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Environmental Energy Technologies Division

August 1998

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Abstract. From the early 1970’s to mid 1990’s, service sector carbon dioxide emissions have increased significantly in OECD countries, despite marked declines in energy intensity. This development is underscored by a widespread shift from fuel use to electricity use in commercial buildings. Service sectors in countries that produce low-carbon electricity, particularly those that operate nuclear- and hydro-powered utilities, have most successfully restrained CO₂ emissions. This study analyzes the impact of activity, structure, energy intensity, final fuel mix, and utility mix on carbon emissions in the service sector for 13 OECD countries, and contrasts the developments before 1990 with those afterwards. The major findings of this analysis are:

(i) Carbon emissions, which rose in 9 of the 13 countries investigated, were bolstered in every country by an expansion of floor area and service sector GDP;
(ii) Declines in energy intensity and carbon intensity lessened the magnitude of emissions increases;
(iii) Electricity’s share of final energy use rose in all 13 countries, but affected carbon emissions quite differently among countries;
(iv) After 1990, energy intensity improvements applied less downward pressure on emissions, while reductions in the average carbon content of final energy restrained emissions more strongly.

1. INTRODUCTION

At the December 1997 Third Conference of Parties (COP-3) meeting in Kyoto, the nations of the world agreed to a protocol to reduce emissions of greenhouse gases such as carbon dioxide. The agreement instructed the industrialized world to reduce emissions approximately 6-8 % below 1990 levels by 2008-2012. With the service sector now accounting for approximately one-sixth of aggregate carbon emissions among Organization for Economic Cooperation and Development (OECD) countries, it should clearly be a major focus of national carbon mitigation plans. However, energy use and carbon emissions in the service sector are more poorly understood than in the manufacturing, residential, and transportation sectors, because surveys and end-use data for the service sector lack the level of detail necessary for a disaggregated analysis (Sezgen and Schipper, 1995). This paper investigates carbon emissions and energy use from 1973 to 1995 in the service sector for 13 OECD countries (the United States, Japan, western Germany, the United Kingdom, France, Italy, the Netherlands, Canada, Australia, Norway, Sweden, Denmark, and Finland). It seeks to describe the underlying causes of service sector carbon emissions, to explain how these causes developed across countries, and to evaluate their relative impacts before and after 1990.
1.1 The Growth of the Service Sector and Increased CO₂ Emissions

The service sector (ISIC 6-9) involves activities that take place in buildings used outside of manufacturing, agriculture, and households—namely, offices, schools, hospitals, retail shops, hotels, restaurants, and numerous others (Schipper, 1997). As the service sector has become a larger part of the economies in OECD countries, it has used more energy and released more CO₂. From 1973 to 1995, the service sector’s share of GDP grew from 60% to 66% in the countries investigated, and over that period, service sector GDP per capita has risen in all thirteen countries. Figure 1 shows the development of per capita services GDP.¹

Largely as a result of these developments, services energy use and CO₂ emissions have increased among the observed countries by a total of more than 20%. But as Table 1 demonstrates, these increases have not been uniform. Sweden, Norway, and France have made dramatic reductions in emissions despite increasing energy consumption. Much of the variation in the levels of carbon dioxide emissions and energy use that we observe among countries can be attributed to electricity use, which has dramatically grown as a proportion of final energy in every country. From 1973 to 1995, the share of electricity use in the service sector nearly doubled from 24% to 44% of final energy for the OECD as a whole. This development has strongly raised emissions in countries with carbon intensive electricity production, and lowered them in countries with low-carbon electricity.

Table 1. Service Sector Final Energy, Emissions, and Electricity Fuel Share in 13 OECD Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Final Energy (PJ)</th>
<th>% Change</th>
<th>CO₂ Emissions (ktC)</th>
<th>% Change</th>
<th>Electricity Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>5,914</td>
<td>7,077</td>
<td>20%</td>
<td>170,701</td>
<td>218,036</td>
</tr>
<tr>
<td>Japan</td>
<td>1,023</td>
<td>1,811</td>
<td>77%</td>
<td>26,020</td>
<td>45,362</td>
</tr>
<tr>
<td>w. Germany</td>
<td>1,092</td>
<td>933</td>
<td>-15%</td>
<td>29,869</td>
<td>24,326</td>
</tr>
<tr>
<td>UK</td>
<td>676</td>
<td>834</td>
<td>23%</td>
<td>22,331</td>
<td>23,191</td>
</tr>
<tr>
<td>Canada*</td>
<td>800</td>
<td>942</td>
<td>18%</td>
<td>12,759</td>
<td>13,838</td>
</tr>
<tr>
<td>Italy</td>
<td>285</td>
<td>465</td>
<td>63%</td>
<td>6,804</td>
<td>11,696</td>
</tr>
<tr>
<td>Australia*</td>
<td>78</td>
<td>169</td>
<td>117%</td>
<td>3,646</td>
<td>9,144</td>
</tr>
<tr>
<td>France</td>
<td>613</td>
<td>735</td>
<td>20%</td>
<td>15,033</td>
<td>8,851</td>
</tr>
<tr>
<td>Netherlands*</td>
<td>208</td>
<td>234</td>
<td>13%</td>
<td>4,264</td>
<td>5,331</td>
</tr>
<tr>
<td>Denmark</td>
<td>78</td>
<td>79</td>
<td>2%</td>
<td>2,226</td>
<td>2,547</td>
</tr>
<tr>
<td>Finland</td>
<td>104</td>
<td>120</td>
<td>15%</td>
<td>2,213</td>
<td>2,300</td>
</tr>
<tr>
<td>Sweden</td>
<td>157</td>
<td>158</td>
<td>1%</td>
<td>3,015</td>
<td>1,189</td>
</tr>
<tr>
<td>Norway</td>
<td>48</td>
<td>86</td>
<td>77%</td>
<td>595</td>
<td>298</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11,075</strong></td>
<td><strong>13,643</strong></td>
<td><strong>23%</strong></td>
<td><strong>299,475</strong></td>
<td><strong>366,109</strong></td>
</tr>
</tbody>
</table>

