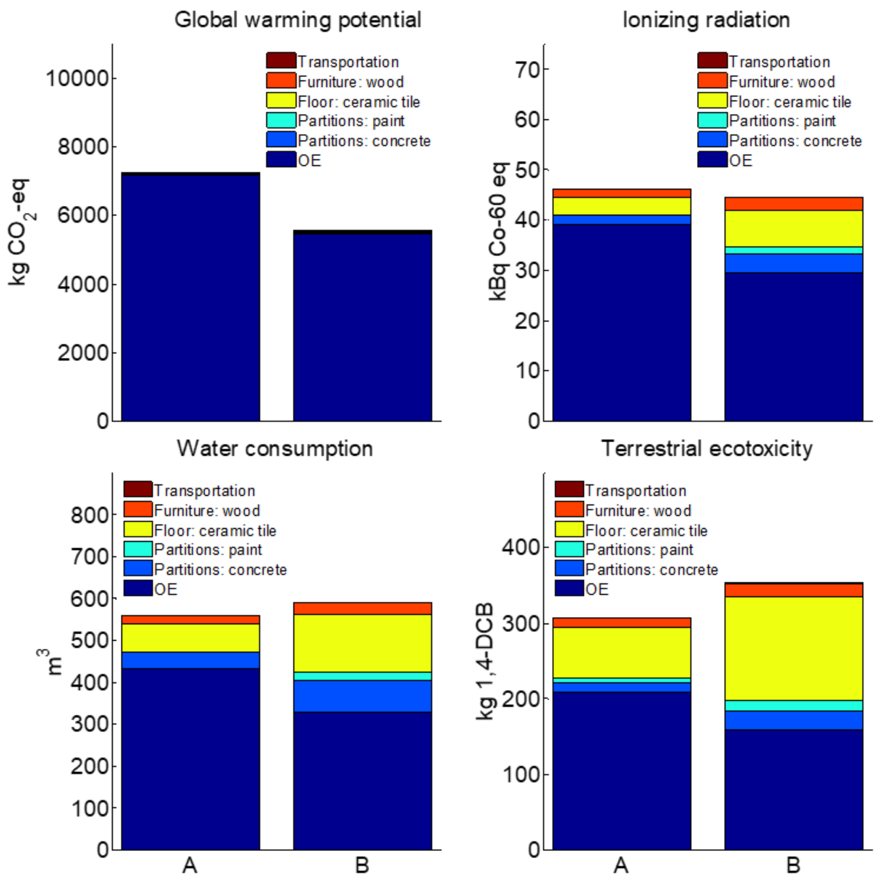

Figure 2. $Energy_{Low}$–$Materials_{High}$ (A) and $Energy_{High}$–$Materials_{Low}$ (B) LEED-CI v4 gold certification strategies with natural gas used for operational energy (OE) production.

Analyzing the global warming impact measured using CO_2-eq emissions, the OE contribution was the most influential, while materials production of ceramic tiles, concrete partitions, and wood furniture was negligible, with OE contributing 98% and other factors 2%. Considering ionizing radiation, water consumption, and terrestrial ecotoxicity, OE was the highest contributing component, followed by the production of ceramic tiles, partitions, and furniture. The significance of the contribution of the energy component is due to the use of natural gas (fossil fuel) for OE production. It is well known that fossil fuels, such as coal, oil, and gas, are highly polluting non-renewable fuels that emit large amounts of global warming gases such as carbon dioxide (CO_2) [41].

However, in the case of using natural gas for OE needs, it was not possible to decide which certification strategy is less environmentally harmful; the $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ strategy is preferable according to global warming potential and ionizing radiation, whereas the $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ strategy is preferable according to water consumption and terrestrial ecotoxicity.

Figure 3 shows the global warming potential, ionizing radiation, human noncarcinogenic, and freshwater ecotoxicity impacts of the $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ and $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ certification strategies when a PV fuel source is used for OE production. As expected, using the $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ strategy led to a low contribution of the energy component and low contribution of the materials component, whereas $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ led to a low contribution of the energy component and a high contribution of the materials component. The low energy contribution in both certification strategies is due to the use of PV (renewable fuel) for OE production.

