

Article

Multi-criteria analysis of green bonds: A hybrid AHP–COPRAS application

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Abstract: There is an increasing pressure by community and customers forcing companies to insert environmental concerns in their practices. To help companies initiatives, the green bonds market was incepted. Our research question is how to select bonds in a growing billion-dollar market. This paper presents a multi-criteria decision analysis (MCDA) model to enable investors identify opportunities based not only in opinions, but grounded on objective facts. Analytic Hierarchy Process (AHP) and Complex Proportional Assessment (COPRAS) are two MCDA methods applied in this paper. Top-fifteen green bonds ranked by specialized media were assessed with the proposed MCDA model. Criteria included the Environmental Performance Index (EPI) proposed by Yale University, and common financial indicators as assets, risks (β), and dividends. The new AHP–COPRAS rank is compared with another published by specialized media.

Keywords: AHP; COPRAS; corporate finance; environmental performance; financial planning; green bonds; MCDA

1. Introduction

Developed by Yale University, the Environmental Performance Index (EPI) provides a data-drive summary of the state of sustainability around the world [1]. EPI is obtained with 32 indicators, across 11 categories under two policy objectives: ecosystem vitality and environmental health [2,3]. With EPI it is possible to identify the greenest countries around the world.

Zooming into company-level, the increased pressures from community and environmentally conscious consumers force companies to insert environmental concerns in their management practices [4,5]. To help companies initiatives, green bonds were inserted in 2007, as bonds issued to support environmental projects [6]. As a matter of fact, the green bond market is a potential source of climate finance for developing countries [7].

Over US\$ 600 billion were issued in green bonds in 2020, nearly doubling the US\$ 326 billion issued the year before [8]. This 53% growth, in a twelve-month basis, includes green, social and sustainability bonds. The multi-billion-dollar market is tracked by most popular financial services worldwide [9,10]. Nevertheless, most relevant investment funds have already moved assets on this path. The question is no longer if green bonds have a relevant market. The question is how to select bonds in this new reality. This is the main goal of this article: to offer a simple framework for bonds selection, beyond financial reports and reviews. This paper presents a multi-criteria decision analysis (MCDA) model to enable investors identify opportunities based not in opinions, but grounded on objective facts. Since green bonds are a new trend in corporate finance, the MCDA proposal for their assessment is the major novelty of this work.



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There are dozen methods for MCDA [11]. Analytic Hierarchy Process (AHP) and Complex Proportional Assessment (COPRAS) are the MCDA methods applied in this paper. AHP and COPRAS were chosen due to a main characteristics of the decision problem: a limited set of alternatives [12]. AHP [13,14], a leading MCDA method, is applied for weighting the criteria. In AHP, weights for the criteria are obtained with pairwise comparison matrix. However, when the number of alternatives increases, the effort for the AHP application is also increased[15]. Then, COPRAS [16] is applied to assess the alternatives, which are real green bonds. COPRAS has been applied for the economic selection alternatives, mainly in manufacturing applications [17,18]. Hybrid methods applications is a new trend in MCDA literature [19,20]

Section 2 presents a literature review, highlighting the new MCDA method COPRAS. Section 3 presents methodology, with MCDA methods AHP and COPRAS. Section 4 presents the results of the hybrid AHP–COPRAS application. Section 5 presents a discussion on the main results. Finally, Section 6 presents conclusions and directions for future research.

2. Literature review

In MCDA literature, research on COPRAS has a positive trend, according to Scopus Database (Figure 1). There are 24,863 documents on MCDA, and only 417 on COPRAS, published in the last fifteen years. However, 264 documents on COPRAS, or 60%, were published in the last five years.