¹Note that we do not have 1973 values for Australia, the Netherlands, and Canada. For these countries we use 1974, 1980 and 1981, respectively. The Netherlands, Norway, the U.S., France, and Finland use 1994 values instead of 1995.

1.2 An Overview of Service Sector Energy Use

In the service sector, energy is used to heat, light, and cool buildings, as well as for water heating, office equipment, other electric appliances, cooking, and refrigeration. Heating,
lighting, and cooling levels are driven primarily by commercial floor area, whereas energy use for water heating, office equipment, and some electric appliances depends more strongly on the number of service sector employees. In the past two decades, electricity use has expanded due to growing use of office equipment, penetration of cooling, and in some countries, fuel switching to electricity in heating (Sezgen and Schipper, 1995 and Schipper, 1997).

End-use data is scarce in the commercial sector. Figure 2 presents end-use energy intensities for five countries, and shows that most countries use less energy per square meter of floor area than in the past. Space heating is the largest end-use for each country, though its share of final energy use declined for all countries. Water heating also became relatively less important as electric end-uses such as appliances, lighting, and cooling increased in share.

2. METHODOLOGY

This report decomposes the underlying components of service sector carbon emissions. It revises a factorial approach established in previous studies (see Howarth, et al. 1993, and Schipper, et al. 1996a) in order to fit the more aggregated data that is available for service sectors in OECD countries. A fixed-year Laspeyres index is used to evaluate changes over time in the components of carbon emissions.

2.1 Data

Most of the data used in this report has been collected for over 20 years at Lawrence Berkeley National Laboratory (LBNL). All service sector GDP, purchasing power parity conversions, and employment data were drawn from OECD National Accounts. The energy use and floor area data were derived from national sources, which are outlined in Appendix A. Floor area data are subject to some uncertainty because of differences among countries with respect to classification of buildings types. Carbon release coefficients are assigned for each fuel as given in the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, Volume 3 – Greenhouse Gas Inventories Reference Manual (1995).

Variations in average winter temperatures each year can influence space heating energy use in commercial buildings. However, in this analysis, we do not normalize for each country’s yearly climatic fluctuations. First, the data on space heating shares of final energy demand is not well understood for most OECD service sectors. Second, the actual variations in energy use due to ambient temperatures is complicated by the degree that internal factors, such as people and electric equipment, affect space heating demand in buildings (Schipper, 1996a).

2.2 Decomposing Carbon Dioxide Emissions in the Service Sector

An identity developed in previous LBNL studies (see Schipper, et al. 1996a), can be revised to express service sector carbon emissions in any year as follows:
Under this model, service sector GDP represents Activity, the sector's primary enterprise. The Structure term, floor area per unit of GDP, provides some insight into the development of service sector productivity. Energy intensity measures the amount of energy used per square meter of floor area. Final fuel mix represents the share of final energy for each fuel type, counting both electricity and district heat at their delivered values. Finally, the carbon release factor denotes each fuel's average release of carbon dioxide per unit of final energy consumed. This term (C_i / E_i) is constant over time for primary fuels such as oil, gas, and coal, and varies for electricity and district heat based on the average primary fuel mix used to produce a unit of final heat or electricity.

Based on the identity above, fixed base-year Laspeyres indices are used to calculate the relative impact over time of each term on total carbon emissions. With 1990 set as a base year, one term is allowed to vary while the others remain constant at their 1990 values. By setting the equation as a ratio to itself, this results in an index that designates the percentage effect of the varying term with respect to 1990 carbon emissions. For instance, if energy intensity decreases by 8% from 1990 to 1995, the energy intensity effect in 1995 would equal 92%. An index is built for each term, namely the activity effect, structure effect, energy intensity effect, final fuel mix effect, and utility mix effect. Figure 3 uses the U.S. as an example to present how each underlying component has effected service sector carbon emissions from 1970-1995. The product of the energy intensity, final fuel mix, and carbon release factor yields a country's carbon intensity, defined as carbon emissions per square meter of floor area (E/F * E_i/E * C_i/E_i = C/F).

