Effects of industrial restructuring on carbon reduction: An analysis of Jiangsu Province, China

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A B S T R A C T

From the perspective of the development stage of China’s economy and the context in which industrial restructuring is highly promoted in China’s “Twelve Five-Year Plan”, industrial structure adjustment is an effective way to balance economic growth and carbon reduction. The current study analysed the effects of industrial restructuring on carbon reduction in Jiangsu Province. Using input–output analysis, we calculated both direct and indirect carbon emissions in 1997, 2000, 2002, 2005 and 2007. The study aimed to classify Jiangsu’s industrial sectors by the carbon reducing potential (CRP), which was indicated both by carbon reducing efficiency (CRE) and by the amount of carbon reduction (ACR), with a 1% decrease in the output of a certain industrial sector. The results indicate that the high CRE of a certain sector might be due to its high direct carbon intensity, indirect carbon intensity or high economic status. Based on the varying contexts, corresponding policy measures were provided. Moreover, export carbon emissions were abundant in sectors with the highest CRE, indicating the production of emissions due to consumption elsewhere.

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1. Introduction

As the most rapidly growing developing country, China consumes a large amount of energy. Between 2000 and 2009, energy consumption in China increased from 1455.31 million to 3066 million tons of standard coal equivalent [1]. Despite not being forced to reduce carbon emissions in the Kyoto Protocol, because China is one of the international economic powers and the biggest emitter of carbon, the country is obliged to kerb its emissions. In its 17th “Fifth Plenary Session,” the party clearly announced that, faced with the contradiction between increasing requirements for energy and environmental pressure, China must enhance crisis awareness, save energy, promote more environmentally friendly consumption practices and strive to transform from high-carbon to low-carbon energy use [2].

Unlike developed countries, industry still serves as the biggest contributor to China’s national economy, with the percentage of heavy industry constantly increasing. Most of the heavy industries consume a considerable amount of energy and grow rapidly while lagging far behind developed countries in terms of energy efficiency [3], thereby causing a large amount of carbon emissions.

Between 1980 and 2005, industry end-use energy consumption constituted 60% [4] of all end-use energy consumption, and the carbon emissions of industries accounted for 65% [5] of the total emissions from energy use. Considering the current economic development and social situation in China, Chinese industries will continue to depend on fossil fuels for a long time, which will likely lead to substantial carbon emissions. To avoid the negative influence of emission reduction on economic growth, the Chinese government faces the difficult issue of balancing economic growth and emission reduction.

Industrial restructuring is an effective way to solve the aforementioned dilemma. Industrial structure is significant for industrial development because reasonable industry structure enhances specialisation and cooperation between industries, increases outputs, increases the rate of innovation and enhances competitiveness. In contrast, unreasonable industrial structure negatively affects industrial development [6]. Zhang and Ren [7] suggested that adjusting industrial structures would directly affect carbon emissions. Moreover, the national “Twelve Five-Year Plan” also aims to reduce energy intensity by 20% through industrial restructuring. Thus, from the perspective of national policy and considering China’s current situation, it is necessary to study the effects of industrial restructuring on carbon reduction.

This study uses input–output analysis to investigate the effects of industrial restructuring on carbon emissions. Leontief devised
input–output analysis in the 1930s and applied it to study links between the economy and the environment. Input–output analysis has long been considered a useful technique to combine energy use between the economy and the environment. Input–output analysis is able to quantify the interdependence between industries [9]; therefore, input–output analysis is quite appropriate for industrial structure analysis. Moreover, input–output analysis overcomes the limitation of merely calculating the direct emissions of a certain industrial sector and instead provides a way to deduce indirect carbon emissions created in other sectors that are linked to the “key” sector [10]. Therefore, the carbon emissions of the complete supply chain can be determined, thereby revealing the actual sources of carbon emissions to policy-makers.

Recently, there has been an increasing trend of using input–output analysis to examine environmental issues, especially carbon emissions. A number of studies have applied input–output analysis to analyse carbon emissions of industrial sectors. Liu et al. used input–output analysis to calculate both the direct and total energy intensity of 52 industrial sectors in China [11]; Munksgaard and Pedersen used input–output analysis to calculate both the direct and indirect carbon emissions of all industries in Denmark [12]; Sanchez–Choliz and Duarte used single–region input–output analysis to analyse the carbon emissions of all industries in Spain in international trade and calculated the direct, indirect, import and export carbon emissions of each industry [13]; and Su et al. concluded that in sector disaggregation, emission levels of approximately 40 sectors are sufficient to capture the overall share of emissions embodied in exports, while in spatial disaggregation, the use of emission levels in a greater number of regions produces more detailed results [14,15].

The focus of our research is to examine the impact of changes in the output of a certain industry on total carbon emissions (known in the literature as the multiplier effect). Previous research has been conducted in this field. Tarancon and Del Rio summarised a series of studies that analysed the impact of changes in the final demand of different sectors on energy use or pollutant generation [10]. Cellura et al. assessed the energy and environmental impacts associated with the consumptions of the Italian households in the period of 1999–2006 by combining the energy and environmental input–output model with the Life Cycle Assessment methodology [16]. Parikh et al. analysed both direct and indirect carbon emissions of the Indian economy by sectors and due to final consumption using the input–output model [17]. Mu et al. studied industrial interrelationships in the electricity consumption chain on the basis of the input–output table of that national economy and applied an electricity demand multiplier to identify sectors with large electricity consumption [18]. Alcantara et al. studied forward and backward linkage effects to identify key electricity consumption sectors in Spain by combining the input–output approach with a sectoral-focused study [19]. Cellura et al. combined an energy and environmental input–output analysis with structural decomposition analysis, evaluated the energy use and air emissions of the productive sectors required to meet Italian household final demand in the period 1999–2006 and identified the sources of variations in energy and environmental indicators [20]. Yuan et al. estimated that the decrease in final demand caused by the Global Financial Crisis could lead to a 7.33% decrease in GDP and a 9.21% reduction in total energy consumption, while the increase of final use caused by the Chinese government’s stimulus plan could lead to a 4.43% increase in GDP per year and an energy consumption increase of 1.83% [21]. Kahrl and Holst examined economic growth in China and analysed the impact of changes in final demand on energy consumption [22]. Could and Kulshreshtha applied input–output analysis to examine the impact of