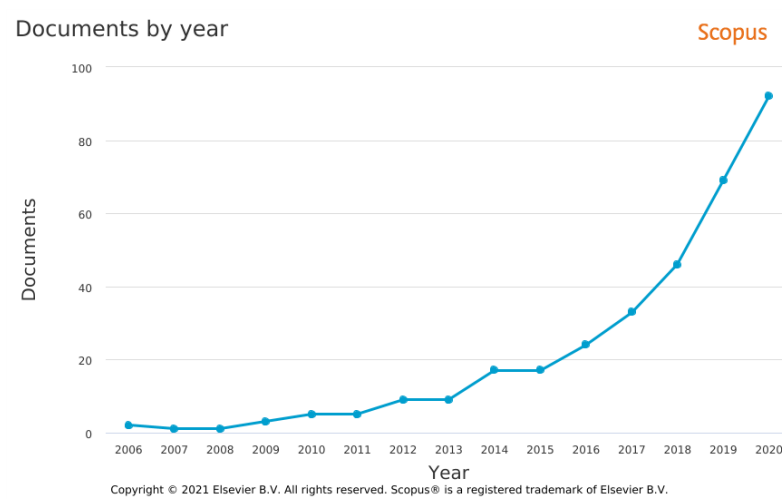


Figure 1. Published documents on COPRAS, by year

Narrowing Scopus search with “economics” or “investment”, publications on COPRAS still has a positive trend (Fig. 2).

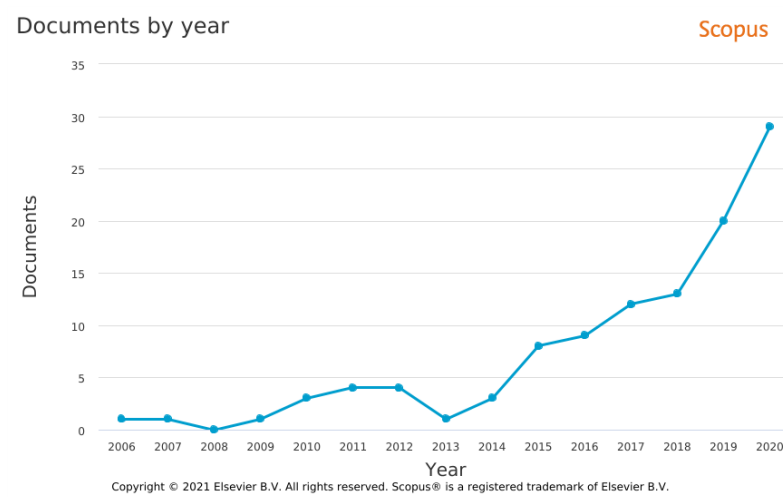


Figure 2. Published documents on COPRAS and "economics" or "investment", by year

Literature on "green bonds" is just beginning. The search TITLE-ABS-KEY("green bond") on Scopus Database resulted in only 258 documents, by July 14, 2021. None with COPRAS or MCDA, in title, abstract or keywords (TITLE-ABS-KEY). Therefore, there is a research gap on MCDA applications on green bonds. The objective of this paper is to present an MCDA model to green bonds assessment.

Table 1 presents an overview of most cited publications on green bonds. A similar overview was presented by Kucera, Vochozka and Rowland[21], for their research on the economic value added.

Table 1. Most cited publications on green bonds

Reference	Year	Citations	Main findings
[22]	2019	91	Low impact of investors' pro-environmental preferences on bond prices.
[23]	2018	61	Green bonds have negligible diversification benefits for investors in corporate and treasury markets.
[24]	2018	47	Liquidity has explanatory power for the yield spread of green bonds.
[25]	2018	47	Financial and corporate green bonds trade tighter than their comparable non-green bonds, and government-related bonds on the other hand trade marginally wider.
[26]	2020	45	Firm's issuance of green bonds is beneficial to its existing shareholders.
[27]	2019	43	Green bonds are more financially convenient than non-green ones, then they can potentially play a major role in greening the economy without penalizing financially the issuers.
[28]	2019	40	The issuer's reputation or green third-party verification are essential to reduce informational asymmetries, avoid suspicion of green bond washing, and produce relatively more convenient financing conditions.
[29]	2016	40	Asian economies should focus on reducing financial barriers towards renewable energy projects.
[6]	2016	39	A shock in the conventional bond market tends to spill over into the green bond market, where this spillover effect is variable over time.

3. Methodology

3.1. Generalities

This paper presents the application of MCDA methods for the assessment of green bonds. Figure 3 presents the steps of the proposed research methodology, including AHP and COPRAS applications, as presented in Sections 3.2 and 3.3.

