A new indicator for carbon-neutral consumption: An enhancement to CFP with cost for emission compensation by renewable energy technologies

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1 INTRODUCTION
Carbon footprint (CFP) has developed for decades. However, it has not been successful in leading consumers to alternative purchase practices via improved understanding of environmental aspects of products [1]. Here, a novel indicator called carbon compensation (CC) is constructed to guide the public to purchase products with lower CFP and has a longer lifetime. This is realized by revealing cost for compensating CFP of a product. Effectiveness of CC in guiding people to alternative purchase behavior will be gauged by questionnaire with demonstrative examples.

2 METHODOLOGY
As shown in the framework (Fig.1), the study comprise of four parts: design, computation, demonstration and evaluation of the CC indicator.

2.1 Design
To better associate carbon emissions to purchase decisions, monetary term is chosen as the unit of the indicator. This is realized by assuming technologies that can compensate carbon emissions by additional investment on technologies. Currently, CC technologies (CCTs) assumed for computing CC are photovoltaic (PV) and wind power (WP). CCTs related data is collected in prior to construct CC model, as shown in Table 1.

2.2 Computation
- Estimation of CC media (CCMi)
First, CC media of type i CCTs (CCMi, i = PV, WP) is estimated. In this study, kWh is the unit, which means electric power generated by the CCTs is compared to the current power generation. CFP of evaluated product (CFP_{EP}), emission factor (EF = 536 gCO2-e/kWh) and CFP of type i CCTs (CFPi) are used, as in equation 1. CFP of PV and WP used for study are 45 and 8.4 gCO2-e/kWh, respectively.

\[
CCM_i = \frac{CFP_{EP} - CFP_i}{EF} \tag{1}
\]

- Estimation of installation quantity (Ni)
Dividing CCMi by CC media generated per CCTs facility (CCM_{PFi}) in evaluated product’s lifetime (LT_{EP}), quantity of installation (Ni) is estimated (equation 2). Both of PV and WP, CCM_{PFi} represents the total electricity (kWh) generated per installation in LT_{EP}, shown in equation 3 and 4 respectively.

\[
N_i = \frac{CCM_i}{CCM_{PFi}} \tag{2}
\]

\[
CCM_{PFi} = NP \times E_m \times PR \times CP \times ST \times LT_{EP} \times 365 \tag{3}
\]

where \( ST \) : Sunshine time

\[
CCM_{PFi} = \frac{\sqrt{2} \times \rho \times \pi \times r_{blade}^2 \times U^3 \times \eta_{trans}}{\eta_{trans}} \tag{4}
\]

where \( \rho \) : Density of blade

\( r_{blade} \): Radius of turbine

\( U \): Wind speed, location specific data

Table 1. Cost of Carbon Compensating Technologies used in this study

<table>
<thead>
<tr>
<th>Lifetime (LT)</th>
<th>Nominal power (NP)</th>
<th>Module efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV [year]</td>
<td>[kW/module]</td>
<td>[kW/turbine]</td>
</tr>
<tr>
<td>PV</td>
<td>25</td>
<td>0.315</td>
</tr>
<tr>
<td>WP</td>
<td>15</td>
<td>0.3</td>
</tr>
<tr>
<td>PV (E_m)</td>
<td></td>
<td>300</td>
</tr>
<tr>
<td>WP (\eta_{trans})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.16</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Performance ratio (PR)</td>
<td>Area needed(A)</td>
<td>Cost</td>
</tr>
<tr>
<td>PV</td>
<td>PV(A_{PV})</td>
<td>WP (A_{WP})</td>
</tr>
<tr>
<td>0.95</td>
<td>1.95</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 1. Framework of constructing a CC indicator
Estimation of CC with CCTs implement

Cost of CCTs implementation is separated in installation and land occupation (Eq.5, which means total cost for evaluated product’s CC by i type CCTs (CC_{EP,i})).

\[
CC_{EP,i} = C_{i,Equip} + C_{i,Land}
\]