### Nomenclature

<table>
<thead>
<tr>
<th>Acronyms</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>CRP</td>
<td>Carbon Reducing Potential</td>
</tr>
<tr>
<td>CRE</td>
<td>Carbon Reducing Efficiency</td>
</tr>
<tr>
<td>ACR</td>
<td>Amount of Carbon Reduction</td>
</tr>
<tr>
<td>AFAF</td>
<td>Agriculture, Forestry, Animal husbandry and Fishery</td>
</tr>
<tr>
<td>TSPT</td>
<td>Transport, Storage, Post and Telecommunication</td>
</tr>
<tr>
<td>WRC</td>
<td>Wholesale, Retail trade and Catering</td>
</tr>
<tr>
<td>IPCC</td>
<td>International Panel on Climate Change</td>
</tr>
</tbody>
</table>

### Symbols

- $\mathbf{Y}$: vector of final demand for goods and services
- $\mathbf{X}$: vector of output
- $\mathbf{A}$: direct coefficient matrix
- $\mathbf{I}$: identity matrix
- $\mathbf{B}$: Leontief inverse matrix
- $X_{ij}$: input into industry $j$ from industry $i$
- $X_{ij}'$: output of industry $j$ from industry $i$
- $\alpha_{ij}$: element of $\mathbf{A}$, direct input into industry $j$ from industry $i$ to produce one unit of product of industry $j$
- $b_{ij}$: element of $\mathbf{B}$, both direct and indirect input into industry $j$ from industry $i$ to produce one unit of product of industry $j$
- $Y_i$: the final demand of industry $i$
- $E_i$: export of industry $i$
- $I_i$: import of industry $i$
- $Q_i$: residual of industry $i$
- $X_i$: total output of industry $i$
- $X_i'$: output of industry $i$
- $\Delta$: the symbol of change
- $\mu_i$: percentage of variation of industry $i$'s output
- $\mu_i'$: average percentage of variation of industry $i$'s output
- $\mu_i''$: change of proportion of variation of industry $i$'s output
- $\mu_i'''$: rate of change of proportion of variation of industry $i$'s output
- $M_i$: amount of carbon emission of industry $i$
- $EF_k$: emission factor of fuel $k$
- $AO_{ik}$: consumption of fuel $k$ in industry $i$
- $C_i$: direct carbon intensity of industry $i$
- $C_i'$: total carbon intensity of industry $i$
- $\Delta C_i$: total change of carbon emissions of all economic sectors
- $\Delta X$: total change of output of all economic sectors

The Nomenclature table provides a concise list of acronyms and symbols used in the text, ensuring clarity and consistency in scientific discourse.
changes in final demand on provincial energy use [23]. Karkacier and Goktoglu studied the impact of changes in the final demand of the agricultural sector on total energy consumption using input–output analysis [24].

However, within this group of investigations, few studies have combined the final demand multiplier with the output value of each sector, which is significant in China. Unlike developed countries, the economic growth in China is still increasing to meet the needs of its citizens. Therefore, while trying to reduce carbon emissions, China cannot sacrifice its economic development. Whether an industrial sector with a high final demand carbon emission multiplier should be controlled is unclear. Moreover, in the process of industrial restructuring, the amount of carbon reduction caused by lowering the economic status of a certain sector should also be calculated, as it directly indicates the effects of reduction.

In our research, these issues are considered, and a case study of China’s major province (Jiangsu) is provided. China contains 23 provinces, 4 municipalities directly under the control of the central government, 5 autonomous regions and 2 special administrative regions. Among the 34 regions, Jiangsu Province plays an important role in the national economy. The permanent population in Jiangsu is now 79.66 million, ranking it fifth among all provinces. Jiangsu significantly contributes to national GDP growth. The GDP of Jiangsu is consistently in the top three of all provinces, and its proportion in the national economy is still increasing, reaching 10.4% in 2010 [25]. Additionally, at the expense of rapid economic growth, Jiangsu consumes a large amount of fossil fuel. In 2009, Jiangsu Province consumed 237.09 million tons of standard coal equivalent, ranking it fourth among the 34 regions in China [26]. Thus, the rapid economic growth and extensive consumption in the Jiangsu Province could be representative of the characteristics of China; therefore, carbon reduction in Jiangsu is of great significance to China as a whole.

The rest of the paper is organised as follows. The method of input–output analysis is described in Section 2, followed by a description of data sources in Section 3. Section 4 discusses the results from the analysis, and conclusions are provided in Section 5.

2. Methodology

2.1. The input–output model

The input–output model shows the economic relationship among all industrial sectors. The standard representation of the input–output model is [27]:

\[ Y = (I - A)X \]  

where \( Y \) is the vector of final demand for goods and services, \( A \) represents the identity matrix, \( X \) is the vector of the direct consumption coefficient and \( X \) is the output vector. \( A \) consists of elements \( a_{ij} \), which represents the direct amount of products delivered to industry \( j \) from industry \( i \) to produce one unit of product of industry \( j \), \( a_{ij} = X_j / X_i \), where \( X_j \) is the input to sector \( j \) from sector \( i \) and \( X_i \) is the output of sector \( i \).

Let \( B = (I - A)^{-1} \), where \( B \) is the inverse Leontief matrix, consisting of characteristic elements \( b_{ij} \) which include both direct and indirect input to industry \( j \) from industry \( i \) required to produce one unit of product of industry \( j \).

In the input–output analysis, the identical equation in row format can be written as [28]:

\[ X_i = \sum_{j=1}^{n} X_{ij} + Y_i + E_i - IM_i + Q_i \]  

where \( X_i \) is the total output of industry \( i \), \( X_{ij} \) is the input to industry \( j \) from industry \( i \), \( Y_i \) is the final demand of industry \( i \), \( E_i \) is the export of industry \( i \), \( IM_i \) is the import of industry \( i \), and \( Q_i \) is the residual of industry \( i \).

2.2. Removal of imports

Because our analysis focuses on domestic carbon emissions, imports must be removed prior to the analysis to avoid calculating emissions from other regions.