In order to better understand the changes in final fuel mix, we employ additional methods of analysis. First, we make a simple estimate of service sector electricity and fuel prices in order to gain some insight into the fuel choice of building owners and operators. Second, we compare the correlations between service sector GDP per capita with electricity use and fuel use in order to draw inferences about the effect of further expansion of service economies in the future.
2.3 Ideas to Improve the Decomposition of Service Sector Carbon Emissions

In this decomposition model, the structure indicator, floor area per service sector GDP, is such an aggregate term that it is likely to overlook some more detailed structural developments. The service sector covers an array of building types, such as offices, retail shops, hospitals, and schools, which use energy in different ways. A better way to gauge structural changes would be to capture energy intensities for specific end-uses in each distinct building type, as well as to recognize shifts among building types within a given country's building stock. Unfortunately, most OECD countries do not collect the data necessary for such a disaggregated analysis.

Another way that end-use data could be used to significantly improve the explanatory power of this model would be, depending on the particular end-use, to substitute the number of employees for floor area in the terms for energy intensity (energy per floor area) and structure (floor area per GDP). The choice of terms should be based on whether floor area or the number of employees more strongly drives energy consumption for each particular end-use. For instance, floor area would be the appropriate term for lighting, space heating, ventilation, and cooling, while the number of employees would be a better choice for office equipment and water heating. However, with only aggregate energy use data, we choose floor area because it is the stronger driving force behind the collection of end-uses that constitute roughly 75% of service sector energy consumption (based on service sector end-use data for the U.S., Canada, and Japan).

3. RESULTS

Table 2 below shows the average yearly impact of activity, structure, energy intensity, final fuel mix, and primary utility mix on service sector CO₂ emissions. Service sector carbon emissions increased over the last two decades in 9 of the 13 observed countries. The strongest driving force behind this increase was the activity effect, namely the growth in sectoral GDP, and the additional floor area and energy-using equipment associated with it. Structural changes produced mixed results on CO₂, limiting emissions in countries that were able to provide services with less floorspace. Most countries reduced energy intensity, which restrained emissions, and all except Italy decarbonized their electricity generation processes. Changes in fuel mix, especially the shift to electricity from fossil fuel, raised emissions in all countries except Sweden, Norway, France, and Canada, each of which operates low-carbon utilities.
Table 2. Decomposition of Components of Carbon Emissions in Service Sectors of 13 OECD Countries: Annual Rates of Change from 1973-95

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>-4.2%</td>
<td>2.1%</td>
<td>-0.3%</td>
<td>-1.7%</td>
<td>-4.0%</td>
<td>-2.7%</td>
</tr>
<tr>
<td>Norway</td>
<td>-3.3%</td>
<td>3.0%</td>
<td>-0.3%</td>
<td>0.0%</td>
<td>-5.5%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>France</td>
<td>-2.6%</td>
<td>2.7%</td>
<td>0.9%</td>
<td>-2.6%</td>
<td>-1.4%</td>
<td>-4.1%</td>
</tr>
<tr>
<td>w. Germany</td>
<td>-0.8%</td>
<td>3.1%</td>
<td>0.0%**</td>
<td>-3.7%**</td>
<td>0.6%</td>
<td>-1.4%</td>
</tr>
<tr>
<td>UK</td>
<td>0.2%</td>
<td>2.5%</td>
<td>-1.1%</td>
<td>0.1%</td>
<td>0.4%</td>
<td>-1.4%</td>
</tr>
<tr>
<td>Finland</td>
<td>0.2%</td>
<td>2.6%</td>
<td>0.4%</td>
<td>-2.3%</td>
<td>0.4%</td>
<td>-1.5%</td>
</tr>
<tr>
<td>Canada</td>
<td>0.6%</td>
<td>2.4%</td>
<td>0.8%</td>
<td>-2.1%</td>
<td>-0.2%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.6%</td>
<td>2.1%</td>
<td>0.0%</td>
<td>-1.9%</td>
<td>1.2%</td>
<td>-0.7%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1.6%</td>
<td>2.5%</td>
<td>0.0%**</td>
<td>-1.7%**</td>
<td>0.9%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>USA</td>
<td>1.2%</td>
<td>2.7%</td>
<td>-0.8%</td>
<td>-1.3%</td>
<td>0.9%</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Italy</td>
<td>2.5%</td>
<td>2.7%</td>
<td>0.0%</td>
<td>-0.4%</td>
<td>0.4%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Japan</td>
<td>2.5%</td>
<td>3.8%</td>
<td>-0.2%</td>
<td>-1.0%</td>
<td>0.5%</td>
<td>-1.1%</td>
</tr>
<tr>
<td>Australia</td>
<td>4.4%</td>
<td>3.4%</td>
<td>0.1%</td>
<td>0.2%</td>
<td>1.1%</td>
<td>-0.5%</td>
</tr>
</tbody>
</table>