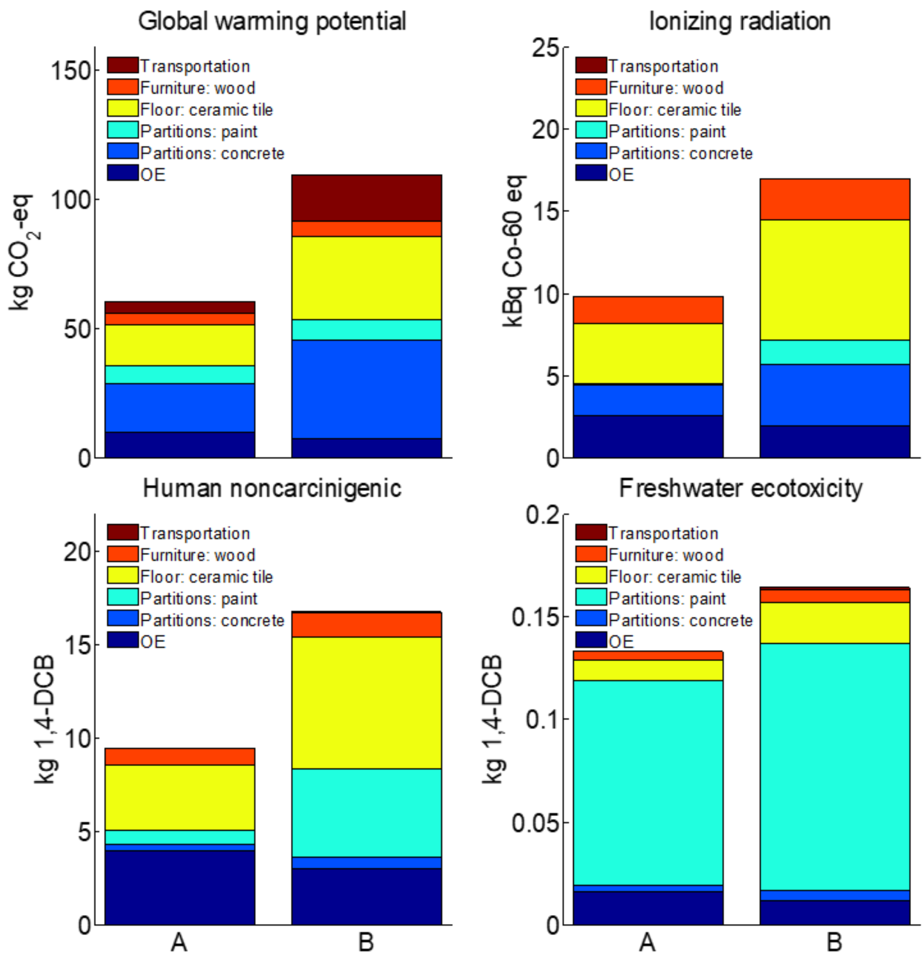

Figure 3. $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ (A) and $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ (B) strategies with photovoltaic (PV) energy used for operational energy (OE).

As a result, the contribution of concrete partitions, ceramic tiles, and wood furniture was very significant in both certification strategies. For example, considering global warming impact (CO_2-eq emissions), the production of ceramic tiles, concrete partitions, and wood furniture were much more influential, while the OE contribution was less influential, at 90% and 10%, respectively.

In the case of using PV for OE needs, it was possible to make a decision about the preferability of a certification strategy in terms of environmental impact level: $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ was less harmful than $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ in all four impacts. This result confirms the results of previous research, finding that using PV for OE decreases the share of the OE contribution, and the production stage, therefore, becomes a significant part of the total LCA [42].

3.2.3. The Environmental Damage from the Certification Strategies

Figure 4 shows the results regarding environmental damage due to the $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ and $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ LEED-CI v4 gold certification strategies for the cases of natural gas (top panel) and PV (bottom panel) use for OE production. When natural gas is used, the $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ strategy shows lower environmental damage compared to the $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ strategy; the difference between these two strategies seems to be positive, with p = 0.0635. Thus, at the endpoint result level, the $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ strategy clarifies the previously uncertain midpoint results presented in Figure 2.