Moving imports \( IM_i \) in Eq. (2) to the left side, the equation can be expressed as:

\[ X_i + IM_i = \sum_{j=1}^{n} X_{ij} + Y_i + E_i + Q_i \]  

Multiplying \( IM_i/(X_i + IM_i) \) on both sides of Eq. (3) yields:

\[ IM_i = \sum_{j=1}^{n} \frac{X_{ij}}{X_i + IM_i} IM_i + Y_i + IM_i + E_i + IM_i + Q_i X_i + IM_i \]  

By substituting Eq. (4) into Eq. (2), a factor to remove imports \( X_i/(X_i + IM_i) \) can be acquired. The equation can then be expressed as:

\[ X_i = \sum_{j=1}^{n} X_{ij} X_i \frac{X_j}{X_i + IM_i} + Y_i + X_i \frac{X_j}{X_i + IM_i} + E_i + X_i \frac{X_j}{X_i + IM_i} + Q_i \]  

Let \( X_{ij} = X_j \frac{X_i}{X_i + IM_i} \), \( Y_i = Y_i \), \( E_i = E_i \), and \( Q_i \)

\[ Q_i = Q_i \]  

where \( X_{ij} \), \( Y_i \), \( E_i \), and \( Q_i \) are the inputs to industry \( j \), final demand, exports and residual of industry \( i \) after the removal of imports, respectively. Then, the total output of industry \( i \), \( X_i \), can be written as:

\[ X_i = \sum_{j=1}^{n} X_{ij} + Y_i + E_i + Q_i \]  

In Section 2.1, it was noted that \( a_{ij} = X_j / X_i \). To eliminate the influence of imports, \( X_j \) should be substituted by \( X_j \). Then, \( a_{ij} = X_j / X_i \).

2.3. Model of carbon reducing potential

Here, carbon reducing potential (CRP) is measured both by carbon reducing efficiency (CRE) and by the amount of carbon reduction (ACR). CRE is defined as the ratio of the carbon variation of all industries to the output variation of all industries when the final demand of a certain industry changes; ACR is defined as the amount of carbon reduction in all industries as the output of a certain industry changes by 1%. CRE and ACR are connected to the input and output model mainly by the technical coefficient of the inverse Leontief matrix.

2.3.1. Final demand multiplier

The final demand multiplier is measured by the sum of the change of output in all sectors incurred by a change of output of a certain sector. The industries are interrelated such that the output of a certain industry requires input from all other industries. Additionally, a change in the output of a certain industry affects the output of other industrial sectors. Assuming that the percentage change in industry \( i \)'s output due to a final demand change is \( \mu_i \), the change in the output of industry \( i \) is \( \mu_i X_i \). As mentioned in Section
2.1. $b_{ji}$ represents both the direct and indirect input to industry $j$ from industry $i$ required to produce one unit of product of industry $j$. Thus, a change in the output of industry $i$ of $\mu_i X_i$ will lead to a variation of $b_{ji} \mu_i X_i$ in the output of industry $j$. Then, the final demand multiplier $\Delta X$ includes both the direct change in industry $i$’s output $\mu_i X_i$ and the induced indirect change in output of all other industries, which can be defined as:

$$\Delta X = \mu_i X_i + \sum_{j=1}^{n} b_{ji} X_i \mu_i$$

(7)

where $\Delta X$ is the total change in output of all economic sectors, $\mu_i$ is the percentage change of industry $i$’s output, $X_i$ is the output of industry $i$, and $b_{ji}$ represents both the direct and indirect input delivered to industry $j$ from industry $i$ required to produce one unit of product of industry $i$.

2.3.2. Multiplier of carbon emission

The multiplier of carbon emission is the sum of the change in carbon emissions in all sectors incurred by a change in emission in a certain sector. Similar to Section 2.3.1, the total change in carbon emission of all sectors includes both the direct carbon change in industry $i$ and the indirect carbon change induced in all other sectors. Any direct carbon reduction from a given industry will also have a secondary effect on the indirect emissions of associated industries [29].

Here, carbon emission is calculated according to the IPCC [30]

$$M_i = \sum_{k}^{n} EF_{k} \times AD_{ik}$$

(8)

where $M_i$ represents the amount of carbon emissions in sector $i$, $k$ refers to a certain type of energy, $n$ is the total number of energy types, $AD_{ik}$ represents activity data on the consumption of energy $k$ in industry $i$, and $EF_{k}$ is the corresponding emission factor of energy $k$.

$$C_i = M_i / X_i$$

(9)

where $C_i$ represents the direct carbon intensity of industry $i$, measured by the amount of carbon emissions per unit of monetary output.

As mentioned in Section 2.3.1, the change in the output of industry $i$ is $\mu_i X_i$. The direct carbon variation in industry $i$ is $C_i \mu_i X_i$, which can be acquired by multiplying the direct carbon intensity of industry $i$, $C_i$, by $\mu_i X_i$. When calculating the indirect carbon variation induced in industry $j$, the carbon intensity is $C_j$ instead of $C_i$ because industry $i$ consumes products in industry $j$. Then, the change in carbon emissions in industry $j$ is $C_j b_{ji} \mu_i X_i$. Thus, the multiplier of carbon emission can be acquired by multiplying the two parts of Eq. (7) by the corresponding carbon intensity:

$$\Delta C = C_i \mu_i X_i + \sum_{j=1}^{n} C_j b_{ji} X_i \mu_i$$

(10)

2.3.3. Derivation of CRE and ACR

CRE can be defined as Eq. (10) divided by Eq. (7):

$$CRE = \frac{\Delta C}{\Delta X} = \frac{C_i \mu_i X_i + \sum_{j=1}^{n} C_j b_{ji} X_i \mu_i}{\mu_i X_i + \sum_{j=1}^{n} b_{ji} X_i \mu_i} = \frac{C_i + \sum_{j=1}^{n} C_j b_{ji}}{1 + \sum_{j=1}^{n} b_{ji}}$$

(11)

Eq. (11) shows that the numerator of CRE comprises the direct carbon intensity of industry $i$ and the indirect carbon intensities induced in other industries. Thus, the total carbon intensity of industry $i$ can be expressed as:

$$C_i = C_i + \sum_{j=1}^{n} C_j b_{ji}$$

(12)

where $C_i$ is the total carbon emissions emitted to meet one unit of final demand of industry $i$.