*Note that we do not have 1973 values for Australia, the Netherlands, and Canada. For these countries we begin with 1974, 1980 and 1981, respectively. Netherlands, Norway, U.S., France, and Finland use 1994 values instead of 1995. Also, we do not have floorspace data for western Germany and the Netherlands. For these countries, we use Energy/GDP as a proxy for energy intensity, and set the structure term to a constant value. This proxy may exaggerate the decline in energy intensity for western Germany and the Netherlands because it encompasses productivity gains (PJ/m² = GDP/m² * PJ/GDP).

3.1 Activity Effect: The Ascent of the Service Sector Economies

The combined service economies of the 13 OECD countries have expanded 3.0% annually since 1973, with western Germany, Japan, and Australia achieving the largest percentage gains. As shown earlier in Figure 1, per capita service sector GDP increased for every country, with the United States remaining more than 50% above the OECD average. Finland and the United Kingdom produce the least services per capita, though each has made significant strides since the early 1970's. This growth in service sector GDP, or activity effect, has clearly accelerated carbon emissions among the observed countries.

3.2 Structure: Mixed Impacts, Difficulty of Making Precise Comparisons

The structure effect, measured as amount of floor area per service sector GDP in our CO₂ decomposition, suppressed carbon emissions in 7 of 11 countries, led by the United Kingdom and United States. Commercial and public activities in Italy, France, and Japan require the least amount of building space to generate a unit of service sector GDP. For Finland, Canada, Australia, and France, structural developments boosted energy use and emissions, because growth in commercial floorspace levels outpaced the expansion of their service sector economies. The number of service sector employees and amount of commercial floorspace rose in all countries, as one might expect within an expanding service sector, and added additional upward pressure on carbon emissions.

We have been able to assemble from national surveys some data that differentiates building types, and thus offers some more insight into structural developments in the
service sector (see Sezgen and Schipper, 1995). Figure 4 highlights the distribution of floorspace over different building types for six countries in 1990. The U.S. has the most commercial floor area per capita (24 m²/person), and the largest proportion of Retail & Wholesale space. Japan has the least floorspace (10 m²/person) and the smallest relative share for Health buildings. Restaurant & Hotel space is most prevalent in France, while Sweden and Denmark have the most area for Health and Education. This breakdown becomes particularly important as we seek to establish a better link between building types and the characteristics of energy use.

3.3 Energy Intensity: Curbing Emissions

Energy intensity, measured as final energy use per square meter, declined by a total of 25% across the 11 OECD countries for which we have floorspace data. The intensity effect pushed CO₂ emissions downward in 8 of the 11 countries. Only in Australia, UK, and Norway was more energy per square meter of floor area used in the mid 1990's than in the early 1970's (though this increase had a negligible effect on Norwegian carbon emissions because of Norway's low-carbon electricity). The reductions in energy intensity were caused by a combination of gains in equipment efficiency, improvements in building shells, and changes in energy usage patterns. Looking more closely, two opposing trends clearly took place. As Figures 5 and 6 show, electricity intensity increased while fuel intensity decreased for every country studied. The Norwegian service sector made the largest divergence, consuming 31% of the fuel and 192% of the electricity per square meter in 1994 that it used in 1973. Much of Norway's huge decline in fuel intensity can be attributed to the growth in electric space heating (Schipper, 1990). Presently about 80% of commercial buildings in Norway use some form of electric heat.

Figure 7 presents 1990 energy intensities for six countries, organized by fuel type and by electric end-uses. The “other electricity” category includes refrigeration, ventilation, office equipment, and appliances. Along with lighting, it is the only category not affected by climate. The sum of the intensities for lighting and other electricity is higher in Japan, Sweden, and Denmark than in the U.S. The longer operating hours of U.S. commercial buildings suggest that those countries have a sizeable potential for efficiency improvements in lighting, electric appliances, and office equipment (Sezgen and Schipper, 1995). Energy intensity is markedly higher in Canada than the other selected countries, mostly because of its large consumption of natural gas for heating, which can be explained in part by its cold weather.

Figure 8 shows the average energy intensities of different building types within the selected countries. Health buildings, followed closely by Restaurants & Hotels, use the most energy per square meter. Retail & Wholesale buildings are the most lighting-intensive buildings, while Education buildings use the least lighting, cooling, and other electricity per square meter of floor area. Based on these observations, we can draw some inferences from the differences in the building stock among countries. The high proportion of Hotels & Restaurants in France and Health buildings in Sweden are structural factors that serve to raise their commercial carbon emissions compared to other countries.
3.4 Final Fuel Mix: Emergence of Electricity and Natural Gas

The OECD countries experienced a major transition in fuel use from oil and coal to electricity and natural gas, as shown for each country in Figure 9 and summarized in Table 3. The final fuel mix effect restrained CO₂ emissions in countries with low-carbon electricity, such as Sweden, France, Canada, and Norway, which now almost entirely uses carbon-free electricity to power its service sector. The fuel mix applied upward.

