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Interpretation of Fairness Concept and Economic Impact Analysis of Carbon Quota Allocation between Industries in Indonesia

M H Imaduddin[1,*], T Ogawa[1], H Okumura[1], K Ishihara[1]

[1]Graduate School of Energy Science, Kyoto University, Japan

Corresponding author: imaduddin987@gmail.com

Abstract. Quota allocation is critical in implementing supporting policies for carbon reduction efforts, such as the carbon cap and trade mechanism. Depending on the allocation rules, certain company types may benefit more economically. Inequality conditions can happen and reduce the willingness to participate in sustainability efforts. This study aims to propose fairness interpretations in the context of company-level carbon quota allocation. Four industries in Indonesia with inherently different emission and financial profiles were selected as case studies: energy, oil palm, basic materials, and finance. Fairness principles were analyzed to represent the interests of companies based on their financial and environmental performance. Indicators were selected to quantify the equality principles and aggregated into a Comprehensive Index (*CI*) for quota allocation, where the companies' quota surplus/deficit is quantified into monetary value to estimate the economic impact with varying reduction targets. According to our analysis, the sectoral advantages/disadvantages would depend on the viewpoint of fairness principles, and the oil palm and financial sectors be less impacted than the basic materials and energy sectors with increased emission reduction targets. The sensitivity analysis suggests that the vertical, horizontal, polluter pays, and historical responsibility principles are more sensitive to weighting than the merit and basic needs principles.

1. Introduction

1.1. Background

Reducing emissions is critical in combating the global climate change. Indonesia as one of the major global economies has declared to participate and reduce its emissions by 29% (unconditional scenario) or 41% (by international assistance) through 2030 [1].Despite the commitment and effort that has been made the global and Indonesian emission trends have shown a steady increase over the years. Indonesia experiences a faster rate of emission growth at 37.9% from 437 Mt CO2eq in 2010 to 603 MT CO2eq in 2021, compared to the global annual emission at 10.8% from 34158 Mt CO2eq in 2010 to 37857 Mt CO2eq in 2021[2].

To mitigate the emission growth rate Indonesia announced the introduction of the carbon tax and carbon cap and trade (CCT) schemes supporting policies [3,4]. The methods have been widely adopted globally to encourage emission reduction. The EU countries are among the first to implement the systems since the 1990s, followed by higher-income Asian countries (Japan, China, Korea, and Singapore) in the 2010s. Data from the World Bank shows that revenue from both schemes grew 640% between

2010 and 2022, from 13391 to 86100 million USD, and 11.66 Gt CO2eq of emission have been covered in 2023 (accounting for 23% of global emissions) [5]. With the growing scale, the systems have globally become critical parts of policy instruments for carbon reduction.

Market-based policy instruments for emission reduction require the participation of emitters at every level. With more participants, the problem of how the decarbonization burden is divided amongst them emerges and becomes more complex [6-8]. The CCT is a market-based mechanism that encourages emission reduction by gradually reducing emissions quotas and engaging carbon transactions from participating emitters [9, 10]. The allocated carbon quota depends on the scope and context of the reduction [11-13]. The scarcity of the quota will create a higher demand and thus increase the carbon price to the point that it is more economical to perform green investments. The quota allowance given to each emitter directly affects their revenue and profit. Meanwhile, emitters' perspectives of fairness can be different from one to another and it depends on their emission and economic profile [14]. Therefore quota allocation for each emitter should be determined carefully based on multiple emitters' perspectives and for maintaining emitters' willingness to participate in emission reduction efforts [6]. The quota allocation problem is illustrated in Figure 1 below.

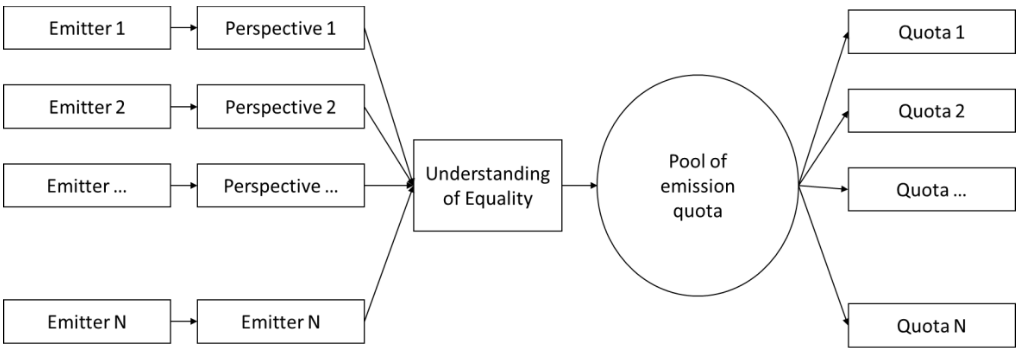

Figure 1. Illustration of multiple emitters' perspectives of quota allocation

The focus of research on equality in carbon burden sharing has shifted over the years since the Kyoto Protocol in 1998. The papers closer to 1998 generally focus on the context of international emission burden-sharing distribution and carbon trading [8, 14-17]. Cost-effectiveness and impact on the country's economy are the main focus of earlier papers [8, 15]. The differences in perspective between higher-income and lower-income countries on how the emission reduction burden should be shared are also highlighted [14]. Lower-income countries prefer population-proportional emission rights. Meanwhile, higher-income countries lean towards the grandfathering rules (maintaining current emission proportion). Higher-income countries' preference is affected by their past spending on emission that used up their "lifetime quota" [18].

Recently, the research on carbon quota allocation shifted towards a smaller and more practical scope as the concept of carbon trading progressed towards the implementation stage. Numerous literatures have emerged from China due to its strong support for the implementation of the Emission Trading System (ETS). Analysis of carbon allocation between provinces is particularly essential [13, 19-27]. However, only a few papers discuss carbon quota allocation fairness in the context of sectoral and company levels [28-32]. Despite the relatively scarce literature, company-level carbon fairness is an essential topic due to companies being the main actors performing carbon transactions and emission reduction actions. Companies' participation will impact the effectiveness of ETS.

The research to develop the interpretation of carbon fairness was carried out more comprehensively to look deeper into the problem of "emissions vs. economics". Groenenberg *et al.,* [16] introduce energy efficiency as a measure of environmental performance. Yu *et al*., [33] use residential income and residential consumption as proxy indicators representing the economic side. Meanwhile, [22] proposes a composite index that quantifies the pressure on policymakers to reduce carbon emissions which is then integrated into the regional quota allocation mechanism. Zhang and Wang [26] suggest that allocation should be made based on the life cycle of carbon emissions. Zhang *et al*., [13] bring the context of regional dependence by integrating the gravity model. Gopalakrishnan *et al*., [28]suggest a different point of view by analyzing emission responsibility within a supply chain. The literature review on existing CCT systems shows that the single equality principle for quota distribution is more commonly used. The method, however, raises the problem as carbon emitters have different interests and views of what is equal. The composite index and Pareto analysis are utilized to idealize the problem and represent the weighted aggregate views [13, 14, 19, 20, 22, 24, 26, 31, 34].