Then, the total carbon emissions of industry $i$ are $C_i X_i$, the export carbon emissions of industry $i$ are $C_i E_i$, the consumed carbon emissions of industry $i$ are $C_i Y_i$, and the intermediate carbon emissions are $C_i X_i - C_i E_i - C_i Y_i$.

The denominator of Eq. (11) contains both direct and indirect inputs to yield one unit of product of sector $i$ in monetary terms. In this way, CRE takes both the final demand multiplier and the multiplier of carbon emission into consideration. Ideally, an industrial sector should have a large multiplier of carbon emission and a small final demand multiplier because, if its economic status is decreased, there could be a large decrease in carbon emissions without significantly affecting the economic output.

ACR measures both the direct carbon change of industry $i$ and the indirect carbon change induced in other sectors by a 1% change in the output of industry $i$, which can be calculated by multiplying Eq. (12):

$$ACR = 1 \% X_i \left( C_i + \sum_{j=1}^{n} C_j b_{ji} \right)$$

(13)

ACR is used to show the actual results of reduction. Considering both CRE and ACR, sectors with a high CRE and a high ACR are regarded as possessing the greatest CRP. These sectors should be identified by policy-makers as key industries.

3. Data sources

The application of the model requires input–output tables, end-use energy data and carbon emission coefficients of different energy sources.

Input–output tables were obtained from “The Statistic Yearbook of Jiangsu Province”. Due to data qualification, only input–output tables in 1997, 2000, 2002, 2005 and 2007 could be acquired [25]. The input–output tables contained 42 sectors. Regarding end-use energy data, in 1997, 2000, 2002 and 2005, a set of raw data consisting of 7 departments (agriculture, forestry, animal husbandry and fishery; industry; construction; transport, storage, post and telecommunication; wholesale, retail trade and catering; life consumption; and others) could be obtained. However, relatively detailed end-use energy data could only be obtained for 2007, and in this dataset, the 7 largest industrial sectors were further divided into 44 sectors.

For the raw analysis, the carbon emission coefficients of different types of energy sources were primarily obtained from the Guidelines for the Establishment of Provincial Greenhouse Gas Inventories issued by China’s National Development and Reform Commission [31]. With regard to fuels not included in the inventory, the default value issued by the IPCC was used [30]. However, in the detailed analysis, different types of energy data could not be obtained and different energy sources were converted into the standard coal equivalent according to their calorific values. Thus, the carbon emission coefficient of the standard coal equivalent, 0.67 tC/t, which was issued by the Energy Research Institute of China’s National Development and Reform Commission [32], was adopted.

In this study, industrial sectors were incorporated to solve the non-correspondence between end-use energy data and industrial...
sectors. Both raw and detailed classifications of industrial sectors were analysed. In the raw classification, the 7 industrial sectors given in “The Statistical Yearbook of Jiangsu Province” were recombined as 6 macro-sectors, namely, agriculture, forestry, animal husbandry and fishery; industry; construction; transport, storage, post and telecommunication; wholesale, retail trade and catering; and others, which were abbreviated as AFAF, Industry, Construction, TSPT, WRC and Others, respectively. The 42 industrial sectors of the input–output table were also merged into the 6 macro-sectors. In the detailed classification, the 42 industrial sectors of the input–output table and the 44 economic sectors with end-use energy data in 2007 were merged into 30 sectors (Table 1). The process of merging economic sectors is described in detail in Appendix A.

4. Results

4.1. An overview of carbon emissions in Jiangsu

Among all the economic sectors, Industry had the largest amount of carbon emissions, which was still rising. The percentage of industrial carbon emissions increased from 77.76% in 1995 to 81.24% in 2009 and had increased significantly since 2003 (Fig. 1).

To understand the environmental pressure posed by economic growth in Jiangsu, a decoupling analysis was applied. The methodology of the decoupling analysis is described in detail in Appendix B. Negative decoupling occurred for the majority of the time, which indicated a negative impact of economic growth on the environment (Fig. 2). Of the 6 macro-economic sectors, Construction reached the peak value of 40 between 2000 and 2001, when Jiangsu focused on urbanisation and a large number of newly built buildings caused increased emissions. AFAF had been in a state of decoupling from 1996 to 2002, showed signs of weak decoupling in 2003 and reached expansive coupling in 2009. As the economy improved, AFAF exerted an increasing amount of pressure on the environment, which corresponded to a growing desire for foods in China, especially meat, eggs and dairy products, leading to over-grazing and increased carbon emissions. The elasticity of Industry remained positive and peaked in 2006, indicating sustained pressure on the environment. Overall, the elasticity of Jiangsu’s industries was gradually decreasing, which was consistent with research suggesting that carbon emissions and economic growth in China tended to decouple [33]. Despite this trend, given the sustained negative decoupling situation, other measures are needed to achieve decoupling.

4.2. Effects of industrial restructuring on carbon reduction

CRP was measured both by CRE and ACR. An industrial sector of high CRP should have both a high CRE and a high ACR because

Table 1
Incorporated industrial sectors of Jiangsu.