Table 3. Rise of Electricity and Gas and Decline of Oil and Coal in the Final Fuel Shares for 13 OECD Countries

<table>
<thead>
<tr>
<th>Fuel Shares</th>
<th>1973</th>
<th>1994/95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil, LPG</td>
<td>50%</td>
<td>23%</td>
</tr>
<tr>
<td>Gas</td>
<td>17%</td>
<td>37%</td>
</tr>
<tr>
<td>Coal, Solids</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>District Heat</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Electricity</td>
<td>22%</td>
<td>37%</td>
</tr>
</tbody>
</table>

Note that we use 1974 values for Australia, 1980 values for the Netherlands, and 1981 values for Canada, since we don’t have 1973 data for those countries. For Canada and the Netherlands, this may underestimate changes in fuel mix, since substitution away from oil was probably greater during the oil price shocks of the 1970’s.

pressure on emissions for countries with carbon-intensive electricity, such as Denmark, the U.S., and Australia. Commercial building operators in the European and Nordic countries have made the most dramatic transition away from oil use. Switching to natural gas as a space heating fuel has served to push down emissions in Europe, while switching to district heat has tended to raise emissions in Finland and lower them in Denmark. Space heating sources in U.S., Canada, and the Netherlands have remained relatively stable since 1980, with natural gas clearly dominating other fuels. The two highest shares of electricity in energy use occur in Norway and Australia, but appear for different reasons. In Australia, space heating equipment is largely powered by fossil fuels, but the warm climate minimizes the demand for heating. In Norway, there is a large demand for heating in commercial buildings, but a sizeable and increasing share of space heating comes from electric systems (Schipper, 1990).

3.5 Utility Mix: Declining Electricity Carbon Factors

As electricity use has risen within the final fuel mix (see Figure 9), the amount of carbon released per unit of delivered electricity becomes an increasingly important determinant of service sector CO₂ emissions. Presently, hydropower in Norway and Canada, nuclear power in France, and both in Sweden and Finland keep electricity production in those countries low in carbon emissions—less than 1/5 the average for the 13 countries investigated. On the other hand, the large proportion of coal-fired power plants in Australia, the U.S., and Denmark maintains a high carbon release factor for electricity in those countries. Figure 10 illustrates the difference in electricity carbon coefficients among countries, and references them against the static carbon release factors for on-site natural gas and coal combustion.
Because the electric utility industries in OECD countries have tended to shift away from carbon-intensive electricity production, the utility mix effect pushes emissions downward in 12 of the 13 countries. Only in Italy, where oil still accounts for over half of electricity production and coal’s share has doubled to 12% since 1973, have shifts in the utility mix bolstered emissions. Changes in the utility mix reduce carbon emissions most sharply in France and Sweden, due to increasing shares of nuclear and hydro-power in electricity generation.

3.6 International Comparisons

As Table 4 shows below, there are major differences in per capita service sector emissions among countries, with the U.S. releasing over four times as much carbon dioxide per person as Italy, France, and Sweden, and more than ten times as much as Norway. The table also presents carbon emissions per dollar of services produced and per square meter of commercial floor area, which provide different yardsticks for comparing service sector carbon emissions. For instance, commercial buildings in Finland emit much more carbon dioxide per dollar of services GDP but much less per capita than buildings in the U.S. This occurs because the Finnish service economy produces significantly less per person than does its American counterpart. Interestingly, carbon emissions per square meter of floorspace are very even among countries, except for Norway, Sweden, and France, which utilize low-carbon electricity. Our analysis suggests that the factor most responsible for the relative differences in emissions among countries is the average carbon content of each country’s mix of service sector energy sources.

Table 4. 1994 Carbon Emissions per Capita, per Services GDP, and per Square Meter of Floor Area for the Service Sectors in 13 OECD Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>kgC/cap</th>
<th>kgC/thousand dollars of services GDP*</th>
<th>kgC/m² of floor area</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>836</td>
<td>51</td>
<td>33</td>
</tr>
<tr>
<td>Denmark</td>
<td>503</td>
<td>49</td>
<td>30</td>
</tr>
<tr>
<td>Australia</td>
<td>482</td>
<td>44</td>
<td>28</td>
</tr>
<tr>
<td>Canada</td>
<td>454</td>
<td>43</td>
<td>28</td>
</tr>
<tr>
<td>Finland</td>
<td>452</td>
<td>59</td>
<td>30</td>
</tr>
<tr>
<td>w. Germany</td>
<td>389</td>
<td>35</td>
<td>n/a</td>
</tr>
<tr>
<td>UK</td>
<td>375</td>
<td>42</td>
<td>28</td>
</tr>
<tr>
<td>Japan</td>
<td>352</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>Holland</td>
<td>347</td>
<td>33</td>
<td>n/a</td>
</tr>
<tr>
<td>Italy</td>
<td>195</td>
<td>19</td>
<td>29</td>
</tr>
<tr>
<td>France</td>
<td>153</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Sweden</td>
<td>142</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Norway</td>
<td>69</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

*$1990 U.S. purchasing power parity

The U.S. commercial sector emits nearly a ton of carbon per person, largely because the U.S. economy delivers 50% more services per capita than any other country. The U.S.