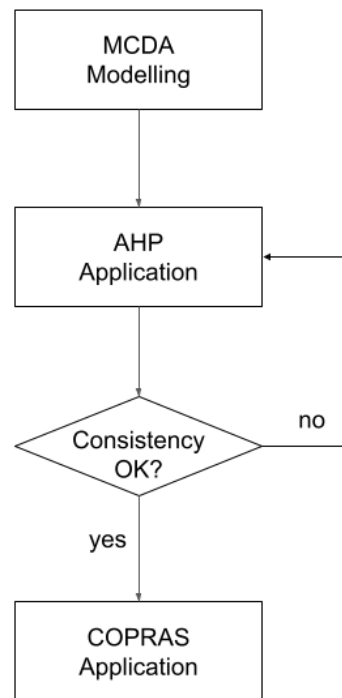


Figure 3. Research methodology

In the first step, the criteria and alternatives for multi-criteria analysis are defined, as presented in Section 4. The next step is the AHP application, weighting the criteria. As presented in Section 3.2, one of the greatest advantages of AHP against other methods is the Consistency Checking. If data processed by AHP were not consistent, the AHP application, including data provided by experts needs to be revised. If consistency is OK, the final step is assessment of alternatives (green bonds) with COPRAS.

3.2. Analytic Hierarchy Process

AHP is a leading MCDA method [30], not only in supply chain management, but in diverse areas, such as chemical engineering, computer science, ecology, energy sector, health sector, higher education sector, manufacturing, mathematical advances, supply chain management and logistics [31]. One important limitation of AHP is on the number of alternatives and criteria. Due the use of pairwise comparison matrices, a three-level hierarchy model must have no more than nine criteria or alternatives [32]. This limitation is one of the main reasons for a new trend in MCDA literature: hybrid-method application, mainly with AHP and Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) [33] or Fuzzy Sets Theory (FST). This paper moves away from that trend combining AHP with COPRAS.

In AHP, weights for the criteria, usually named priorities, are obtained normalizing the right eigenvector w of the pairwise comparison matrix A , as in Equation 1, where λ_{max} is its maximum eigenvalue.

$$Aw = \lambda_{max}w \quad (1)$$

Consistency checking is one of the great advantages of AHP against other MCDA methods. A consistent pairwise matrix A satisfies $a_{ij} = a_{ik}a_{kj}$, for $i = 1, 2, 3 \dots n$, $j = 1, 2, 3 \dots n$, and $k = 1, 2, 3 \dots n$, resulting in $\lambda_{max} = n$, where n is the number of criteria. Consistency index μ is a measure of consistency of a pairwise matrix, as in Equation 2.

$$\mu = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

Consistency ratio CR is a better measure since it compares μ with a random index RI , computed by Oak Ridge Laboratory with more than 50,000 matrices [13], as in Equation 3.

$$CR = \frac{\mu}{RI} \quad (3)$$

Consistent matrices have $\lambda_{max} = n$, then $\mu = 0$ and $CR = 0$. Inconsistent matrices have at least one comparison, and its reciprocal, $a_{ij} \neq a_{ik}a_{kj}$, resulting in $\lambda_{max} > n$. It is desirable that $CR \leq 0.1$, then A may be accepted, meaning "conformity with previous practice" or that decision-makers did not change their minds, when fulfilling a pairwise comparison matrix.

Alternatives could be assessed regarding each criteria, resulting their importance, likelihood, membership, or preference x . In AHP, these values of preferences are usually named as local priorities of alternatives [14]. However, according to AHP theory, pairwise comparison matrices are limited to order 9×9 [34]. Fortunately, there are available data for green bonds performance on a set of criteria, as presented in Section 3. The decision matrix $X = [x_{ij}]$ is composed by performances of Alternative i regarding Criterion j , with $i = 1, 2, 3 \dots m$ and $j = 1, 2, 3 \dots n$.

