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Viewpoint

The decrease of CO_2 emission intensity is decarbonization at national and global levels

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Abstract

This viewpoint proposes the definition: "Decarbonization refers to a decrease of CO_2 emission intensity in a trend". This viewpoint then argues that an analysis of decarbonization at national and global levels based on that definition would lead to the correct calculation of decarbonization.

Keywords: Decarbonization; Carbonization index; CO_2 emission intensity

1. Introduction

Achieving decarbonization is an environmental aim, which is both rewarded and promoted by energy policy. However, there are different decarbonization definitions that may result in the incorrect calculation of the results of decarbonization and hence give misleading or contradictory conclusions for the assessment of a country's energy policy. Firstly this viewpoint reviews these different definitions of decarbonization. It then proposes that decarbonization should refer to the decrease of CO_2 emission intensity from a social and economic point of view. This definition should lead to the correct calculation of the results on decarbonization at national and global levels, and be the most beneficial for the assessment of current energy policy in most countries.

2. The questions

Decarbonization is the inevitable trend result of technological progress and social development. Technological progress develops tools and industry that decrease the amount of CO_2 emissions released into the atmosphere. Social development reduces the CO_2 emissions that result from human activities. The world's countries and regional grouping have identified decarbonization as the energy and environmental policy target, and have achieved significant results.

Since the beginning of the 1990s, decarbonization has been studied from energy and environmental perspectives. Decarbonization refers to decreases in CO_2 emissions from fuel generated/consumed. For example, decarbonization denotes the declining average carbon dioxide intensity of primary energy over time (Kanoh, 1992). It also refers to the decrease of the ratio of carbon to hydrogen atoms with each succeeding energy source (Nakicenovic, 1993, 1996a). Based on Nakicenovic's definition, decarbonization was understood as the decreasing carbon intensity of the global energy mix (Hoffert, 1998) and a decrease in the emission of carbon into the atmosphere of energy produced, which is measured by g of carbon per megajoule (Margolis and Kammen, 1999). Decarbonization is often linked to a fuel and the aim of research based on it is to define science and technology's ability to decrease CO_2 emissions. The carbon dioxide intensity of primary energy is termed the carbonization index (C), i.e. $C = E/W$ where E and W stand for CO_2 emissions and energy consumption (Grubler, 1998). Thus, decarbonization also refers to the decrease of the carbonization index (Mielnik and Goldemberg, 1999). In this viewpoint, these definitions are termed the technological point of view on decarbonization. The estimation of decarbonization (ΔE) between $T = 0$ and t based on these definitions can be calculated by Eq. (1), if decarbonization occurs, i.e. $\Delta C = (C^t - C^0) < 0$, where $T = 0$ and t stand for the base year and the observation year, respectively:

$$\Delta E = -(C^t - C^0)W^t. \tag{1}$$

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Another explanation related to decarbonization argues that decarbonization can be regarded as belonging in part to the process of dematerialization. Thus, dematerialization with reference to energy use includes the decrease of energy intensity—energy saving, and the decrease of CO_2 emission intensity—decarbonization (Sun and Meristo, 1999). Based on this explanation, decarbonization can refer to the decrease of CO_2 emission intensity (I_E), which is the ratio of CO_2 emissions to GDP, i.e. $I_E = E/\mathrm{GDP}$. This is here called the social and economic point of view on decarbonization. The estimation of decarbonization (ΔE) between $T = 0$ and t based on this definition can be calculated by Eq. (2), if decarbonization occurs, i.e. $\Delta I_E = (I_E^t - I_E^0) < 0$.

$$\Delta E = -(I_E^t - I_E^0)\mathrm{GDP}^t \tag{2}$$

There are two questions, which require explanation. Firstly, the technological point of view on decarbonization has been generally accepted and is well known. Thus, is the social and economic point of view on decarbonization necessary or logical? Furthermore, if the social and economic point of view on decarbonization is logical, what is the relationship between the indicators of the carbonization index and CO_2 emission intensity?

3. The theoretical demonstration

This theoretical explanation points out that when an estimation of decarbonization uses the carbonization index at national and global levels, the results may be incorrect and not reflect the actual situation.

Firstly, it is argued that the carbonization index at national and global levels has lost its original meaning, and reflects not only the scientific and technological ability to reduce CO_2 emissions, but also the energy mix. Hence it is possible that the carbonization index of an impoverished country with undeveloped scientific and technological abilities is lower than the carbonization index of an advanced country. This occurs because the share of fossil fuels in its energy mix is much low in some developing countries. For example, according to the IEA's (2002) statistics, the carbonization index in 20 of the 22 Latin America countries was lower than the US's in 2000 (IEA, 2002).