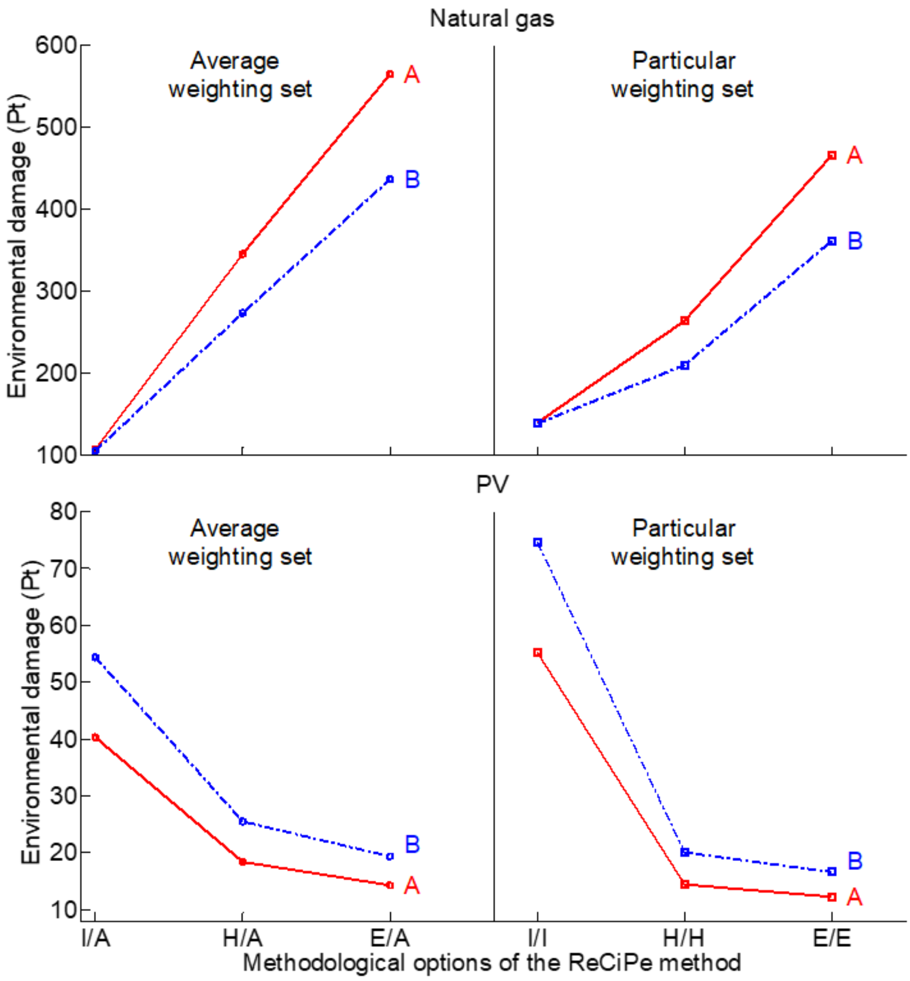

Figure 4. $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ (A) and $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ (B), with natural gas (**top** panel) and photovoltaic (PV) technology (**bottom** panel) used for operational energy (OE) production.

However, when PV is used, the $\text{Energy}_{\text{Low}}$–$\text{Materials}_{\text{High}}$ strategy shows lower environmental damage compared to the $\text{Energy}_{\text{High}}$–$\text{Materials}_{\text{Low}}$ strategy; the difference between these two strategies seems to be positive, with $p = 0.0036$. These results confirm the midpoint results presented in Figure 3.

The previous study of the LCA of the two different certification strategies used by LEED-CI v4 gold-certified office projects in Californian cities (public transportation-oriented or operational energy saving-oriented) found the strategies to be dependent on the different options of typical cars, eco-friendly cars, and typical buses [17]. The author reported that the public transportation-oriented strategy was preferred when typical buses and eco-friendly cars were used, whereas the operational energy-oriented strategy was preferred when typical cars were used.

These results outline the uncertainty in the environmental consequences LEED certification strategies and their high dependency on variable inputs such as operational energy fuel sources (the present study) or forms of private/public transportation (the study of Pushkar [17]).

4. Conclusions

Two different certification strategies were identified in LEED projects with the same characteristics of location (Manhattan, New York City), certification version (v4), certification level (gold), and space type (office). One group of LEED projects used a strategy of high operational energy and low materials achievements, while the other group used a strategy of low operational energy and high material achievements. In these two certification strategies, operational energy was accredited via EAc6 (optimize energy performance) and materials were accredited via MRc2 (interiors life cycle impact reduction), MRc5 (building product disclosure and optimization—material ingredients), and EQc2 (low-emitting materials).

In the LCA, the operational energy stage was evaluated using non-renewable fuel (natural gas) or renewable fuel (photovoltaic), and the material production stage was evaluated in the production of ceramic tiles, concrete partitions, and wood furniture. At the midpoint of the ReCiPe2016 H methodological options, when natural gas was used, the low energy and high materials achievements strategy was less environmentally harmful in water consumption and terrestrial ecotoxicity, but the high energy and low materials achievements strategy was less harmful in global warming potential and ionizing radiation. However, when photovoltaic energy was used, the low energy and high materials achievements strategy was associated with the lowest global warming potential, ionizing radiation, water consumption, and terrestrial ecotoxicity impacts.