3.3. Complex Proportional Assessment

In COPRAS, X must be firstly normalized to R , as in Equation 4, for $i = 1, 2, 3 \dots m$ and $j = 1, 2, 3 \dots n$.

$$r_{ij} = \frac{x_{ij}}{\sum_{j=1}^n x_{ij}} \quad (4)$$

Then, normalized decision matrix R must be weighted to D , as in Equation 5, for $i = 1, 2, 3 \dots m$ and $j = 1, 2, 3 \dots n$.

$$d_{ij} = r_{ij}w_j \quad (5)$$

Criteria must be identified as beneficial or non-beneficial. Then, for every Alternative i weighted normalized performances must be summed for beneficial, S_+ , and non-beneficial criteria, S_- , as in Equations 6 and 7.

$$s_{+i} = \sum_{j=1}^n d_{ij} \text{ for beneficial criteria} \quad (6)$$

$$s_{-i} = \sum_{j=1}^n d_{ij} \text{ for non-beneficial criteria} \quad (7)$$

Then, the significance of Alternative i , q_i , is obtained with Equation 8, for $i = 1, 2, 3 \dots m$.

$$q_i = s_{+i} + \frac{\min(s_{-i}) \sum_{i=1}^m s_{-i}}{s_{-i} \sum_{i=1}^m \frac{\min(s_{-i})}{s_{-i}}} \quad (8)$$

Finally, relative utility of Alternative i , u_i , is obtained with Equation 9, for $i = 1, 2, 3 \dots m$.

$$u_i = \frac{u_i}{\max(u_i)} \quad (9)$$

Despite the same name, U is not the linear utility function, as in Multi-Attribute Utility Theory [15]. Eventually, a COPRAS application may result alternatives without zero

utilities and even negative utilities. Alternative i with the highest utility, $u_i = 1$, is the best one.

4. Results

As previously mentioned in Section 1, the objective of this paper is to assess investment options, with a MCDA model instead of the traditional valuation method. For that, top-fifteen green funds, ranked by specialized media[35], were selected. Seven indicators of this evaluation were selected as criteria, alphabetically by acronym:

- Assets (AST): Volume of capital invested on each fund, expressed in US dollars (USD).
- Risk (BET, for Greek letter beta, β): Risk exposure of a company, stock, fund or any other form of investment traded in open market.
- Dividend Yield (DIV): How much a company pays yearly on dividends per its stock prices. It is a ratio that express the profitability of an investment.
- Country's EPI (EPI): Environmental Performance Index of bond's country, as in Yale's 2020 ranking.
- Share (SHR): The cost of each participation quota on a fund, in USD.
- Expenses (XPS): Administrative costs of each fund, expressed as a percentage for every dollar invested by a group or individual.
- Returns (YTD, from year-to-date): Amount of profits or losses realized by a given investment, since the first trade of the current calendar year, in USD.

Table 2 presents a pairwise comparison matrix A and weights of criteria w . Comparisons were provided by one of this paper authors, based on his previous experience in American and Brazilian financial markets. The consistency ratio, $CR \approx 0.077$ indicates that A can be accepted.

Table 2. Pairwise comparison matrix and weights of criteria

Criteria	AST	BET	DIV	EPI	SHR	XPS	YTD	Weight
Assets (AST)	1	1/3	1	7	3	3	1	17.1%
Risk (BET)	3	1	1	7	1	5	1/3	18.4%
Dividend Yield (DIV)	1	1	1	9	3	3	1	20.7%
Country's EPI	1/7	1/7	1/9	1	1/5	1/5	1/9	2.1%
Share (SHR)	1/3	1	1/3	5	1	3	1/3	10.2%
Expenses (XPS)	1/3	1/5	1/3	5	1/3	1	1/5	5.5%
Returns (YTD)	1	3	1	9	3	5	1	26.1%

Table 3 presents the decision matrix X . Data were collected from <https://epi.yale.edu> and <https://www.kiplinger.com>. Bonds names were suppressed for confidentiality reasons. After all, despite their data, including, their names are public, this paper is not intended to advertise or to promote any green bond.