1.2. Research objectives and contribution

Previous research suggests that the discussion of carbon fairness has long been a subject in international and inter-regional contexts. However, less research has focused on the context of companies, especially inter-sectoral carbon quota allocation, despite companies' critical role as main actors in emission reduction. The existing literature also shows that the majority of analyses only consider single principle or a specific sector. Study on multiple company sectors with multiple fairness perspectives is still scarce. Therefore, this research aims to study and propose the interpretation of the fairness concept for carbon quota allocation at the inter-sectoral company level, and to understand its economic implications. Indonesia is selected as a case study due to its diversity of economies and its importance in reducing global emissions.

2. Method and data

2.1. Framework of analysis

The general framework of analysis is given by the following illustration Figure 2:

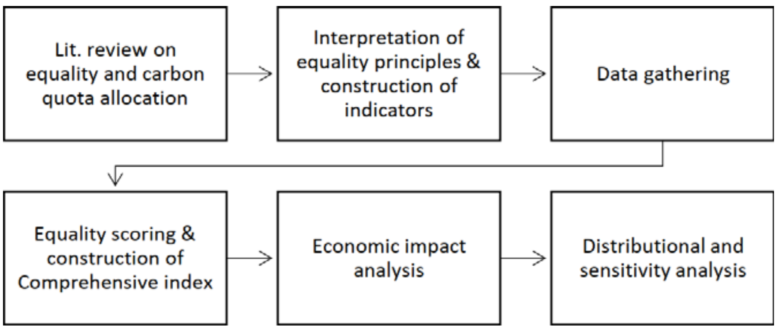

Figure 2. Framework of analysis

A literature review was conducted by using the keywords of "fairness", "equality", "inequality" "carbon quota allocation", and "emission trading system" to understand the existing concept of fairness in carbon quota allocation. Equality principles and their proxy indicators are then examined and selected to obtain a more suitable interpretation of fairness in the context of the multi-sectoral company level. A mathematical definition of equality scoring is then constructed for each principle. The individual scoring is then aggregated into a comprehensive index (*CI*). The index is then used as a multiplication factor to determine the quota allocation for each company. Economic impact analysis is performed under constant carbon price to clarify the effect of carbon reduction targets on each sector. The Gini index [35] and Lorenz curve are used for fairness analysis to quantify the inequality of quota distribution among companies. The result of the proposed method is then compared to the emission-proportional distribution method, without consideration of companies' historical emissions. The emission-proportional distribution method is used by the Tokyo Cap and Trade Program [10]. Finally, sensitivity analysis was conducted by varying the weight of each principle to understand each principle's significance on the final quota distribution, represented by standard deviation.

2.2. Data

Proxy indicators for the companies' business performance are represented by financial data of revenue, net operating income, equity, and valuation [36]. The data is obtained from the Yahoo Finance web database (https://finance.yahoo.com/) and Google Finance web database (https://www.google.com/finance/). The environmental performance is represented by the CO_2 emission and is obtained from the companies' self-published sustainability reports. Only scope I and scope II emissions are considered. Due to the limitation of publicly available data, only three years of data were collected for each indicator (2019, 2020, 2021).

Companies from four sectors were selected to represent different roles in energy stations based on emission and business characteristics. The energy sector (coal and natural gas) is selected due to its role as the primary energy producer in the current system. Meanwhile, the oil palm sector is selected based on its prospect as an alternative fuel. The oil palm is regarded as a more sustainable option compared to fossil fuel. The basic materials sector has been known for its intensive energy use compared to other sectors. Finally, the financial sector represents the sector that typically has low emissions but high market capitalization.

The list of companies is retrieved from the Indonesia Stock Exchange (IDX) Guideline for Classification [37]. Only companies with at least two data points for each indicator are considered for analysis. Linear interpolation was performed when the data from a company was incomplete. Forty-five companies were selected upon data examination, consisting of 16 energy companies, 10 oil palm companies, 9 basic material companies, and 10 financial sector companies. The complete list of the company's name and statistics is provided under the appendix A.

2.3. Method of analysis

The following section describes the detailed steps for the analysis and consideration of principle and indicator selection.

2.3.1. Interpretation of Fairness and scoring of equality principles

Equality principles of polluter pays, historical responsibility, merit, basic needs, vertical and horizontal are adopted based on their suitability for a company-level application [8, 14, 15]. Mathematical interpretation is made for each principle to reflect the definition. The equality score $P_{m,i}$ is calculated for each principle and company. Where m indicates the index of the principle, and i is the index of the company.

a) Polluter pays principle

The principle states that the abatement burden corresponds to the level of emission [8]. Therefore, the share of abatement costs across emitters should be in proportion to their emission level [20]. Within the country context, the burden should be proportional to the GDP level [14]. Similar to the GDP in the context of a country, the company revenue is a measure of its gross economic activity. Company revenue as a monetary proxy indicator can accommodate the differences in products between industries. Revenue shows a company's gross income. The polluter pays principle can understood that highly polluting companies should be responsible for their CO2 emission as a result of their revenue-generatingactivity. The ratio of revenue to emission is used to define the first principle (P_1):

$$P_{1,i} = \frac{R_i}{E_i} \qquad \textit{Equation 1}$$

Where Ri (million-USD) and Ei (kilotons of CO2eq) indicate the revenue and emission of company i in the current calculation year (2021).

Under the Emission Trading Scheme, the abatement cost is reflected by the allocated quota for each participant. A higher score value of P_1 means that the company can generate more revenue with lower emission outcomes (high efficiency) and therefore should be rewarded with more quota allocation.

b) Historical responsibility principle

Generational rights to use atmospheric resources need to be taken into account when determining the emitters' shares' of the reduction burden [13]. Countries' emission reduction burden should be proportional to their accumulated emission [14] . Researchers [12, 24] suggest that provinces with higher accumulated historical carbon emissions should be allocated smaller emission quotas. Similarly, the accumulated past emissions of a company can be viewed as emission debt and should be paid in the future by allocating less carbon emission quota. The average value of emission efficiency of a company during the observed years is used to represent its historical responsibility P_2:

$$P_{2,i} = \frac{\sum_{j=1}^{t} \frac{R_{i,j}}{E_{i,j}}}{t} \qquad \textit{Equation 2}$$

Where t is the number of observed years. In this research, three years of data from 2019, 2020, and 2021 were used. A company with a higher P_2 value reflects higher historical performance and is entitled to a larger carbon quota.

c) Merit principle

The improvement of environmental performance over time reflects the extra effort made by companies in reducing emissions. Incentives based on merit can encourage more improvement efforts to further reduce emissions. The concept of merit principle and quota incentives are suggested by [14] in terms of country and [12] in terms of regional context. In this study, the scoring for merit principle P_3 is defined as:

$$P_{3,i} = 1 - \frac{E_{0,i}}{R_{0,i}} * \frac{R_{-t,i}}{E_{-t,i}} \qquad \textit{Equation 3}$$

Where $-t$ is the index of the base year. The equation represents the change in environmental performance indicated by the ratio of revenue (R) and emissions (E) between the current year (2021) and the base year (2019). A higher P_3 value means that a higher improvement, hence more quota is given to the company with a higher P_3 value.