<table>
<thead>
<tr>
<th>30 industrial sectors</th>
<th>Code</th>
<th>Name Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture, forestry, animal husbandry and fishery</td>
<td>a</td>
<td>Equipment for general use and special purpose p</td>
</tr>
<tr>
<td>Coal mining and dressing</td>
<td>b</td>
<td>Transport equipment q</td>
</tr>
<tr>
<td>Petroleum and natural gas extraction</td>
<td>c</td>
<td>Electrical machine manufacturing r</td>
</tr>
<tr>
<td>Metal minerals mining and dressing</td>
<td>d</td>
<td>Telecommunications, computer and other s</td>
</tr>
<tr>
<td>Non-metal minerals mining and dressing</td>
<td>e</td>
<td>Instrument, metres, cultural and office products t</td>
</tr>
<tr>
<td>Food manufacturing and tobacco processing</td>
<td>f</td>
<td>Manufacturing of handicrafts and others u</td>
</tr>
<tr>
<td>Textile industry</td>
<td>g</td>
<td>Scrap sector v</td>
</tr>
<tr>
<td>Textile, clothing, leather, fur and other products</td>
<td>h</td>
<td>Electric and heat power w</td>
</tr>
<tr>
<td>Wood processing industry and furniture making</td>
<td>i</td>
<td>Gas production and supply x</td>
</tr>
<tr>
<td>Paper, printing, stationery and sporting goods manufacturing</td>
<td>j</td>
<td>Production and supply of water y</td>
</tr>
<tr>
<td>Petroleum refining, coking and nuclear</td>
<td>k</td>
<td>Construction z</td>
</tr>
<tr>
<td>Chemical industry</td>
<td>l</td>
<td>Transport, storage, post and telecommunication aa</td>
</tr>
<tr>
<td>Non-metal mineral products</td>
<td>m</td>
<td>Wholesale and retail trade ab</td>
</tr>
<tr>
<td>Metal melting and rolling industry</td>
<td>n</td>
<td>Others ac</td>
</tr>
<tr>
<td>Metal mineral products</td>
<td>o</td>
<td>Life consumption ad</td>
</tr>
</tbody>
</table>

Fig. 1. Percentage of direct carbon emissions of Jiangsu’s 6 major industries.

Fig. 2. Elasticity of Jiangsu’s 6 major industries from 1995 to 2009.
a high CRE ensures a significant constraint on carbon emissions without significantly affecting economic growth, while a high ACR indicates a good reduction effect.

Eq. (11) indicated that sectors with a high CRE usually possessed large multipliers of carbon emissions. In addition, sectors with large multipliers were dominant sectors [18]. The value of CRE was largely determined by the direct carbon intensity of a sector and the indirect carbon intensity induced in other industrial sectors. At times, the carbon intensity of the sectors themselves was not the cause of the large emissions, but the inputs from other sectors led to a high carbon intensity. Sectors of high CRE should be targeted with different reduction policies on the basis of their direct and indirect carbon intensity. If the high CRE was caused by direct carbon intensity, then the reduction policy should aim to reduce the carbon intensity of the sector itself by introducing new technologies, substituting fossil fuels with clean energy, and enhancing energy efficiency, as well as by other similar tactics. If the high CRE was caused by indirect carbon intensity, then the reduction policy might be more complex. Measures should attempt to reduce the carbon intensity associated with the supply sector. When more than one sector was involved, sector-specific measures were clearly insufficient and needed to be complemented with cross-sectoral policies [19].

4.2.1. A raw analysis of 6 macro-industries in Jiangsu

Starting from the input–output table of 1997, 2000, 2002 and 2005 and applying the input–output analysis in Section 2.1, the matrix of complete technical coefficients could be obtained. The direct carbon intensity of each sector was calculated by means of Eqs. (8)–(9). Then, according to Eq. (11), the CRE of all sectors was acquired. Among all the sectors, TSPT scored the highest in terms of CRE, with approximately 0.3 ton C/ten thousand yuan, followed by Industry (Fig. 3). The calculation of both direct and indirect carbon intensity by applying Eq. (12) revealed that the high CRE in TSPT was primarily due to its direct carbon intensity, which was much higher than that of the other 5 macro-sectors. Interestingly, despite the fact that the indirect carbon intensity of TSPT was also large, the sector contributing most to the indirect intensity of TSPT was itself, with the percentage increasing from 63.2% in 1997 to over 70% in 2005. This result indicated that the consumption practices or the type of energy used within TSPT led to large carbon emissions. In this case, policy measures that predominantly aim to reduce carbon emissions should be applied in this sector itself, and the adoption of renewable energies and better technologies should be encouraged.

The direct carbon intensity of Industry ranked second among all six sectors (Table 2), and its indirect carbon intensity scored the highest (Table 3) because the production in Industry required a considerable amount of input from other sectors, such as factory building in Construction, transportation services in TSPT and others. This finding suggests that the sector itself should be targeted for reduction and that a cross-sectoral policy is also needed to mitigate carbon emissions in the supply chain.

Another interesting finding emerged in the Construction sector. The direct carbon intensity in Construction was quite low, even less than that in AFAF. In contrast, the indirect carbon intensity in Construction was much higher. The sector itself did not emit many on-site carbon emissions, but the industrial linkages among Construction and other sectors created a large amount of emissions. In the pre-manufacturing area of Construction, some activities (especially the calcinations of limestone in cement production and the use of coke as a reducing agent in iron and steel production) are likely to cause a large amount of carbon emissions [34]. Thus, policy...
measures should be implemented in these upstream sectors. New production processes and carbon capture and sequestration are recommended.

However, the application of Eq. (13) revealed that there was no absolute positive correlation between the CRE and ACR of a sector. Despite possessing a high CRE, a certain sector might have a low ACR if the sector was of low economic status. Among the 6 macro-sectors, Industry had the highest ACR, which increased from 1039.2 thousand tons in 1997 to 2732.4 thousand tons in 2005 as its output significantly increased. Nevertheless, despite having a high CRE, TSPT ranked quite low in terms of ACR due to its low output, indicating that lowering the economic status of TSPT would not cause a significant decrease in carbon emissions. Thus, instead of decreasing the proportion of TSPT in the economy, the reduction policy should concentrate on the introduction of new technologies and renewable energy as mentioned in the paragraph above because carbon emissions in TSPT are primarily caused by direct carbon intensity.

Considering both CRE and ACR, Industry had the greatest CRP. The above analysis suggests that three pathways to carbon reduction exist, which could be combined together in policy making. First, the direct carbon intensity of Industry was high, indicating that the policy should target the sector itself, including the application of new energies and technologies. Second, the indirect carbon intensity induced in other sectors was also high, indicating that a cross-sectoral policy is effective in reducing upstream carbon emissions. The third path is related to the high ACR of Industry. A proper decrease of the economic status of Industry combined with an increase of modern green sectors would also lead to a significant reduction in carbon emissions. In addition, the output of Industry accounts for almost 70% of the total output in all sectors in Jiangsu. Industry primarily consists of heavy processing industry and traditional manufacturing, which inefficiently consume a considerable amount of energy. Rare high-tech industries are present in the industry cluster, thus warranting an adjustment of Industry.