This is because using fossil fuels (natural gas) and renewable fuels (photovoltaic) for operational energy production leads to different contributions of the operational energy and material production stages. In terms of the global warming impact (CO_2-eq emissions), when using natural gas, the operational energy stage contributed approximately 98% and the materials production stage contributed 2% of the total impact; however, when using photovoltaic energy, the materials production stage contributed approximately 90% and the operational energy and 10% of the total impact.

At the single-score endpoint of the six methodological options of ReCiPe2016, the results confirm the trend that was revealed in the assessment at the ReCiPe2016 midpoint. When using natural gas for operational energy, the high energy and low materials strategy was preferable to the low energy and high materials strategy ($p = 0.0635$). When using photovoltaic energy for operational energy, the low energy and high materials strategy was preferable to the high energy and low materials strategy ($p = 0.0036$).

Thus, it can be concluded that the same level of certification of LEED projects can be achieved through different certification strategies that may have different environmental consequences. In this study, due to the involvement of OEc6 (optimize energy performance) in both certification strategies, the environmental preference for one strategy or the other was highly dependent on the fuel source used to produce the OE. Based on the results of this study, it is recommended that LCAs are not neglected when choosing a certification strategy.

5. Future Research

An analysis of the literature shows that the introduction of building information modeling and life cycle assessments into green building rating systems can lead to an increase in the effectiveness of these systems [43]. Another promising direction in green building studies is to replace the concept of the life cycle assessment with the concept of the life cycle sustainability assessment, which considers such aspects as life cycle cost assessment (economic aspect), social life cycle cost assessment (social aspect), and life cycle assessment (environmental aspect) [44].

Funding: This research received no external funding.

Data Availability Statement: Publicly available datasets were analyzed in this study. The data can be found here: https://www.usgbc.org/projects (USGBC Projects Site) (accessed on 3 January 2023) and http://www.gbig.org (GBIG Green Building Data) (accessed on 3 January 2023).

Conflicts of Interest: The author declares no conflict of interest.

Abbreviations

LEED: Leadership in Energy and Environmental Design; USGBC: US Green Building Council; GBIG: Green Building Information Gateway; LEED categories, IP: integrative process; LT: location and transportation; SS: sustainable sites; WE: water efficiency; EA: energy and atmosphere; MR: materials and resources; EQ: indoor environmental quality; IO: innovation; RP: regional priority; LEED credits, EAc6: optimize energy performance; MRc2: interiors life cycle impact reduction; MRc5: building product disclosure and optimization—material ingredients; EQc2: low-emitting materials; FU: functional unit; LCI: life cycle inventory; LCIA: life cycle impact assessment; ReCiPe2016: LCIA method; LCAs: life cycle assessments.

References

1. Ceglia, F.; Marrasso, E.; Roselli, C.; Sasso, M.; Tzscheutschler, P. Exergetic and exergoeconomic analysis of an experimental ground source heat pump system coupled with a thermal storage based on Hardware in Loop. *Appl. Therm.* **2022**, *212*, 118559. [CrossRef]
2. Santos, R.; Costa, A.A.; Silvestre, J.D.; Pyl, L. Integration of LCA and LCC analysis within a BIM-based environment. *Autom. Constr.* **2019**, *103*, 127–149. [CrossRef]
3. Cohen, S.; Demeritt, D.; Robinson, J.; Rothman, D. Climate change and sustainable development: Towards dialogue. *Glob. Environ. Chang.* **1998**, *8*, 341–371. [CrossRef]
4. Ade, R.; Rehm, M. The unwritten history of green building rating tools: A personal view from some of the 'founding fathers'. *Build. Res. Inf.* **2020**, *48*, 1–17. [CrossRef]
5. Vierra, S. *Green Building Standards and Certification Systems*; National Institute of Building Sciences: Washington, DC, USA, 2016; Available online: https://www.wbdg.org/resources/green-building-standards-and-certification-systems (accessed on 4 December 2022).
6. Lu, D.; Realff, M.J. The Design of a Sustainability Assessment Standard Using Life Cycle Information. *J. Ind. Ecol.* **2013**, *17*, 493–503. [CrossRef]
7. *ISO 14040*; Environmental Management Life Cycle Assessment Principles and Framework. International Organization for Standardization: Geneva, Switzerland, 2006.
8. Scheuer, C.W.; Keoleian, G.A. *Evaluation of LEED Using Life Cycle Assessment Methods*; U.S. Department of Commerce: Washington, DC, USA; National Institute of Standards and Technology: Gaithersburg, MD, USA, 2002.
9. Humbert, S.; Abeck, H.; Bali, N.; Horvath, A. Leadership in Energy and Environmental Design (LEED). A critical evaluation by LCA and recommendations for improvement. *Int. J. LCA* **2007**, *12*, 46–57. [CrossRef]
10. Suh, S.W.; Tomar, S.; Leighton, M.; Kneifel, J. Environmental Performance of Green Building Code and Certification Systems. *Environ. Sci. Technol.* **2014**, *48*, 2551–2560. [CrossRef]
11. Al-Ghamdi, S.G.; Bilec, M.M. Life-Cycle Thinking and the LEED Rating System: Global Perspective on Building Energy Use and Environmental Impacts. *Environ. Sci. Technol.* **2015**, *49*, 4048–4056. [CrossRef]
12. Al-Ghamdi, S.G.; Bilec, M.M. Green Building Rating Systems and Whole-Building Life Cycle Assessment: Comparative Study of the Existing Assessment Tools. *J. Archit. Eng.* **2017**, *23*, 04016015. [CrossRef]