First, cost of CCTs installation is calculated with equation 6. For equipment installation, cost ratio (CR) is relied on LT_{EP} since installation might not long as LT_{PV}, shown in table 2. For PV, UC_{PV, Equip} equal to NP_{PV} times cost per kW (C_{PKW}=18,766NTD^{(3)}), shown in equation 7. For WP, UC_{WP, Equip} shown in equation 8, which is the cost per turbine (CPT, assumed 50,000NTD).

\[
C_{i,Equip} = N_i \times CR \times UC_{i,Equip}
\]

\[
UC_{PV,Equip} = NP_{PV} \times C_{PKW}
\]

\[
UC_{WP,Equip} = CPT
\]

Secondary, cost for land use shown in equation 9, \( C_{i,Land} \) is the cost for unit area occupation in Taiwan.

\[
C_{i,Land} = N_i \times A_i \times UC_{i,Land}
\]

### 2.3 Demonstration and evaluation

Demonstrating by using the constructed CC table (Table 3 and 4) guides consumers to the products with lower CFP_{EP} and longer LT_{EP}. The demonstration part is summarized in questionnaire.

In preliminary survey, 50 objects are investigated. Each questionnaire is designed in two sections, products with same 1)LT_{EP} and 2)CFP_{EP}. Subsection of section1), 1)without CFP_{EP} and CC, 2)with CFP_{EP} and 3)with CFP_{EP} and CC. Subsection of section2), 1) with LT_{EP} and 2)with LT_{EP} and CC. The effectiveness between CFP and CC indicator with the population from different sex, ages and career can be known.

### 3 RESULT AND DISCUSSION

CC tables of PV and WP are constructed as shown in table 3 and 4 respectively. Forming of CC table, the idea to lead consumers purchasing lower CFP_{EP} and longer LT_{EP} is discussed below.

#### 3.1 Guide to lower CFP_{EP} product

For purchasing the same LT_{EP} (1yr) products, A and B, CFP_{EP} are 0.1 and 0.2 kgCO_{2-e} respectively. Corresponding to Table 3, CC_{i, PV} is 100 NTD, CC_{i, WP} is 200 NTD. Via the CC, the lower CFP_{EP} the less should be paid for compensation. Therefore, guides consumers toward the lower CFP products indirectly.

#### 3.2 Guide to longer LT_{EP} product

For purchasing the same CFP_{EP} (0.1kgCO_{2-e}) of products, C and D, LT_{EP} are 1 and 2 years respectively. Relying on Table 4, CC_{C, WP} is 12 NTD, CC_{D, WP} is 6 NTD. As the result expresses, longer LT_{EP} have less cost for compensation. Hence, by estimating of CC can guide consumers toward products with longer LT_{EP}.

### 3.3 Effectiveness of CC indicator

Section1) with same LT_{EP} is help to choose the lower CFP_{EP}, Subsection1), price is the main factor for purchasing, 75%. Occupation of price and CFP_{EP} in subsection2) to 3) are from 41% to 34% and 39% to 25% respectively. Occupation of CC in subsection3) is 21%, which means the effectiveness of CC will share out from price and CFP_{EP}.

Section2) with same CFP_{EP} is guiding to longer LT_{EP}. Portion of price and LT_{EP} from subsection1) to 2) are 41% to 30% and 32% to 23% respectively, portion of CC is 27% in subsection2), which means effectiveness is divided from price and LT_{EP}.

### 4 CONCLUSION

Situation without CFP_{EP} and LT_{EP}, price is the main factor for purchasing, it helps to confirm the appearance used for CC will affect the purchasing habit. Situation between with and CFP_{EP} with CFP_{EP} and CC reveals the effectiveness of CFP_{EP} is shared out for CC. However, the effectiveness of CFP_{EP} is still higher than CC since the unclear definition and display. The survey should be redesign for evaluation the effectiveness.

Most of the parameters in CCTs calculation are assumed. Sensitivity analysis is needed to establish a solid CC model to be widely used for communication of environmental impacts associated with products.

### REFERENCES

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