Moreover, the analysis of export, consumed and intermediate carbon emission in Industry revealed that Industry in Jiangsu adopted an export-driven economic growth pattern instead of a demand-pull pattern. Export carbon emissions accounted for a significant percentage of the total industrial emissions and were continuously rising in 2005, while consumed carbon only comprised 4.7% of the total carbon emissions (Fig. 4). This finding is consistent with the notion that China’s economy is shared by export revenues through the outsourcing of its skilled work force and by goods due to lower product costs [35], and a large number of exports were the main reasons for the increase in China’s carbon emissions [36]. The finding also indicates that Jiangsu managed too many emissions that were caused by consumption in other regions or countries (the phenomenon of “carbon leakage”). Thus, during Jiangsu’s “Twelve Five-Year” period, to reduce export carbon emissions caused by low-level processing, Industry should upgrade its manufacturing process and transfer from the low periphery of the output value chain to a higher level [37].

4.2.2. A detailed analysis of 30 sectors in Jiangsu

In the above paragraphs, we analysed the effects of industrial restructuring on carbon reduction at a six-sector raw level, concluding that Industry had the greatest CRP. However, making suggestions using raw data alone is insufficient. To further examine and determine the specific industries with the largest CRP, we applied the same analysis to detailed data from 2007.

Applying the input–output analysis in Section 2.1, the 30 × 30 matrix of complete technical coefficients of 2007 could be obtained. The direct carbon intensity of each economic sector could be calculated by Eqs. (8)–(9). Then, the CRE and ACR of each sector could be acquired according to Eq. (11) and Eq. (13), respectively. The results revealed that, as in the previous analysis, no positive relationship existed between CRE and ACR. Among all the sectors, electric and heat power ranked first in CRE, scoring 1.33 ton/ten thousand yuan, followed by coal mining and dressing, non-metal mineral products, non-metal minerals mining and dressing, and the metal melting and rolling industry. The top five sectors in terms of ACR were the electric and heat power, chemical, metal melting and rolling, textile and life consumption sectors (Fig. 5).

Interestingly, the calculation of direct and indirect carbon intensity by applying Eq. (12) revealed that the electric and heat power, coal mining and dressing, non-metal mineral products and non-metal minerals mining and dressing sectors also ranked in the top four in terms of both direct (on site) and indirect carbon intensity (Table 4). The direct and indirect carbon intensities of these sectors were much higher than that of the other sectors, indicating that the high CRE in these sectors was primarily caused by low energy use efficiency within the sectors themselves and the upstream sectors. Thus, on the one hand, policy measures should focus on the enhancement of energy efficiency, introduction of new technologies and use of new types of energies such as wind, solar energy, water and bio-fuel; on the other hand, cross-sectoral policies aiming at reducing the linkages between upstream heavy sectors should also be considered.

The production and supply of the water sector and the metal minerals mining and dressing sector ranked 7th and 8th in terms of CRE, respectively. Both of these sectors had a high indirect carbon intensity of 6 macro-sectors in Jiangsu unit: ton/ten thousand yuan.

<table>
<thead>
<tr>
<th>Year</th>
<th>1997</th>
<th>2000</th>
<th>2002</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFAF</td>
<td>0.129</td>
<td>0.224</td>
<td>0.027</td>
<td>0.084</td>
</tr>
<tr>
<td>Industry</td>
<td>0.266</td>
<td>0.253</td>
<td>0.220</td>
<td>0.219</td>
</tr>
<tr>
<td>Construction</td>
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<td>0.006</td>
<td>0.008</td>
<td>0.020</td>
</tr>
<tr>
<td>TSPT</td>
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<td>0.406</td>
<td>0.323</td>
</tr>
<tr>
<td>WRC</td>
<td>0.020</td>
<td>0.037</td>
<td>0.026</td>
<td>0.027</td>
</tr>
<tr>
<td>Others</td>
<td>0.152</td>
<td>0.100</td>
<td>0.093</td>
<td>0.084</td>
</tr>
</tbody>
</table>

4.2.3. Pattern identified by industrial matrix of complete technical coefficients of 2007

The production and supply of the water sector and the metal minerals mining and dressing sector ranked 7th and 8th in terms of CRE, respectively. Both of these sectors had a high indirect carbon intensity of 6 macro-sectors in Jiangsu unit: ton/ten thousand yuan.

<table>
<thead>
<tr>
<th>Year</th>
<th>1997</th>
<th>2000</th>
<th>2002</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFAF</td>
<td>0.269</td>
<td>0.234</td>
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<tr>
<td>Industry</td>
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<tr>
<td>Construction</td>
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<tr>
<td>TSPT</td>
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<td>0.403</td>
<td>0.613</td>
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<tr>
<td>WRC</td>
<td>0.211</td>
<td>0.206</td>
<td>0.170</td>
<td>0.110</td>
</tr>
<tr>
<td>Others</td>
<td>0.340</td>
<td>0.269</td>
<td>0.229</td>
<td>0.199</td>
</tr>
</tbody>
</table>

Fig. 4. Export, consumed and intermediate carbon emissions of industry.
intensity and a relatively low direct carbon intensity, suggesting that the high CRE of these two sectors was due to high-carbon inputs from other associated sectors. Thus, a single-sector reduction policy was insufficient, requiring the implementation of a cross-sector policy. Importantly, the electric and heat power and chemical industries comprised 62.7% of the indirect carbon intensity of the production and supply of water sector, while the electric and heat power, metal melting and rolling and chemical industries contributed 60.6% to the indirect carbon intensity of the metal minerals mining and dressing sector. Thus, efforts to reduce the linkages between these sectors might significantly contribute to carbon reduction.

The high ACR of the chemical, metal melting and rolling, equipment for general use and special purpose and construction industries was primarily due to their high output, which ranked above that of all other sectors. A small decrease in the economic status of these sectors could lead to a substantial decrease in carbon reduction. Thus, it was necessary to properly reduce the investment and development of these sectors. When analysing the construction sector, it should also be noted that the indirect carbon intensity of this sector was 0.38 ton/ten thousand yuan, which is much higher than its direct carbon intensity of 0.03 ton/ten thousand yuan. This result is consistent with that of the raw analyses, which demonstrated that carbon emissions in the construction sector primarily originated from upstream sectors, such as cement production and iron and steel production [34]. However, the high ACR of the electric and heat power industry could be explained by its especially high carbon intensity instead of its proportion of output in all sectors. Thus, the reduction policy should aim at increasing the efficiency of energy use in the electric and heat power industry, as outlined earlier, rather than focus on lowering the economic status of this industry.