2 In addition to the mix of primary fuels inputs, the utility mix effect is also determined in part by the efficiency level of power generation within each type of fossil fuel power plant.
uses less floor area per unit of services GDP and less energy per unit floor area than the OECD average, but has the third most carbon-intensive fuel mix of the observed countries. Like the U.S., Denmark's high per capita emissions levels stem from its reliance on high-carbon fuel sources, but also result from the relatively high amount of commercial space it uses per dollar of services delivered. Relatively low energy intensity (PJ/m²) and per capita services GDP in Denmark tend to moderate these forces.

If not for its extraordinarily high-carbon primary fuel mix (60% above the rest of the OECD), service sector emissions in Australia would lie significantly below average. In fact, commercial building owners and operators in Australia use the least energy per square meter of floor area by a large margin.

Canada and Finland have nearly equivalent carbon emissions per person, but for some different reasons. To begin with, they share two characteristics: (1) they have the two most energy intensive service economies; and (2) they have approximately average output per floor area. However, the Finnish commercial sector produces the least amount of services per capita, and uses energy with below average fuel carbon content, while the Canadian commercial sector uses energy with one of the lowest fuel carbon contents, and produces slightly below average service GDP per capita.

Commercial buildings in Japan and the U.K. emit an average amount of carbon dioxide per capita. Japan balances the third highest amount of service GDP per capita with the second most efficient use of space. The U.K., on the other hand, produces very little services per person, but employs carbon-intensive energy sources. Western Germany and the Netherlands must be considered in less detail, since they lack data on commercial floor area. They tend to be in the middle of the pack for most factors, though the Dutch service economy produces less services per capita.

The service sector in Italy releases relatively little CO₂ per person because it requires by far the least amount of floorspace per unit of services. The service sector in France also uses relatively little building space per dollar of services GDP. However, commercial buildings in France emit the third least amount of carbon per person despite France's large service economy, mostly because of the availability of low-carbon electricity. It's no coincidence that the countries with the least carbon-intensive energy, namely Norway and Sweden, have the lowest per capita emissions levels. Even though the commercial sectors in those countries use more space per unit of services value-added than any country except Finland, their reserves of hydro-powered electricity keep emissions low.

3.7 Service Sector Energy Prices

Another influence on service sector energy demand and carbon emissions, as well as possible explanation for the changes in service sector fuel mix, are energy prices. Service sector energy prices are not collected and published for most OECD countries, so we

3 It is important to note that this is not tantamount to an inefficient use of space, since it depends on whether the mix of service sector activities provided in Denmark is high value-added or low value-added compared to the rest of the OECD.
constructed a simple approximation of them in order to provide a hint of the trends over the last 25 years. Figures 11 and 12 chart the development of prices over time for electricity and fossil fuels, expressing real price per unit of energy in 1990 U.S. purchasing power parity dollars. The fuel prices are calculated as the consumption-weighted average prices of natural gas, oil, and district heat. Clearly, the oil shock of the late 1970's increased electricity prices and, even more dramatically, fuel prices. Starting in 1986, however, real fuel prices have dropped significantly and real electricity prices have either stagnated or declined.

Interestingly, in addition to having the least carbon-intensive electricity, the service sectors in Norway and Sweden enjoy the lowest electricity prices. This helps explain why electricity has so strongly usurped fossil fuels in the commercial fuel mix for those countries. Table 5 presents the percent change in electricity prices and fuel prices for each country from 1973 to 1995. Fuel prices increased more (or decreased less) than electricity prices for all except France and western Germany over this time period. This price development probably reinforced the trend in OECD commercial sectors towards greater electricity use and less fuel use. The Swedish service sector, which made a particularly dramatic transition from fuel use to electricity use, experienced the greatest decline in the price of electricity relative to that of fuels. Since 1973, commercial electricity prices in Sweden have dropped, while fuel prices have more than doubled.