d) Basic needs principle

Countries need to emit minimal level emissions to satisfy the basic needs of the population [8]. A minimum level of emission performance is also required by companies to economically sustain their operations. Companies that are listed in the IDX are assumed to be able to economically sustain themselves. Therefore, the burden resulting from carbon pricing should not deprive the net income of the participating company that it could not sustain its operation. The net income indicates company income after operations, administrative, and depreciation costs. A negative net income indicates that a company will not be able to economically sustain its operations. The basic needs principle (P_4) is then translated by comparing a company with the bottom performers in its respective sector, given by:

$$P_{4,i} = \begin{cases} \alpha_i & \alpha_i < \alpha_{70} \\ \alpha_{70} & \alpha_i \geq \alpha_{70} \end{cases} \qquad \textit{Equation 4}$$

$$\alpha_i = \frac{E_i}{I_i}$$

Where α_i is the ratio of company i emission (E_i) to its net income (I_i), and $\alpha_{s,70}$ is the 70th percentile of the ratio from companies within the evaluated sector s. A higher value of α means a company has a lower capability to pay its emissions using its available income hence it requires more quota to relax its carbon burden. Company with α ratio on the 70th percentile and above is assumed to be bottom performers in their respective sector.

e) Vertical principle

Bigger economies have a greater ability to pay for the emission burden [8]. Therefore, the net abatement cost should also be positively correlated to the GDP, suggesting that richer provinces have stronger emission reduction capacity [14, 20, 24]. The region with higher added value has more scope to reduce emissions. *Zhang et al*., [13] also demonstrated proportional quota allocation to the power plant's capacity. Similarly, larger companies have a smaller ratio of emission reduction costs to company size. Meaning that it uses a lower economic ability to reduce emissions relative to its size compared to smaller companies. Considering the proportionality, smaller companies should be given more quota allocation to ease the carbon burden and maintain their business sustainability. The vertical equality principle score P_5 is represented by:

$$P_{5,i} = \frac{V_i}{E_i} \qquad \textit{Equation 5}$$

Where Vi is the valuation of the company i.

The mixed valuation method is used as the company with different sectors, levels of maturity, and business models are involved. The valuation can be estimated by the UEC mixed method given by the following formula [36]:

$$V_i = \frac{A_i + (a_{n,i} * I_i)}{1 + int_i * a_{n,i}} \qquad \textit{Equation 6}$$

Where Ai is the corrected asset of the company i. The corrected asset can be understood as equity (Q), defined as the company's total asset minus the liability. I_i is the net income of company i, int is the interest rate of comparable investment and $a_{n,i}$ is the present value of the company i. The rate of comparable investment is assumed to be 5%, referencing the lower value of the coupon rate of Indonesia's state bonds (Central Bank of Indonesia: https://www.bi.go.id/id/archive/ obligasi-negara/default.aspx). The present value of company i (PVi) reflects the monetary value of time and can be estimated with the present value formula:

$$a_n = PV_i = \frac{1 - (1 + r)^{-t}}{r_i} \qquad \textit{Equation 7}$$

The notation r_i refers to the discount rate. The discount rate is understood as the company's profitability and can be calculated by using the Compounded Annual Growth Rate ($CAGR$) formula:

$$r_i = CAGR_i = \left(\frac{CV_i}{BV_i}\right)^{\frac{1}{t}} - 1 \qquad \textit{Equation 8}$$

CV_i and BV_i are the current and base year valuation of the company i, whereas t is the number of years. In this research, the present and past value of equity is used for CV_i and BV_i.

f) Horizontal principle

Countries with similar economic circumstances have similar emission rights and burden-sharing responsibilities [8]. Therefore, companies with similar business profitability performance should also be obliged with similar emission burdens regardless of sector. The Return on Equity is an indicator thatis commonly used to measure the company's profitability. The formula is given by subtracting the company's net income I_i from its equity Q_i:

$$RoE_i = \frac{I_i}{Q_i} \qquad \textit{Equation 9}$$

Companies with higher ratios of profitability should be obliged by a higher amount of reduction burden or given less carbon quota. The score value of the horizontal principle for the company i, $P_{6,i}$ is then given by:

$$P_{6,i} = \frac{1}{RoE_i} \qquad \textit{Equation 10}$$

A higher P_6 score represents less profitability for a company, therefore, more quota should be given.

2.3.2. Scores Normalization

Normalization is carried out to standardize the range between the scoring of the principles. The Min-max normalization is one of the most commonly used methods and can accommodate data with both positive and negative values. The results of normalization range from 0 to 1. Generally, a higher score means more quota should be given to a company for all principles. An exception is on principle 5 (vertical principle), where a company with a lower score should be given less quota. The normalization formula used for principles 1, 2, 3, 4, and 6 is:

$$PN_{m,i} = \frac{P_{m,i} - P_{m,\min}}{P_{m,max} - P_{m,min}} \qquad \textit{Equation 11}$$

Where PN_{mi} is the normalized score value of company *i* for principle m. $P_{m,min}$ is the companies' minimumscore for the principle *m*. $P_{m,max}$ is the companies' maximum score for the principle *m*. The normalization formula for P_5 is given by:

$$PN_{m,i} = -\frac{P_{m,i} - P_{m,max}}{P_{m,max} - P_{m,min}} \qquad \textit{Equation 12}$$

2.3.3. Construction of Comprehensive Index

Compromises between these emitters should be made so that equality represents the weighted aggregate views [13, 14, 19, 20, 22, 24, 26, 31, 34]. In this research, a comprehensive index is constructed for each company by aggregating all of the scoring values. Depending on the data condition certain types of aggregation can be selected [38]. For example, geometric aggregation is usually used for collections of values with high standard deviation. In this research, arithmetic mean aggregation is used since the scoring values have previously been normalized. The comprehensive index of the company *i* (CI_i) is given then by:

$$CI_i = \sum\nolimits_{m=1}^{k} w_m PN_{m,i} \qquad \textit{Equation 13}$$

Where w_m is the weight factor of principle *m* and *k* is the number of principles (k = 6). The w_m value is assumed to be 1 for all principles, initially.

2.3.4. Quota distribution. The basic premise of quota distribution is that a company is given a quota linearly proportional to its emission size and *CI* score. The calculation starts with determining the total available quota (Qt_{total}), which depends on the reduction target (*RT*). The total quota is calculated as:

$$Qt_{total} = (1 - RT)\sum\nolimits_{i=1}^{n} E_i \qquad \textit{Equation 14}$$

Where *RT* is an exogenous variable assumed between 0 to 30% value. The quota in Tones of CO2eq for each company is then can be calculated as:

$$Qt_i = \frac{CI_i * E_i}{\sum_{i=1}^{n} CI_i * E_i} * Qt_{total} \qquad \textit{Equation 15}$$

2.3.5. Economic surplus and deficit. Higher reduction targets mean less quota to be distributed. The given quota for a company Qt_i can be proportionally higher or lower than its current emission level depending on the *CI*. A quota surplus happens when a company's quota is higher than the emission level. This surplus can be sold to other participants that require more quota. The amount of money (M_i) a company spends or receives can be calculated by multiplying the surplus or deficit (Tonnes of CO_2eq) by the carbon price (*CP*):

$$M_i = (Qt_i - E_i) * CP \quad \textit{Equation 16}$$

For simplicity of analysis, the carbon price (*CP*) is assumed at a fixed price of USD 2.1/Tones of CO_2eq [39]. Sectoral surplus or deficit is the result of the aggregation of all companies within a sector, calculated as:

$$MS_s = \sum_{i=1}^{n} M_i \quad \textit{Equation 17}$$

Where MS_s is the monetary surplus or deficit in sector *s*, and *n* is the number of companies in the sector *s*.