To select industries with both high CRE and high ACR, a coordinate method was applied. The 30 industries in Jiangsu were divided into four quadrants, with the fifteenth industry defining the origin of the coordinate, the amount of reduction as the x-axis and efficiency as the y-axis. CRP was then classified into three levels: first-, second- and third-level potential. Sectors in the first quadrant were low in both CRE and ACR, with a third-level potential; industries in the second quadrant were low in CRE but high in ACR, with a second-level potential; industries in the third quadrant were high in both CRE and ACR, with a first-level potential; and industries in the fourth quadrant were high in CRE but low in ACR, with a second-level potential (Table 5).

The third quadrant contained the chemical; non-metal mineral products; metal melting and rolling; textile; paper, printing, stationery and sporting goods manufacturing; transport, storage, post and telecommunication; electric and heat power and life consumption industries (Fig. 6). These 8 industries were high in both CRE and ACR. Implementing policies of carbon reduction in these sectors would not significantly affect economic output but would result in a relatively large amount of carbon reduction. Among these eight sectors, 4 (electric and heat power, chemical, non-metal mineral products, and metal melting and rolling industries) are analysed in the above paragraphs. With regard to the other four sectors, the textile industry ranked 4th in terms of ACR, mainly due to its high output, which ranked 6th among all sectors, while its CRE ranked 14th. Therefore, reduction policies should aim at lowering its economic status. Paper, printing, stationery and sporting goods manufacturing ranked 19th in output; however, both its direct and indirect carbon intensities were high, indicating the need for policies targeting reduction both within the sector itself and between the sector and the upstream sectors. The transport, storage, post and telecommunication sector had a high direct carbon intensity, ranking 5th among all sectors,
suggesting that the sector emits a considerable amount of carbon emission mainly due to the type of fuels, technology and consumption style within the sector itself. Life consumption is an incorporated sector consisting of 6 sectors, namely the water, environment, and public facilities management industry; resident services and other services; education; health, social security and social welfare; culture, sports and recreation; and public administration and social organisations. Its high ACR was primarily due to its high output. However, given the large number of sectors included, the sector might not be targeted for reduction.

The first quadrant contained 10 industries that were lowest in CRP, namely the agriculture, forestry, animal husbandry and fishery; food manufacturing and tobacco processing; textile, clothing, leather, fur and other products; wood processing and furniture making; transport equipment; instrument, metres, cultural and office products; manufacturing of handicrafts and other products; scrap; gas production and supply; and wholesale and retail trade industries. These 10 sectors were low in both CRE and ACR. The output of these ten industries only comprised 20.5% of the total output, which was much lower than the contribution of the eight industries comprising the first-level CRP, suggesting a small contribution of traditional industries to the economy. The third-level CRP consisted primarily of traditional industries, with both low direct and indirect carbon intensities. To stimulate economic growth, Jiangsu has gradually discarded its traditional industries and relied on heavy industries. This extensive mode of economic growth resulted in the consumption of a large amount of energy and the production of a large amount of carbon emissions. Additionally, the export carbon emissions of the eight high-CRP sectors, with the exception of the life consumption sector, also ranked in the top tier, with the highest export carbon emissions found in the chemical industry. This finding indicated an export-driven economic growth pattern for these economic sectors (Fig. 7). The manufacturing industries in Jiangsu mainly produce primary products, which contribute little to the added value. These industries are normally labour intensive, with production costs much lower than those in developed countries. Thus, developed countries often transfer labour-intensive and highly pollutant industries to developing countries, acquire profits at the high end of the industry value chain and optimise their own industrial structure at the same time [38]. Additionally, because of international industrial competition, developed countries often strictly control the transfer of high technology when shifting labour-intensive and highly pollutant industries to developing countries to curb the enhancement of technology in developing countries, which in turn aggravates the environmental pressure posed by economic growth in developing countries. Therefore, in addition to the aforementioned reduction policies, measures should also be taken to upgrade products to reduce export carbon emissions.

5. Conclusion

The input–output analysis of Jiangsu Province regarding the effects of industrial restructuring on carbon reduction in 1997, 2000, 2002, 2005 and 2007 revealed that the CRE of each economic sector did not necessarily correspond to ACR. Different sectors

<table>
<thead>
<tr>
<th>Code</th>
<th>Rank of reduction</th>
<th>Rank of efficiency</th>
<th>Classification of potential</th>
<th>Code</th>
<th>Rank of reduction</th>
<th>Rank of efficiency</th>
<th>Classification of potential</th>
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<td>o</td>
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<td>10</td>
<td>22</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 6. Distribution map of carbon reducing potentials of Jiangsu’s 30 industries.

Fig. 7. Export, consumed and intermediate carbon emissions of the 8 industries with first-level carbon reducing potential.
Eight sectors (chemical industry; non-metal mineral products; metal melting and rolling industry; textile industry; paper, printing, stationery and sporting goods manufacturing; transport, storage, post and telecommunication; electric and heat power; and life consumption) comprised the first CRP level. Sectors of high direct carbon intensity (electric and heat power; non-metal minerals products; paper, printing, stationery and sporting goods manufacturing; and transport, storage, post and telecommunication) should concentrate on within-sector reduction by introducing new energies or technologies. Sectors of high indirect carbon intensity (electric and heat power; non-metal mineral products; and paper, printing, stationery and sporting goods manufacturing) should aim to adjust upstream industrial linkages to reduce carbon emissions. Sectors with large economic statuses (chemical, metal melting and rolling, and textile industries) should be properly limited to promote a more balanced economy and guarantee reduction. For example, policies such as carbon tax could be implemented to minimise the effects on economic gain on the one hand and provide financial incentives and tax benefits to encourage private investors to improve energy efficiency, as well as to adopt carbon reduction plans, on the other [39]. Moreover, the analysis also revealed that the economic growth pattern of Jiangsu's dominant heavy industries was output-driven. During the period of the “Twelve Five-Year Plan”, it is the government’s responsibility to introduce limits on the exports of high-carbon products, encourage the upgrade of production processes and help transform the economic growth pattern from export-driven to demand-pull.