Table 5. Electricity and Fuel Prices in the Service Sectors for 13 OECD Countries: Price Ratios Between 1995 and 1973

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>141%</td>
<td>165%</td>
<td>86%</td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>63%</td>
<td>86%</td>
<td>73%</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>73%</td>
<td>72%</td>
<td>102%</td>
<td></td>
</tr>
<tr>
<td>w.Germany</td>
<td>88%</td>
<td>86%</td>
<td>103%</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>129%</td>
<td>150%</td>
<td>86%</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>112%</td>
<td>197%</td>
<td>57%</td>
<td></td>
</tr>
<tr>
<td>Norway</td>
<td>150%</td>
<td>179%</td>
<td>84%</td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>92%</td>
<td>208%</td>
<td>44%</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>114%</td>
<td>161%</td>
<td>71%</td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>110%</td>
<td>121%</td>
<td>92%</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>93%</td>
<td>127%</td>
<td>73%</td>
<td></td>
</tr>
</tbody>
</table>

* Fuel prices are calculated as consumption weighted averages of natural gas, oil, and district heat prices

4. IMPLICATIONS FOR SERVICE SECTOR CO2 MITIGATION

The strong growth in service sector economies, both in absolute terms and as a share of GDP, has served to amplify carbon emissions levels in the OECD. With 7 of 11
countries creating more services value per square meter of floor area, OECD service economies show some evidence of having made productivity gains, and thus having dampened emissions increases. However, total floorspace, the most direct driving force of energy use and emissions in the service sector, has risen approximately 2.1% per year in the observed countries over the period of investigation. Owners and operators of commercial buildings have reduced emissions levels per square meter of floor area in most countries through changes in either energy intensity or fuel mix. But in an era of expanding service economies, carbon intensity levels must be more sharply diminished in order to prevent further heightening of carbon emissions. As electricity continues to emerge as the dominant energy source in commercial buildings, the carbon release from electric generation becomes a more important factor for emissions reduction possibilities.

4.1 Carbon Intensity

The challenge for policymakers is to diminish carbon intensity (kgC/m²) more rapidly than commercial floorspace increases. Over the period of observation, every country except Australia experienced reduced carbon intensity, although in 12 of 13 countries building space expansion outpaced these improvements in carbon intensity. By the mid 1990's, Norway, Sweden, and France stood out from the other countries with carbon intensities less than half the level of the next closest country. As Figure 13 shows, the other OECD countries are clustered extremely tightly in the mid 1990's, with commercial buildings emitting approximately equal amounts of carbon dioxide per square meter of floorspace.

There is a wide disparity among countries, however, in the average amount of carbon released per unit of energy consumed, as indicated in Figure 14. The key to understanding the differences among countries lies with two aspects of electricity use: carbon release factor and share of final energy. For instance, the commercial sector in Australia has the most carbon-intensive energy sources by far, both because Australian electricity production releases more carbon dioxide than in any other country, and because electricity comprises two-thirds of final energy—more than any other country except Norway. As one might expect, the countries with the least carbon-intensive electricity, namely Norway, Sweden, France, Finland, and Canada also emit the least CO₂ per unit of service sector energy use. The commercial sector in the Netherlands, however, uses more carbon-intensive electricity than western Germany, Italy, and Japan, but emits less carbon per unit of energy. This occurs because electricity is a minor energy source in Dutch commercial buildings relative to natural gas.

4.2 Developments since 1990

Since 1990, the annual growth rate of carbon emissions across the OECD has declined from historic levels as shown in Table 6, largely because the rate of floorspace expansion has eased in each of the observed countries, and because the fuel mix is less carbon intensive. For the 13 countries in total, the annual rate of emissions increases has dropped from 1.0% from 1973-1990 to 0.6% after 1990. The annual rate of floor area growth has declined from 2.3% to 1.7% and the average carbon content of fuels dipped from 0.6 to (-1.2). However, as Table 6 describes, changes in energy intensity put much
less downward pressure on carbon emissions after 1990, a development that may jeopardize future CO₂ reductions. Aggregate energy intensity improvements among the observed countries have decreased from 1.5% to 0.1% annually, which implies some combination of reduced energy-efficiency gains or increased penetration of energy-using equipment. The commercial sectors in France, Japan, the U.K., Denmark, and Sweden have all reversed historical energy intensity improvements, and are using an increasing amount of energy per square meter of commercial floorspace in the 1990’s.

<table>
<thead>
<tr>
<th>Country</th>
<th>Carbon Emissions</th>
<th>Floor Area</th>
<th>Energy Intensity</th>
<th>Average Fuel Carbon Release</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-90</td>
<td>post-90</td>
<td>pre-90</td>
<td>Post-90</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.5</td>
<td>1.0</td>
<td>2.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Finland</td>
<td>0.5</td>
<td>-0.8</td>
<td>3.2</td>
<td>1.5</td>
</tr>
<tr>
<td>France</td>
<td>-2.8</td>
<td>-0.9</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>w. Germany</td>
<td>-1.0</td>
<td>-0.8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Italy</td>
<td>2.9</td>
<td>1.1</td>
<td>3.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Japan</td>
<td>2.3</td>
<td>3.4</td>
<td>3.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Norway</td>
<td>-5.1</td>
<td>3.5</td>
<td>2.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Sweden</td>
<td>-5.6</td>
<td>0.4</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>UK</td>
<td>0.5</td>
<td>-1.0</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>US</td>
<td>1.3</td>
<td>0.5</td>
<td>2.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Australia</td>
<td>4.6</td>
<td>3.6</td>
<td>3.8</td>
<td>2.4</td>
</tr>
<tr>
<td>Canada</td>
<td>0.7</td>
<td>0.4</td>
<td>3.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Holland</td>
<td>1.4</td>
<td>1.7</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Pre-1990 annual rates of change begin in 1973, except for Australia, the Netherlands, and Canada, which begin in 1974, 1980 and 1981, respectively.
** Energy Intensity totals are weighted by floor area. Average Fuel Carbon Content totals are weighted by energy use.