Secondly, it neglects the effect of energy intensity on energy consumption, if the carbonization index is used for calculating the decrease in CO_2 emissions based on energy consumption statistics. It should be obvious that if energy consumption in two countries is the same and the carbonization index in the first country is lower than the second country, then CO_2 emissions in the first country are lower than the second country. However, energy is consumed by social and economic activity, and energy consumption is the product of energy intensity (I_W) and GDP—the outcome of social and economic activity, i.e. $W = I_W \times \mathrm{GDP}$. Thus, energy consumption may not be the same, even if GDP is the same in these two countries. It is possible that CO_2 emissions in the second country are lower than the first country even though GDP is same for these two countries, because energy intensity in the second country is much lower than in the first country. Therefore, the calculated decrease of CO_2 emissions based on energy consumption is incorrect because the results neglect the effect of energy intensity on energy consumption. The following demonstration sets out to prove this.

Assume that the rate of decrease in energy intensity is λ between $T = 0$ and t in a nation or global. Thus, we have $W^0 = I_W^0 \mathrm{GDP}^0$ and $W^t = I_W^0(1-\lambda)\mathrm{GDP}^t$. So, Eq. (1) becomes:

$$\begin{aligned}\Delta E &= -(C^t - C^0)W^t \\ &= -\left(\frac{E^t}{I_W^0(1-\lambda)\mathrm{GDP}^t} - \frac{E^0}{I_W^0\mathrm{GDP}^0}\right) \\ &\quad \times I_W^0(1-\lambda)\mathrm{GDP}^t \\ &= -\left(\frac{E^t}{\mathrm{GDP}^t} - \frac{(1-\lambda)E^0}{\mathrm{GDP}^0}\right)\mathrm{GDP}^t. \end{aligned} \tag{3}$$

On other hand, Eq. (2) can be written as follows:

$$\Delta E = -(I_E^t - I_E^0)\mathrm{GDP}^t = -\left(\frac{E^t}{\mathrm{GDP}^t} - \frac{E^0}{\mathrm{GDP}^0}\right)\mathrm{GDP}^t. \tag{4}$$

Comparing Eqs. (3) to (4), the difference is clear.

The case analysis for the decrease of CO_2 emissions in the world between 1998 and 2000 shows the difference. In the world's statistics (IEA, 2002), CO_2 emissions (Sectoral Approach) came to 22767.5, 22844.7 and 23422.3 Mton in 1998, 1999 and 2000, respectively. Total primary energy supply (TPES) amounted to 9672.89, 9857.10 and 10102.46 Mtoe in 1998, 1999 and 2000, respectively, whilst GDP in Billion 1995 US$ using PPPs was 38595.2, 39940.8 and 41750.6 in 1998, 1999 and 2000, respectively. Based on these statistics and the preceding year is regarded as the base year, the decreases in CO_2 emissions were 356.42 and 716.58 Mtons based on Eqs. (1) and (2) for 1999, respectively. In this case, the decrease of CO_2 emissions was 360.16 Mton due to the effect of the decrease in energy intensity. However, the year 2000 case is more interesting. The decreases in CO_2 emissions were -8.96 and 457.54 Mtons based on Eqs. (1) and (2) for 2000, respectively. In this case, carbonization occurred if the calculation uses Eq. (1). The decrease of CO_2 emissions was 466.5 Mton due to the effect of the decrease in energy intensity.

Thirdly, a decrease in CO_2 emission intensity being termed decarbonization may reflect the evolution of new technological terms. New technological and scientific terms are being generated with the emergence of new technologies and new discoveries that hold the promise of higher productivity and less environmental stress. Furthermore, the definition of such terms changes and becomes broader as the term enters more general social use. The general rule is that at first such terms are only related to materials and technology and science, but later they are related to social and economic areas, but with a slightly altered meaning.

The term dematerialization provides a good example. *Dematerialization* was defined as "the decline over time in weight of the materials used in industrial and products" (Herman et al., 1989, 1990). At that time, the term *dematerialization* was only related to the material world. Later, dematerialization was defined as "the reduction in the raw material (energy and material) intensity of economic activities, measured as the ratio of energy consumption in physical terms to the gross domestic product (GDP) in deflated constant terms" (Bernardini and Galli, 1993). Therefore it is plainly obvious that the term *dematerialization* has been widely used in social and economic areas, not just in technological areas.