2.3.6. Distributional and sensitivity analysis. Inequality measures such as the Gini index, Atkinson index, and Thiel index is often used in conjunction with multiple equality principle for quota allocation and distributional analysis [12, 21-23, 26, 27]. Other approaches including the Multicriteria Decision Making Analysis (MCDA) family [12, 14, 24, 29, 34] and the Shapley value method [13, 33, 40] can also be used to measure the equal carbon burden.

In this research, the Gini index is selected due to its *simplicity* and the character of the data being analyzed. The index measures the deviation of cumulative population income distribution to the perfect inequality line. The Gini value (*G*) can be calculated by the mean difference method as:

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|x_i - x_j|}{2n^2\mu} \quad \textit{Equation 18}$$

Where x_i is the proportion of quota given to the company *i* relative to its emission, *n* is the total number of companies, and μ is the average *x* value of the companies. It should be noted that x_i should be arranged from the smallest to the largest when calculating the Gini value.

The Lorenz curve is often used to visualize the Gini ratio of a population. The curve is created by plotting the cumulative population (abscissa) against its cumulative income (ordinate). In this research, population refers to the collection of companies and cumulative income refers to the ratio of a company's obtained quota to its actual emission. The equality line represents the quota allocation based on the emission-proportional distribution method. Hence, the deviation from the equality line reflects the distribution differences with the emission-proportional distribution method.

The sensitivity analysis is performed by varying the weight of each principle. The standard deviation of the final quota distribution proportional to emission is used to measure the distributional change along the weighting value. The standard deviation (σ) is given as:

$$\sigma = \left(\frac{\sum_{i=1}^{n}(x_i - \mu)}{N}\right)^{\frac{1}{2}} \quad \textit{Equation 19}$$

3. Results and discussion

3.1. Scoring of the equality principles and *CI*

Scores of each equality principle are aggregated to a *CI*. A higher *CI* value means more quota advantage is given to a company. **Table 1** shows the average score value for each sector. Under the polluter pays principle the finance sector obtains the highest value of 0.35, far above basic materials, oil palm, and energy sectors (0.037, 0.034, 0.027). These results can be explained since the finance sector generates revenue mostly from financial services (lending, borrowing, institutional investment) which require little energy consumption during its operation. Meanwhile, the coal mining, oil palm plantation, and basic materials sectors require more intensive energy consumption or emit more CO_2 as a result of their operation.

The scoring results of historical responsibility principles yield similar results since the principle represents past emissions. The financial sector obtains the highest score of 0.276, far above the basic materials, oil palm, and energy sectors which score 0.026, 0.16, and 0.12, respectively.

In contrary to the first two principles, the merit principle yields more uniform results across sectors. The similarity shows that a similar level of emission reduction effort is performed by companies across sectors over the data observation period (2019-2021). The oil palm sector obtains the highest score (0.633) followed by the energy (0.572), finance (0.547), and basic materials sector (0.533).

The basic needs principles show similar value for energy, oil palm, and basic materials sectors. Companies are compared with their peers within the same sector when interpreting the principle. The similar results show that there is a similarity of companies' emissions to the net income profile ratio (*E/I*) distribution profile between sectors. The energy sector shows a slightly higher score value of 0.654, compared to the finance (0.607), oil palm (0.601), and basic materials (0.549). A higher score value means that the E/I value within the sector is more uniformly distributed.

The vertical principle compares the ratio of company valuation to its emission. Companies with higher ratios are interpreted to have a stronger ability to reduce their emissions, hence they should be given less quota, represented by a lower score value. The finance sector scores lower than the rest (0.707). While the energy, basic materials, and oil palm score similarly (0.972, 0.975, 0.978).

Under the horizontal principle, the basic materials have the highest score value (0.118) due to their low profitability ratio compared to their equity value. A low ratio of profitability to equity means that a company cannot perform business well with the asset on its own. Poorly performing companies should not be burdened more by carbon pricing, hence they should be given more quota. The finance, oil palm, and energy sectors obtained the score value of 0.010, 0.004, and 0.002, respectively.

Table 1. Sectoral scoring for the six equality principles

Sector	Polluter pays	Historical responsibility	Merit	Basic needs	Vertical	Horizontal	*CI* score
Energy	0.027	0.012	0.572	0.654	0.972	0.002	2.240
Oil palm	0.034	0.016	0.633	0.601	0.978	0.004	2.266
Basic Materials	0.037	0.026	0.533	0.549	0.975	0.118	2.238
Finance	0.350	0.276	0.547	0.607	0.707	0.010	2.497

The aggregation of principles scoring resulted in *CI* values of 2.24, 2.266, 2.238, and 2.497 for the energy, oil palm, basic materials, and finance sectors, respectively. Sectors gain advantages and disadvantages by the equality principles. Overall, no sector has a significant advantage over the others in quota allocation as shown by the little deviation that can be observed from the *CI* values between sectors. Figure 3 visualizes the scoring values scaled to the maximum value for each sector. The aggregated results are the average value of all companies within the sectors. It should be noted that the allocated quota depends on the company's score rather than the aggregated value. The individual scoring value for each company is given in the appendix B.

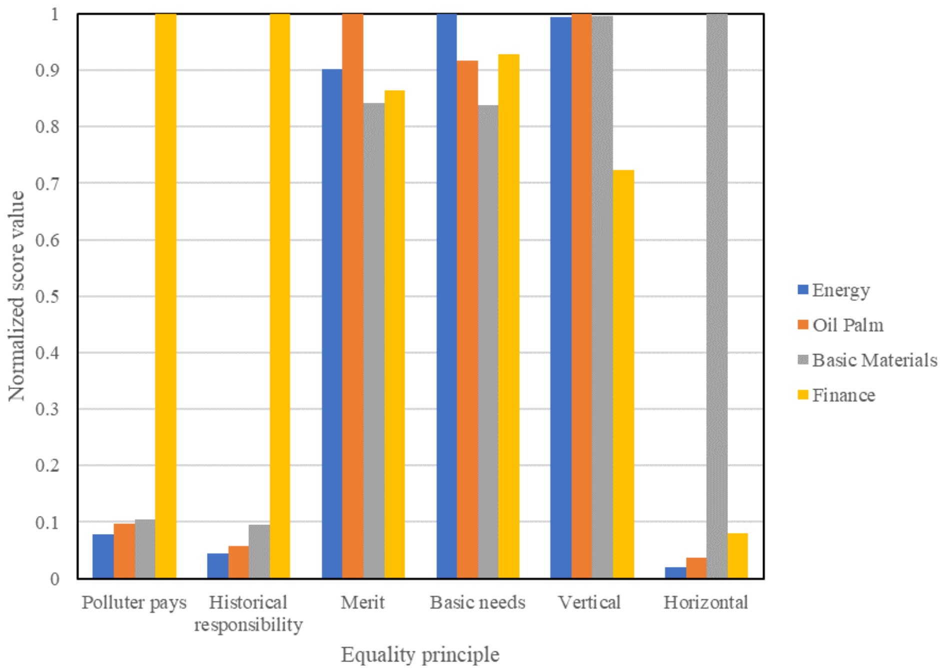

Figure 3. Sectoral average scoring value for each equality principle (normalized to maximum value)

3.2. Quota distribution and the economic impact of the reduction target

The quota is allocated proportional to the companies' *CI* value and emissions. Table 2 shows the quota allocated to each sector under the 0% emission reduction target. The sectoral emissions and quotas represent the total value of companies within the respective sector. It can be observed that there is a less prevalent effect of *CI* in quota distribution at the sectoral level. The oil palm and the finance sector receive more quota than they emit (105% and 107%, respectively). While the energy and basic materials sectors receive lessquota (99% and 99%, respectively).