Ten traditional industries (i.e., agriculture, forestry and animal husbandry; food manufacturing and tobacco processing; textile, clothing, leather, fur and other products; wood processing industry and furniture making; transport equipment; instrument, metres, cultural and office; manufacturing of handicrafts and others; scrap sector; gas production and supply; and wholesale and retail trade) showed the lowest CRP after they gradually lost their dominant status as Jiangsu’s economy soared. During the period of the “Twelve Five-Year Plan”, Jiangsu should actively renovate its traditional industries, remove redundant departments and substitute some low-efficiency procedures with modern, green processes. In this way, it may be able to mitigate the over-reliance on heavy industries and create a more balanced economy.

Nevertheless, the current analyses are not without shortcomings. First, the approach that we adopted here assumed structural stability of the productive relationships, i.e., the technical coefficients were considered fixed and only the “flow” variables changed [10]. This approach was insufficient, and the impact of technological enhancement should be considered. Further research could involve the selection of methodologies that allow one to assess the impact of changes in technical coefficients. Moreover, some more complex social issues must still be addressed. In the current imbalanced social structure, many people rely on manual labour positions in heavy manufacturing for subsistence. This group of people lack food, medical care, sanitation and education. A large adjustment in industrial structure might cause excessive job losses and damage social security. Additionally, disagreements in policy between the central government and local governments further impede the implementation of industrial restructuring. These issues are important and worthy of exploration in future research.

Acknowledgements

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Appendix A

Table A1. 42 sectors of the input–output table.

| 42-sector Input–output table | 22. scrap sector | 23. electric and heat power | 24. gas production and supply | 25. production and supply of water | 26. construction | 27. transport and storage | 28. post and telecommunication | 29. information transmission, computer services and software industry | 30. wholesale and retail trade | 31. accommodation and catering industry | 32. financial sector | 33. real estate | 34. leasing and business services | 35. research and experimental development industry | 36. integrated technical services | 37. water, environment and public facilities management industry | 38. resident services and other services | 39. education | 40. health, social security and social welfare | 41. culture, sports and recreation | 42. public administration and social organizations |

Table A2. 45 sectors of the end-use energy data in 2007.

| 45-sector end-use energy data | 24. rubber products | 25. plastic products | 26. non-metal mineral products | 27. ferrous metal smelting and rolling industry | 28. nonferrous metal smelting and rolling industry | 29. metal mineral products | 30. equipment for general use | 31. equipment for special purpose | 32. transport equipment | 33. electrical machinery manufacturing | 34. telecommunications, computer and other | 35. instrument, metres, cultural and office products | 36. manufacturing of handicrafts and others | 37. waste resources and materials recycling and processing industry | 38. electric and heat power | 39. gas production and supply | 40. production and supply of water |
In the raw analysis, the 42 sectors of the input–output table and the 7 macro-sectors of the end-use energy data are merged into 6 macro-sectors. With respect to the end-use energy data, life consumption and others were combined as others. The 7 macro-economic sectors of the end-use energy data in "The Statistical Yearbook of Jiangsu Province" were recombined as agriculture, forestry, animal husbandry and fishery; industry; construction; transport, storage and telecommunication; wholesale, retail trade and catering industry and others, which were respectively abbreviated as AFAF, Industry, Construction, TSPT, WRC and Others.

With regard to the input–output table (Table A.1), the 1st sector remains unchanged; the 24 sectors from the 2nd sector to the 25th sector are merged into the macro-sector Industry; the 26th sector construction remains unchanged; the 27th and 28th sectors are merged into the macro-sector TSPT; the 30th and 31st sectors are merged into the macro-sector WRC; and the remaining sectors of the input–output table are merged into Others.

In the detailed analysis, both the 42 sectors of the input–output table (Table A.1) and the 45 sectors of the end-use energy data in 2007 (Table A.2) are merged into 30 economic sectors (Table 1). The 4th and 5th sectors in Table A.2 are merged to match the 4th sector in Table A.1; the 8th, 9th, 10th, and 11th sectors in Table A.2 are merged to match the 6th sector in Table A.1; the 13th and 14th sectors in Table A.2 are merged to match the 8th sector in Table A.1; the 15th and 16th sectors in Table A.2 are merged to match the 9th sector in Table A.1; the 17th, 18th and 19th sectors in Table A.2 are merged to match the 10th sector in Table A.1; the 21st, 22nd, 23rd, 24th, and 25th sectors in Table A.2 are merged to match the 12th sector in Table A.1; the 27th and 28th sectors in Table A.2 are merged to match the 14th sector in Table A.1; the 30th and 31st sectors in Table A.2 are merged to match the 16th sector in Table A.1; the 27th and 28th sectors in Table A.2 are merged to match the 42nd sector in Table A.2; the 30th and 31st sectors in Table A.1 are merged to match the 43rd sector in Table A.2; and the 37th, 38th, 39th, 40th, 41st, and 42nd sectors in Table A.1 are merged to match the 45th sector in Table A.2. Thus, both the 42 sectors of the input–output table and the 45 sectors of the end-use energy data are merged into 30 sectors (Table 1) to solve the non-correspondence between end-use energy data and industrial sectors.

Appendix B

Decoupling indicators are created based on the “Driving force–pressure–state–impact–reflect” framework [40]. Here, the elastic analysis is applied to analyse the relationship between the environmental pressure (carbon emissions) and the economic growth of Jiangsu Province.

Elasticity = the percentage change in carbon emission/ the percentage change in GDP = %ΔC/%ΔGDP. The criterion is shown in Fig. B.1, in which the environmental “bads”, ΔVOL can be substituted with ΔC here.

References

[20] Cellura M, Longo S, Mistrutta M. Application of the structural decomposition analysis to assess the indirect energy consumption and air emission changes
related to Italian households consumption. Renewable & Sustainable Energy Reviews 2012;16(2):1135–45.


[40] OECD. Indicators to measure decoupling of environmental pressure from economic growth; 2002.