13. LEED-NCv4 2019. LEED v4 for New Construction and Major Renovations. 2019. Available online: https://www.usgbc.org/sites/default/files/LEED%20v4%20BDC_07.25.19_current.pdf (accessed on 3 January 2023).
14. Lessard, Y.; Anand, C.; Blanchet, P.; Frenette, C.; Amor, B. LEED v4: Where Are We Now? Critical Assessment through the LCA of an Office Building Using a Low Impact Energy Consumption Mix. *J. Ind. Ecol.* **2018**, *22*, 1105–1116. [CrossRef]
15. Ismaeel, W.S.E.; Ali, A.A.M. Assessment of eco-rehabilitation plans: Case study 'Richordi Berchet' palace. *J. Clean. Prod.* **2020**, *259*, 120857. [CrossRef]
16. Greer, F.; Chittick, J.; Jackson, E.; Mack, J.; Shortlidge, M.; Grubert, E. Energy and water efficiency in LEED: How well are LEED points linked to climate outcomes? *Energy Build.* **2019**, *195*, 161–167. [CrossRef]
17. Pushkar, S. Life-Cycle Assessment in the LEED-CI v4 Categories of Location and Transportation (LT) and Energy and Atmosphere (EA) in California: A Case Study of Two Strategies for LEED Projects. *Sustainability* **2022**, *14*, 10893. [CrossRef]
18. Wu, P.; Song, Y.; Wang, J.; Wang, X.; Zhao, X.; He, Q. Regional Variations of Credits Obtained by LEED 2009 Certified Green Buildings—A Country Level Analysis. *Sustainability* **2018**, *10*, 20. [CrossRef]
19. Pushkar, S. A Comparative Analysis of Gold Leadership in Energy and Environmental Design for New Construction 2009 Certified Projects in Finland, Sweden, Turkey, and Spain. *Appl. Sci.* **2018**, *8*, 1496. [CrossRef]
20. USGBC Projects Site. Available online: https://www.usgbc.org/projects (accessed on 3 January 2023).
21. GBIG Green Building Data. Available online: http://www.gbig.org (accessed on 3 January 2023).
22. Building Codes Assistance Project. ASHRAE 90.1 Standard, Residential Code Status. Available online: https://bcapcodes.org/code-status/residential/ (accessed on 3 January 2023).
23. Pushkar, S.; Verbitsky, O. LEED-NC 2009 Silver to Gold certified projects in the US in 2012–2017: An appropriate statistical analysis. *J. Green Build.* **2019**, *14*, 83–107. [CrossRef]
24. Bergmann, R.; Ludbrook, J.; Spooren, W.P.J.M. Different outcomes of the Wilcoxon-Mann-Whitney test from different statistics packages. *Am. Stat.* **2000**, *54*, 72–77. [CrossRef]
25. Altman, D.G. *Practical Statistics for Medical Research*; Chapman and Hall (Monograph): London, UK, 1991; ISBN 13 978-0412276309.
26. Hedges, L.V. Distribution Theory for Glass's Estimator of Effect Size and Related Estimators. *J. Educ. Stat.* **1981**, *6*, 107–128. [CrossRef]
27. Cliff, N. Dominance statistics: Ordinal analyses to answer ordinal questions. *Psychol. Bull.* **1993**, *114*, 494–509. [CrossRef]
28. Cohen, J. A power primer. *Psychol. Bull.* **1992**, *112*, 155–159. [CrossRef]
29. Romano, J.; Corragio, J.; Skowronek, J. Appropriate statistics for ordinal level data: Should we really be using t-test and Cohen's *d* for evaluating group differences on the NSSE and other surveys? In Proceedings of the Annual Meeting of the Florida Association of Institutional Research, Cocoa Beach, FL, USA, 1–3 February 2006; Florida Association for Institutional Research: Cocoa Beach, FL, USA, 2006; pp. 1–33.