Table 2. Sectoral quota distribution under 0% emission reduction target

Sector	Emission (Tones CO2eq)	Allocated quota (Tones CO2eq)	Quota/Emission (%)
Energy	18,714,583	18453772.88	99%
Oil palm	9,452,023	9,933,513	105%
Basic Materials	17,559,695	17,306,561	99%
Finance	470,896	503,350	107%

The effect of quota redistribution due to *CI* is more prevalent at the company level as shown in Figure **4.** The abscissa shows the company name code and the ordinate axis shows the percentage of quota relative to the company's emission. The left-positioned bar means that a company allocated less quota than it emits, and vice versa.

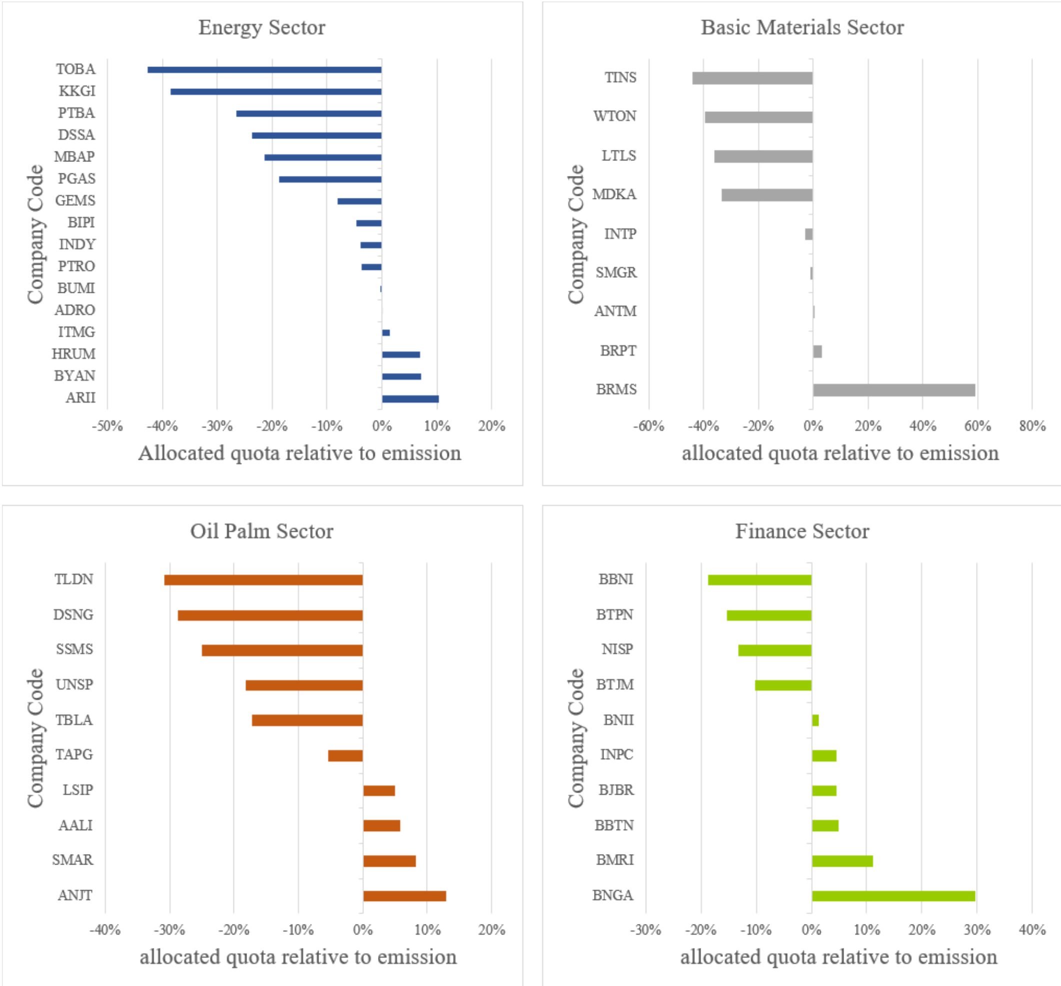

Figure 4. Quota redistribution based on CI for the four sectors under the 0% reduction target

The basic materials sector experienced the widest range of the company's quota distribution relative to emission, with a gap of 103% between the company with the least relative quota (TINS, -44%) and the company with the highest relative quota (BRMS, +59%). Only 3 companies are gaining extra quota in the basic material sector, while 6 other companies have deficit quota. The relative quota change in the energy sector is 53%. Companies with the highest and least relative quota in the energy sector experience -43% and +10% quota changes, respectively. Figure 4 shows that the majority of the companies in the energy sector experience quota deficit (10 companies), 2 companies do not experiencerelative quota changes, while 4 companies gain extra quota. The high number of companies experiencinga deficit in both sectors while the overall sectoral deficit is small (-1% for both basic materials and energy sectors, see Table 2) indicates that smaller companies are allocated relatively less quota than bigger companies. The oil palm sector also experiences similar results with 6 companies experiencing deficit and 4 companies experiencing surplus. The sector experienced a 48% gap between its highest and lowest gainers. Meanwhile, the financial sectors experience a slightly less extreme gap in relative quota between their companies at 44%. Overall, the financial sector experiences quota surplus (Table 2) which is reflected with more companies experiencing quota surplus (6 companies) than deficit (4 companies).

The wider range of relative quota allocation reflects higher variability in company economic performance. The subtle change in quota to original emission at the sectoral level shows that there is little sectoral impact of *CI*. Meanwhile, the *CI* significantly impacts allocation at the company level. The ETS transaction happens at the company level, therefore the fairness and change of distribution between companies are more essential and sensitive for the carbon trading participants.

Figure 5 shows the sectoral economic impact, assuming a carbon price of 2.1 USD/TonesCO2eq. The abscissa and ordinate axis show the monetary gain/loss and emission reduction target. Under the 0% reduction target, the oil palm and finance sectors will receive a surplus of 1.01 and 0.07 million USD, respectively. While the energy and basic materials sectors will receive a deficit of -0.55 and -0.53 million USD, respectively. Increasing the emission reduction target will have consequences of decreased carbon quota. As a result, all sectors will experience a monetary deficit. Sectors experience deficits at different rates. The financial sector is the least impacted with only -0.25 million USD of deficit at a 30% reduction target. While the oil palm is experiencing a surplus at a lower reduction target, the sector will be significantly affected resulting in a -5.25 million USD deficit at a 30% reduction target. The energy and basic materials sectors are affected at a similar rate with -12.17 and -11.43 million USD deficit at a 30% reduction target, respectively.