Table 3. Decision matrix

Bond	AST [USD]	BET	DIV	EPI	SHR [USD]	XPS	YTD [USD]
1	13,200,000,000	1.03	1.05	69.3	40.97	0.14%	12.02
2	478,000,000	0.90	0.93	69.3	98.22	0.49%	5.51
3	27,610,000,000	0.86	0.40	69.3	60.70	0.84%	13.23
4	7,880,000,000	0.95	0.18	69.3	44.02	0.98%	7.95
5	16,500,000,000	1.20	1.20	69.3	95.23	0.15%	13.05
6	7,300,000,000	1.20	1.30	69.3	44.90	0.25%	6.38
7	5,400,000,000	1.20	1.60	69.3	79.21	0.20%	8.68
8	5,500,000,000	1.20	0.40	69.3	23.24	0.46%	-19.17
9	1,100,000,000	0.99	1.20	69.3	104.77	0.20%	12.85
10	870,000,000	0.99	0.95	81.3	33.06	0.78%	5.00
11	917,000,000	0.96	1.25	69.3	37.49	0.35%	16.03
12	834,000,000	0.00	0.50	69.3	44.00	0.40%	5.00
13	6,600,000,000	1.13	1.53	69.3	10.55	0.64%	5.00
14	783,000,000	1.57	2.02	69.3	27.63	0.18%	-1.71
15	193,000,000	1.01	0.70	69.3	23.67	0.10%	5.00

Table 4 presents the normalized decision matrix R , obtained from X , as in Equation 4.

Table 4. Normalized decision matrix

Bond	AST	BET	DIV	EPI	SHR	XPS	YTD
1	0.139	0.068	0.069	0.066	0.053	0.020	0.127
2	0.005	0.059	0.061	0.066	0.0128	0.069	0.058
3	0.290	0.057	0.026	0.066	0.079	0.119	0.140
4	0.083	0.063	0.012	0.066	0.057	0.139	0.084
5	0.173	0.079	0.079	0.066	0.124	0.021	0.138
6	0.077	0.079	0.086	0.066	0.058	0.035	0.067
7	0.057	0.079	0.105	0.066	0.103	0.028	0.092
8	0.058	0.079	0.026	0.066	0.030	0.065	-0.202
9	0.012	0.065	0.077	0.066	0.136	0.028	0.136
10	0.009	0.065	0.063	0.077	0.043	0.110	0.053
11	0.010	0.063	0.082	0.066	0.049	0.050	0.169
12	0.009	0.000	0.033	0.066	0.057	0.057	0.053
13	0.069	0.074	0.101	0.066	0.014	0.091	0.053
14	0.008	0.103	0.133	0.066	0.036	0.025	-0.018
15	0.002	0.066	0.046	0.066	0.031	0.142	0.053

Table 5 presents the normalized weighted decision matrix D , obtained from R , as in Equation 5.

Table 5. Normalized weighted decision matrix

Bond	AST	BET	DIV	EPI	SHR	XPS	YTD
1	0.02377	0.01251	0.01428	0.00139	0.00541	0.00110	0.03315
2	0.00086	0.01086	0.01263	0.00139	0.01306	0.00380	0.01514
3	0.04959	0.01049	0.00538	0.00139	0.00806	0.00655	0.03654
4	0.01419	0.01159	0.00248	0.00139	0.00581	0.00765	0.02192
5	0.02958	0.01454	0.01635	0.00139	0.01265	0.00116	0.03602
6	0.01317	0.01454	0.01780	0.00139	0.00592	0.00193	0.01749
7	0.00975	0.01454	0.02174	0.00139	0.01051	0.00154	0.02401
8	0.00992	0.01454	0.00538	0.00139	0.00306	0.00358	-0.05272
9	0.00205	0.01196	0.01594	0.00139	0.01387	0.00154	0.03550
10	0.00154	0.01196	0.01304	0.00162	0.00439	0.00605	0.01383
11	0.00171	0.01159	0.01697	0.00139	0.00500	0.00275	0.04411
12	0.00154	0.00000	0.00683	0.00139	0.00581	0.00314	0.01383
13	0.01180	0.01362	0.02091	0.00139	0.00143	0.00501	0.01383
14	0.00137	0.01895	0.02753	0.00139	0.00367	0.00138	-0.00470
15	0.00034	0.01214	0.00952	0.00139	0.00316	0.00781	0.01383

Assets, Dividend Yield, Country's EPI, and Returns are beneficial criteria. Otherwise, Expenses, Risk, and Share are non-beneficial criteria.