30. PRé Consultants. *SimaPro*; Version 9.1. 0.35; PRé Consultants: Amersfoort, The Netherlands, 2019.
31. Huijbregts, M.A.J.; Steinmann, Z.J.N.; Elshout, P.M.F.; Stam, G.; Verones, F.; Vieira, M.; Zijp, M.; Hollander, A.; van Zelm, R. ReCiPe2016: A harmonised life cycle impact assessment method at midpoint and endpoint level. *Int. J. LCA.* **2017**, *22*, 138–147. [CrossRef]
32. Verbitsky, O.; Pushkar, S. Eco-Indicator 99, ReCiPe, and ANOVA for evaluating building technologies under LCA uncertainties. *Environ. Eng. Manag. J.* **2018**, *17*, 2549–2559. [CrossRef]
33. Picquelle, S.J.; Mier, K.L. A practical guide to statistical methods for comparing means from two-stage sampling. *Fish. Res.* **2011**, *107*, 1–13. [CrossRef]
34. Hurlbert, S.H.; Lombardi, C.M. Final collapse of the Neyman-Pearson decision theoretic framework and rise of the neoFisherian. *Ann. Zool. Fenn.* **2009**, *46*, 311–349. Available online: https://www.jstor.org/stable/23736900 (accessed on 3 January 2023). [CrossRef]
35. Gotelli, N.J.; Ellison, A.M. *A Primer of Ecological Statistics*, 2nd ed.; Sinauer Associates: Sunderland, MA, USA, 2004; p. 638. ISBN 1605350648.
36. Pushkar, S. Relationship between Project Space Types, Optimize Energy Performance Credit, and Project Size in LEED-NC Version 4 (v4) Projects: A Case Study. *Buildings* **2022**, *12*, 862. [CrossRef]
37. Li, W. Quantifying the Building Energy Dynamics of Manhattan, New York City, Using an Urban Building Energy Model and Localized Weather Data. *Energies* **2020**, *13*, 3244. [CrossRef]
38. LEED-CIv4. LEED v4 for Interior Design and Construction. 2014. Available online: https://www.usgbc.org/sites/default/files/LEED%20v4%20IDC_07.25.19_current.pdf (accessed on 21 September 2022).
39. Pushkar, S.; Yezioro, A. Life Cycle Assessment Meeting Energy Standard Performance: An Office Building Case Study. *Buildings* **2022**, *12*, 157. [CrossRef]
40. Hischier, R.; Nowack, B.; Gottschalk, F.; Hincapie, I.; Steinfeldt, M.; Som, C. Life cycle assessment of facade coating systems containing manufactured nanomaterials. *J Nanopart Res.* **2015**, *17*, 68. [CrossRef]
41. Van den Heede, P.; De Belie, N. Environmental impact and life cycle assessment (LCA) of traditional and 'green' concretes: Literature review and theoretical calculations. *Cem. Concr. Compos.* **2012**, *34*, 431–442. [CrossRef]
42. Pushkar, S. Environmental damage and saving benefit of external shading devices via PV energy generation. *J. Green Build.* **2016**, *11*, 95–109. [CrossRef]

43. Veselka, J.; Nehasilová, M.; Dvořáková, K.; Ryklová, P.; Volf, M.; Růžička, J.; Lupíšek, A. Recommendations for Developing a BIM for the Purpose of LCA in Green Building Certifications. *Sustainability* **2020**, *12*, 6151. [CrossRef]
44. Ramani, A.; García de Soto, B. Estidama and the Pearl Rating System: A Comprehensive Review and Alignment with LCA. *Sustainability* **2021**, *13*, 5041. [CrossRef]