It should be indicated that Nakicenovic developed the social and economic point of view on decarbonization in 1996. In the article, "Decarbonization: Doing More with Less", Nakicenovic wrote. "Decarbonization can be expressed as a product of two factors: (1) specific carbon emissions per unit energy; and (2) energy requirements per unit value added, often called energy intensity" (Nakicenovic, 1996b).

4. The relationship between the indicators of the carbonization index and CO_2 emission intensity

This viewpoint does not point out which indicator is the most important between the carbonization index and CO_2 emission intensity, it only indicates how the definition of the term decarbonization has evolved.

The carbonization index can be used for assessing technological development at various levels within a country. However, CO_2 emission intensity is the indicator used for measuring decarbonization, and it is also used for assessing energy policy on a national level. Thus if a national energy policy is examined with reference to the carbonization index, the conclusion will be incomplete and not readily acceptable.

For example, CO_2 emission intensity in China has declined since 1979 due to the quick decline of energy intensity. However, the carbonization index increased between 1979 and 1996. Table 1 lists the relevant data.

If the carbonization index is examined for CO_2 emissions in China, the conclusion is that China experienced carbonization between 1979 and 1996 (Mielnik and Goldemberg, 1999). If CO_2 emission intensity is examined for CO_2 emissions in China, the conclusion is that China has experienced decarbonization since 1979.

In a long-term trend, the social and economic point of view on decarbonization develops based on the occurrence of the decrease of carbonization index (Nakicenovic, 1996b). However, this may not always be seen for a country during a period of economic transfer, but it will develop at some point during the whole economic development process.

Table 1
Energy related CO_2 emissions (E), total primary energy supply (TPES), GDP and the estimated index of E/TPES (C), energy intensity (I_W), and CO_2 emission intensity (I_E) in China from 1979 to 2000

Year	E	TPES	GDS	C	I_W	I_E
1979	1412.36	605.64	754.56	2.333	0.803	1.872
1981	1398.72	600.09	849.78	2.331	0.707	1.646
1983	1531.70	644.12	1024.69	2.378	0.629	1.495
1985	1749.47	711.59	1316.45	2.459	0.541	1.329
1986	1850.98	737.50	1430.77	2.510	0.516	1.294
1987	1994.50	775.60	1592.23	2.572	0.488	1.253
1988	2149.40	819.11	1759.68	2.625	0.466	1.222
1989	2227.13	835.80	1830.60	2.665	0.457	1.217
1990	2289.50	881.10	1903.01	2.599	0.464	1.204
1991	2407.06	884.22	2073.62	2.723	0.427	1.161
1992	2540.03	916.75	2360.62	2.771	0.389	1.077
1993	2674.43	969.02	2671.73	2.760	0.363	1.002
1994	2839.14	1011.91	3005.15	2.806	0.337	0.945
1995	3009.62	1080.39	3313.08	2.786	0.327	0.909
1996	3177.03	1127.76	3623.48	2.818	0.312	0.877

Units: TPES in Mtoe; E in Mton; GDP in billion 1995 US$ using PPPs; C in Mton/Mtoe; I_W in kg oe/US$ at 1995 prices and PPPs; and I_E in kg of CO_2/US$ at 1995 prices and PPPs.

Sources: II.8–9 CO_2 Emissions: Sectoral Approach; II. 38–39 Total Primary Energy Supply; II. 50–51 GDP using Purchasing Power Parities in the book "CO_2 Emissions From Fuel Combustion, 1971–2000"(IEA, 2002).

There are three different ways for the social and economic point of view on decarbonization to be identified: $\Delta I_E/I_E<0$.

Because,

$$I_E = \frac{E}{W}\times\frac{W}{\mathrm{GDP}} = C\times I_W \rightarrow \frac{\Delta I_E}{I_E}\approx\frac{\Delta C}{C}+\frac{\Delta I_W}{I_W}.$$

Thus

(1). $\Delta C/C<0$ and $\Delta I_W/I_W<0$. This is the long-term trend. But the following two cases may occur temporarily.
(2). $\Delta C/C<0$ and $0\leq\Delta I_W/I_W$, but $\Delta I_E/I_E<0$.
(3). $0\leq\Delta C/C$ and $\Delta I_W/I_W<0$, but $\Delta I_E/I_E<0$.

5. Conclusion

Decarbonization is a new academic term created in response to technological progress and social development. Thus, the definition of decarbonization should be altered and made broader to accommodate both processes.

For energy policy making, a social and economic point of view on decarbonization should be the target for energy policy makers in a nation.

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