Table 6 presents the normalized performance for beneficial S_+ and non-beneficial S_- criteria, relative significance Q and utility U of alternatives, obtained as in Equations 6–9.

Table 6. Results from AHP–COPRAS application

Bond	S_+	S_-	Q	U
1	0.073	0.019	0.098	1
2	0.030	0.028	0.030	0.306
3	0.093	0.025	0.093	0.949
4	0.040	0.025	0.040	0.408
5	0.083	0.028	0.083	0.847
6	0.050	0.022	0.050	0.510
7	0.057	0.027	0.057	0.582
8	-0.036	0.021	-0.036	-0.367
9	0.0550	0.027	0.055	0.561
10	0.030	0.022	0.030	0.306
11	0.064	0.019	0.064	0.653
12	0.024	0.009	0.024	0.245
13	0.048	0.020	0.048	0.490
14	0.026	0.024	0.026	0.265
15	0.025	0.023	0.025	0.255

5. Discussion

Table 7 presents the rank of Kiplinger's top-fifteen green bonds with AHP-COPRAS application. Ranks only coincided in the pole position and in the tenth position, with tie between Bonds 2 and 10 with AHP-COPRAS.

Table 7. Rank with AHP-COPRAS application

Bond	New rank
1	1
2	10
3	2
4	9
5	3
6	7
7	5
8	15
9	6
10	10
11	4
12	14
13	8
14	12
15	13

Bond 2 is the most downranked green bond with AHP-COPRAS. Otherwise, Bond 11 is the most upranked green bond. The correlation coefficient between Kiplinger's rank and AHP-COPRAS rank is around 0.56, indicating a moderate positive correlation between the ranks. This result was expected by authors, since AHP-COPRAS added important subjectivity to green bonds assessment, weighting their performance indicators.

Coincidences and correlation are indications those ranks were pointing for the same direction. The divergence on other positions, was due to different ranking methodologies. Perhaps, more detailed comparison from the ranks, for instance with compatibility indices [36,37], may be useful for this specific discussion.

When there are resources limitation, top rank changes may result in the selection of a new green bond against another. For instance, if there were resources only for three bonds, MCDA application will change the top-three rank from 1-2-3 portfolio to 1-3-5. In this case, Bond 2 will be no longer selected, being replaced by Bond 5.

That is the main managerial implication of our work: Portfolio selection not only based in a single criteria, as Assets, Risks or Dividend Yield. Our methodology proposes a multi-criteria assessment, with MCDA methods as the leading AHP and the new method COPRAS.

6. Conclusions

This paper achieved its main objective presenting an hybrid MCDA assessment of green bonds, with applications of AHP and COPRAS. A consistent pairwise matrix was provided on the criteria, by one expert in financial market. Data were collected from specialized database as Kiplinger magazine and Yale University's Center for Environmental Law & Policy.

A different rank was obtained with MCDA. However, there is moderate positive correlation between the ranks. Outstandingly, both ranks coincided in the pole position. Coincidence is an indication those ranks pointing for the same direction. Divergence was due to different ranking methodologies. The green bonds assessment with COPRAS is the major novelty of this paper. Besides the novelty of the method, literature searches have not found an MCDA study in the promising field of green bonds.

Future research directions include the extension of green bonds from other countries than UK (Bond 10) and UK (all other bonds). Other MCDA methods may also included, incorporating decision approaches as Delphi Method or Fuzzy Systems. The consideration of dependency and feedback among criteria could be incorporated to another model, with the Analytic Network Process (ANP).

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Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic Hierarchy Process
AST	Assets
BET	Risk (for Greek letter beta, β)
COPRAS	Complex Proportional Assessment
DIV	Dividend yield
EPI	Environmental Performance Index
FST	Fuzzy Sets Theory
MCDA	Multi-criteria decision analysis
SHR	Share
TITLE-ABS-KEY	Title–abstract–keywords search
TOPSIS	Technique of Order Preference by Similarity to Ideal Solution
UK	United Kingdom
USA	United States of America
USD	United States dollar
XPS	Expenses
YTD	Returns (from year-to-date)

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