The quota allocation formula has the component of *CI* and actual emission, therefore, sectors with higher actual emissions will be impacted more along with the increase in emission reduction targets. Therefore sector the finance sector is the least impacted, while the energy and basic materials are significantly affected.

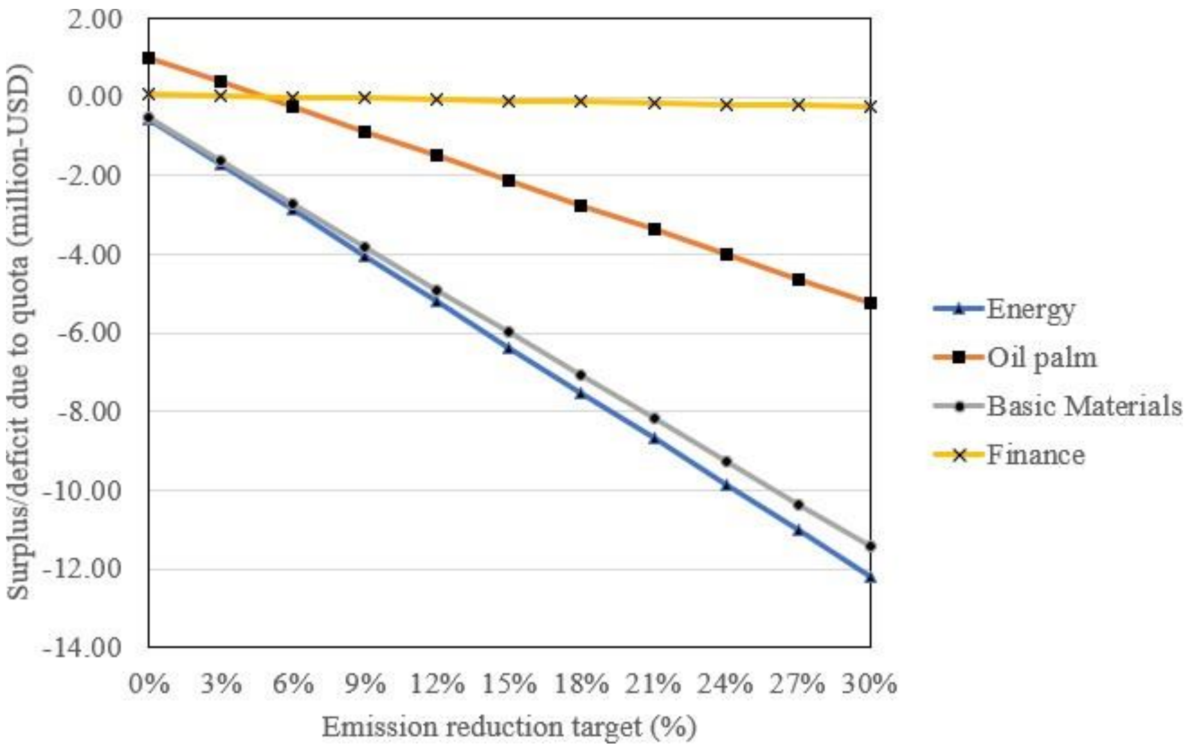

Figure 5. Surplus/deficit for the four sectors over the reduction target

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3.3. Distributional analysis of the quota allocation

Figure 6 shows the Lorenz curve of the proposed method under a 0% reduction target. It can be observed from Figure 6 that companies in different sectors are distributed relatively uniformly along the Lorenz curve. The uniform distribution shows that no advantages are given to a particular sector by the *CI*.

The perfect equality line is constructed based on the emission-proportional distribution method, where quotas are distributed at 100% emission to each company. The equality line has a Gini value of 0 (a Gini value of 1 means perfect inequality). It should be noted that the equality line in Figure 6 does not mean ideal equality, it rather be viewed as a comparison to the proposed method. The proposed *CI* method yields a Gini value of 0.116, indicating a slightdeviation in overall distribution compared to the benchmarked method. Despite the lower Gini value, the standard deviation (SD) was estimated to be 0.158, 0,157, 0.306, and 0.139 for energy, oil palm, basic materials, and finance sectors, respectively, which indicates higher variability in individual quota changes. The individual relative quota allocation is shown in detail in Figure 4.

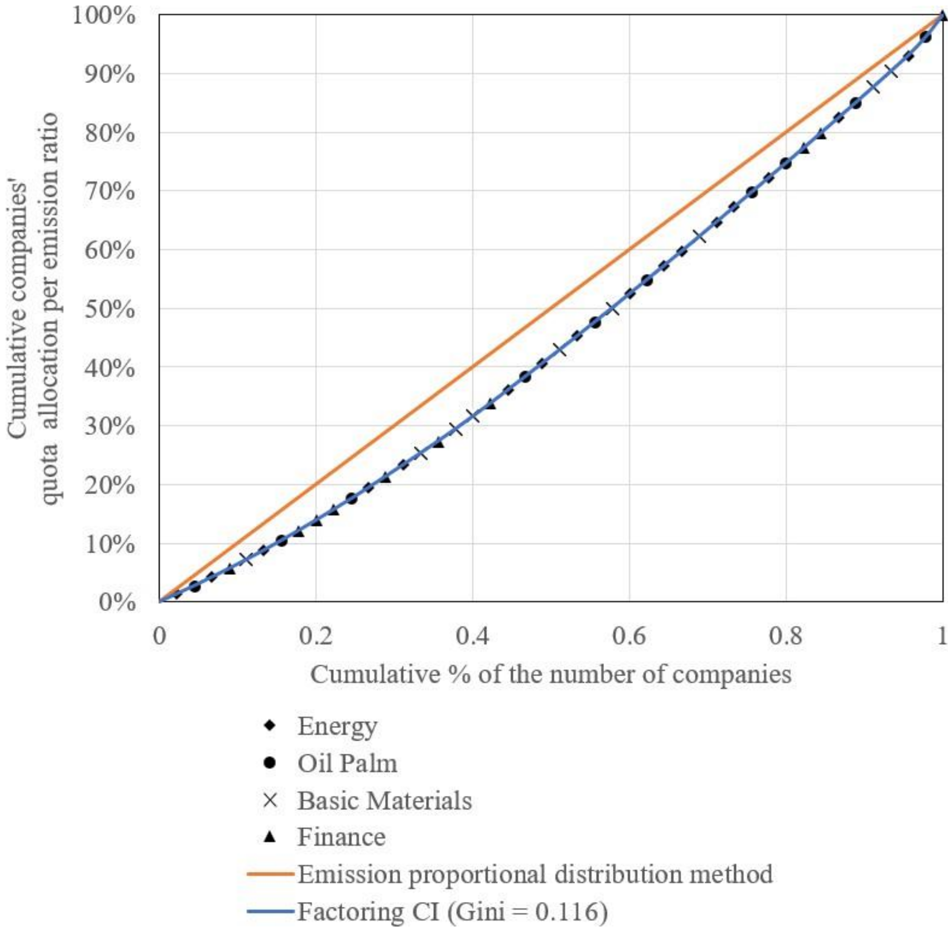

Figure 6. Lorenz curve of companies' quota allocation per emission at 0% reduction

3.4. Sensitivity Analysis

Figure 7 shows the sensitivity analysis via varying the weighting of a principle while keeping the other principles' weighting value at 1. The SD is calculated from all companies in the four sectors. The abscissa shows the weighting factor and the ordinate axis shows the SD. The weighting effect on each principle is represented by the colored line. It can be observed from Figure 7, that for all principles, the SD decreases and then increases as the weighting factor shifts from 0 to 5. A higher SD value implies higher variability in individual quota to emission distribution when an equality principle is discarded (weight=0) or becomes very significant (weight=5).

Discarding the vertical principle has the most significant impact on the company-level distribution and resulted in an SD of 0.343. The impact is less significant for the equality principle of polluter pays, basic needs, merit, historical responsibility, and horizontal with SD values of 0.223, 0.221, 0.214, 0.202, 0.147, and 0.176, respectively. All lines intercept at the weighting factor of 1 where all principles are weighted equally. The intercept value is 0.198. When the weighing value is increased to the extreme of 5, the polluter pays principle results in the highest SD value of 0.374 followed by the horizontal, historical responsibility, basic needs, merit, and vertical principles, with values of 0.371, 0.369, 0.323, 0.243, and 0.138, respectively. The merit principle is the least impacted by weighting variability with the difference between the lowest and highest point being 0.045, followed by the basic needs (0.138), historical responsibility (0.173), polluter pays (0.177), horizontal (0.195), and vertical principles(0.207). It is shown in Figure 7 that lowering the SD value can be achieved by equalizing the weight ofeach equality principle. Furthermore, maintaining the deviation of individual quota proportion to less extreme can limit the monetary flow between sectors when the emissions reduction target increases.

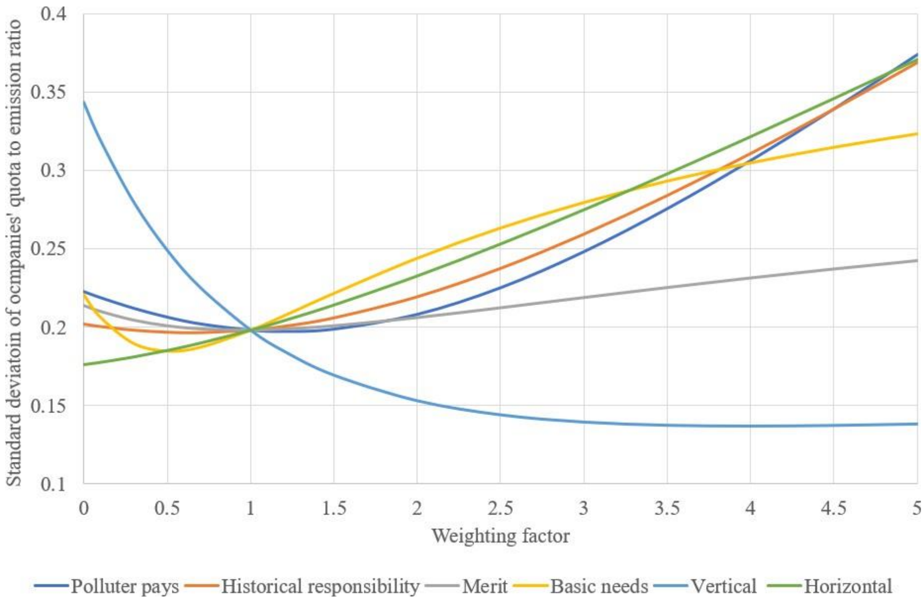

Figure 7. Sensitivity analysis of weighting factor for the equality principles

4. Conclusion and Outlook

A comprehensive view of fairness is one of the keys to implementing carbon reduction policy in a broader scope. The company-level analysis is particularly essential due to its role as the main actor in emission reduction efforts. The paper translates the concept into company-level settings using multiple equality principles. The results show that each sector has advantages depending on the principles used. The comprehensive index summarizes all principles and negates individual principles' advantages to a particular sector, as shown by the sensitivity analysis. The Lorenz curve shows that theoverall distribution does not change dramatically compared to the emission proportional method. However, the individual quota changes can be observed as an adjustment to the equality principles, as indicated by the SD. From an economic analysis, it can be seen that the sectors affected in succession, starting from the least affected, are finance, oil palm, basic materials, and energy sector. As the transition progresses toward a cleaner industry, changes in sectoral condition is also expected. Therefore weight adjustment to the equality principles is critical to prevent particular industries from being disadvantaged by the allocation.

The index is constructed as an alternative quota allocation method that captures multiple equality points of view. The concept can be developed by incorporating the energy trilemma concept: security, sustainability, and affordability. Research on the topic can bring a Pareto optimum solution that balances the multi-dimensional aspect of the just energy transition.

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Appendix

Appendix A *Company data*

Company Code	Main operation	Emission (Kilo-Tones CO2eq)			Equity (million-USD)			Revenue (million USD)			Net operating income (million-USD)		
		2021	2020	2019	2021	2020	2019	2021	2020	2019	2021	2020	2019
Energy sector													
PGAS	Natural Gas	52	73	126	3,285	2,955	3,234	3,036	2,886	3,849	523	90	503
ADRO	Coal	3,404	3,360	4,289	4,458	3,952	3,983	3,993	2,535	3,457	1,577	410	725
BIPI	Coal	1,839	1,998	1,896	406	386	363	66	79	71	40	54	50
ARII	Coal	390	439	454	39	28	46	115	42	63	14	-10	-7
BYAN	Coal	4,077	2,733	3,374	1,863	862	619	2,852	1,395	1,392	1,678	285	317
PTBA	Coal	541	482	474	1,617	1,129	1,228	1,951	1,155	1,453	661	165	334
BUMI	Coal	2,177	2,393	2,745	646	133	510	1,008	790	1,113	124	-2	32
GEMS	Coal	763	931	817	316	349	358	1,586	1,061	1,107	473	137	107
HRUM	Coal	1,201	1,353	1,569	651	455	400	336	158	263	132	6	24
ITMG	Coal	1,728	1,667	1,955	1,202	846	884	1,202	846	884	789	100	179
MBAP	Coal	53	100	111	200	138	146	310	201	261	128	36	48
KKGI	Coal	36	35	34	99	84	93	132	72	115	132	72	115
PTRO	Coal	329	251	370	260	231	213	416	341	476	42	42	54
DSSA	Coal	401	476	412	1,750	1,589	1,638	2,165	1,507	1,666	497	174	238
INDY	Coal	1,197	1,353	1,569	884	867	1,046	3,069	2,077	2,783	627	-26	149
TOBA	Integrated (oil palm, coal, power generation)	526	230	363	354	291	264	463	332	526	463	332	526
Oil palm sector													
TBLA	oil palm	29	25	46	433	393	358	1,065	724	569	132	123	105
TAPG	oil palm	1,362	1,351	877	520	444	383	419	351	289	79	64	26
SMAR	oil palm	5,727	6,595	6,574	961	835	729	3,800	2,696	2,413	259	155	72
SSMS	oil palm	239	207	120	407	325	271	347	267	219	111	78	34
AALI	oil palm	748	666	832	1,411	1,283	1,265	1,621	1,254	1,164	229	123	65
ANJT	oil palm	879	943	1,144	433	396	389	267	164	130	62	13	-6
UNSP	oil palm	28	27	30	-460	-467	-363	265	167	132	34	-6	-21
DSNG	oil palm	64	75	71	468	415	249	475	447	382	93	69	53
TLDN	oil palm	20	20	21	90	70	39	196	181	139	56	62	37
LSIP	oil palm	355	360	426	678	619	567	302	236	247	108	54	21
Basic materials sector													
ANTM	metal mining andprocessing	1,182	1,232	1,156	1,389	1,269	1,209	2,563	1,825	2,181	193	135	64
BRMS	metal mining and processing	246	28	873	980	588	713	11	8	4	1	0	-1
BRPT	petrochemicals	2,842	3,502	2,889	4,267	2,951	2,756	3,156	2,334	2,402	621	423	423
INTP	cement production	12,070	11,500	13,180	1,375	1,478	1,539	985	946	1,063	138	125	127
LTLS	chemicals	25	27	28	180	150	144	442	373	436	38	29	31
MDKA	metal mining andprocessing	145	119	151	779	564	524	381	322	402	90	90	135
SMGR	cement production	904	2,600	6,370	2,652	2,377	2,259	2,331	2,345	2,691	342	381	423
TINS	metal mining andprocessing	137	92	149	421	329	351	974	1,014	1,287	141	10	-8
WTON	concrete	9	6	10	230	226	234	288	320	472	8	13	53
Finance sector													
BBNI	Banking	30	32	22	8,435	7,525	8,334	3,805	3,623	3,608	727	219	1,026
BBTN	Banking	58	34	50	1,427	1,333	1,589	995	736	725	158	107	14

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BJBR	Banking	25	22	21	872	800	803	639	535	477	135	112	104
BTJM	Banking	2	2	2	727	667	612	333	298	296	102	99	92
BNGA	Banking	22	1	37	2,893	2,737	2,886	1,182	1,081	1,122	273	134	243
BMRI	Banking	275	332	363	14,807	12,920	13,936	7,507	6,133	6,077	1,869	1,141	1,832
BNII	Banking	31	34	38	1,915	1,815	1,779	631	657	733	110	84	123
BTPN	Banking	20	23	25	2,405	2,198	2,098	836	781	809	267	176	268
INPC	Banking	6	6	7	264	237	302	71	50	69	-11	1	-4
NISP	Banking	3	3	4	2,155	1,989	1,844	647	613	555	168	140	196

Appendix B Company *CI* scoring

Company Code	Main operation	Equality principles						Comprehensive index
		Polluter pays	Historical responsibility	Merit	Basic needs	Vertical	Horizontal	
Energy sector								
PGAS	Natural Gas	0.291	0.130	0.734	0.000	0.872	0.005	0.339
ADRO	Coal	0.006	0.003	0.628	0.884	0.980	0.002	0.417
BIPI	Coal	0.000	0.000	0.392	1.000	0.983	0.008	0.397
ARII	Coal	0.001	0.000	0.772	1.000	0.983	0.002	0.460
BYAN	Coal	0.003	0.002	0.692	1.000	0.982	0.000	0.447
PTBA	Coal	0.018	0.009	0.522	0.308	0.976	0.002	0.306
BUMI	Coal	0.002	0.001	0.505	1.000	0.983	0.004	0.416
GEMS	Coal	0.010	0.005	0.651	0.649	0.981	0.000	0.383
HRUM	Coal	0.001	0.000	0.686	1.000	0.982	0.004	0.446
ITMG	Coal	0.003	0.002	0.652	0.897	0.981	0.001	0.423
MBAP	Coal	0.029	0.010	0.818	0.133	0.971	0.001	0.327
KKGI	Coal	0.018	0.009	0.470	0.074	0.967	0.000	0.256
PTRO	Coal	0.006	0.004	0.411	1.000	0.982	0.005	0.401
DSSA	Coal	0.027	0.013	0.587	0.304	0.974	0.003	0.318
INDY	Coal	0.013	0.006	0.625	0.777	0.980	0.001	0.400
TOBA	Integrated (oil palm, coal, power generation)	0.004	0.004	0.000	0.445	0.980	0.000	0.239
Oil palm sector								
TBLA	oil palm	0.182	0.078	0.856	0.000	0.951	0.002	0.345
TAPG	oil palm	0.001	0.001	0.377	1.000	0.983	0.005	0.394
SMAR	oil palm	0.003	0.001	0.716	1.000	0.983	0.003	0.451
SSMS	oil palm	0.007	0.005	0.256	0.626	0.980	0.003	0.313
AALI	oil palm	0.011	0.005	0.656	0.988	0.980	0.005	0.441
ANJT	oil palm	0.001	0.000	0.832	1.000	0.983	0.006	0.470
UNSP	oil palm	0.048	0.020	0.772	0.193	1.000	0.011	0.341
DSNG	oil palm	0.037	0.019	0.601	0.153	0.971	0.004	0.297
TLDN	oil palm	0.048	0.025	0.636	0.046	0.972	0.001	0.288
LSIP	oil palm	0.004	0.002	0.632	1.000	0.980	0.005	0.437
Basic materials sector								
ANTM	metal mining and processing	0.011	0.005	0.509	1.000	0.981	0.006	0.419
BRMS	metal mining and processing	0.000	0.000	1.000	1.000	0.979	1.000	0.663
BRPT	petrochemicals	0.005	0.003	0.588	1.000	0.981	0.005	0.430
INTP	cement production	0.000	0.000	0.431	1.000	0.983	0.008	0.404
LTLS	chemicals	0.087	0.047	0.488	0.000	0.970	0.004	0.266
MDKA	metal mining and processing	0.013	0.008	0.415	0.242	0.975	0.007	0.277

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SMGR	cement production	0.013	0.004	0.971	0.505	0.979	0.006	0.413
TINS	metal mining and processing	0.035	0.027	0.281	0.078	0.976	0.002	0.233
WTON	concrete	0.167	0.142	0.115	0.117	0.948	0.026	0.253
Financial sector								
BBNI	Banking	0.647	0.409	0.249	0.167	0.549	0.010	0.338
BBTN	Banking	0.087	0.054	0.533	1.000	0.943	0.007	0.437
BJBR	Banking	0.127	0.073	0.487	1.000	0.923	0.005	0.436
BTJM	Banking	0.857	0.433	0.596	0.000	0.356	0.006	0.374
BNGA	Banking	0.275	1.000	0.718	0.465	0.775	0.009	0.540
BMRI	Banking	0.137	0.063	0.677	1.000	0.894	0.006	0.463
BNII	Banking	0.103	0.060	0.462	1.000	0.895	0.015	0.422
BTPN	Banking	0.207	0.109	0.560	0.441	0.794	0.007	0.353
INPC	Banking	0.060	0.029	0.566	1.000	0.938	0.020	0.436
NISP	Banking	1.000	0.530	0.626	0.001	0.000	0.011	0.361