### 4.3 The Critical Role of Electricity Use

For service sector CO₂ mitigation, all forms of energy conservation are not created equal, as Figure 15 suggests. Reducing electricity use (through efficiency gains, fuel switching, or changing usage patterns) would provide large benefits for countries with high-carbon electricity, such as Australia, Denmark, the U.S., and the U.K. However, countries with low-carbon electricity, like Norway, Sweden, and France, would achieve very small marginal reductions in emissions from decreased electricity use. Decreases in fossil fuel combustion, on the other hand, would yield uniform CO₂ reductions in all countries. Thus, fuel savings would make proportionately greater progress in countries that use low carbon electricity. Because its utility mix is essentially carbon-free, Norway is in a unique position: electricity conservation would have a negligible impact on its emissions levels. Still, Norwegian electricity savings would reduce the need to build gas-fired electric power plants if demand grows in the future, and conserved hydro-power electricity would become available for export.
Looking to the future, electricity use in the service sector appears likely to increase more rapidly than fossil fuel consumption. Figure 16 shows that per capita electricity use is strongly correlated with per capita service sector GDP. Figure 17 demonstrates that fuel use has been essentially independent of service sector GDP, and thus is less likely to rise as service economies enlarge. So in an era of expanding service sector economies, growth in electricity consumption provides the most significant threat of raising emissions levels in the future--an emissions increase that will occur most severely in countries with high-carbon electricity production.

5. CONCLUSIONS

Carbon dioxide emissions from the service sector have increased by 22% since the early 1970's in the 13 OECD countries we investigated. This phenomenon was driven primarily by the growth of service economies and the requisite expansion of floorspace in commercial and public buildings. Emissions increases were diminished in most countries by the declining energy intensity of service sector activities, achieved through improved energy efficiency and changes in equipment usage patterns.

Since 1990, annual growth rates of carbon emissions have dropped below historic levels for many countries because additions to the building stock have slowed and because the mix of fuels powering the service sector has become less carbon-intensive. However, energy intensity levels have shown signs of stagnating or even increasing in recent years, largely because greater penetration of electric equipment is counterbalancing energy efficiency savings.

Electricity is rising as a proportion of final energy use for all 13 countries, which makes crucial the mix of fuels that produce it. Countries that generate low-carbon electricity, such as Norway, Sweden, and France, have most successfully restrained CO₂ emissions. Countries with carbon-intensive electricity sources will have a very difficult time mitigating further emissions growth, even with energy efficiency improvements, unless they address their utility fuel mix. The evolution of electricity use and carbon emissions in the service sectors of OECD countries suggests that serious policy interventions will be required for the service sector to carry its weight under the Kyoto Protocol. As electricity continues to expand its share of energy use in commercial and public buildings, government policies to decarbonize utility fuel mix may be the most effective mechanism for reducing emissions among OECD service sectors.
APPENDIX A. DATA SOURCES

Most of the data used in this report has been collected for over 20 years at Lawrence Berkeley National Laboratory. The most complete listing of data sources is supplied in the Appendix to Schipper (1997).

All service sector GDP (ISIC 6-9) data, Purchasing Power Parity conversions, and employment data were drawn from OECD National Accounts.

The energy and floor area data were derived from national sources, although definitions of service sector floor area are subject to uncertainty among countries. The major data sources are:

Australia:
Energy data provided by the Australian Bureau of Applied Research and Economics

Canada:
Aggregate energy, end-uses, building type and floor area data drawn from the Natural Resource Canada (NRCAN) public database on commercial buildings.

Denmark:
Energistyrelsen for energy consumption data.
Electricity Supply Ten-Year Overview put out by Danske Elvarkers Forening.
Bygning og Bolig Register for floor area.

Finland:
Imatran Voima Oy.
Sahkolaitosyhdistys.

France:
Obervatoire d'Energie Report for energy and end-use data.
Tableaux des consommations d'énergie en France for energy data in the 1980's.

western Germany:
For the German service sector, the official energy balances are used, as analyzed by VDEW.
Italy:
ENI/ENEL figure provide service sector floor area.

Japan:
Japn Institute of Energy Economics (IEE) provides estimates of energy, end-uses, and floor area based on information from many sources.

Netherlands:
Energy data from Nederlandse Energihuishouding, the Central Bureau of Statistics, Voorburg, Netherlands.

Norway:
Energibalance and Energiregskap (Central Bureau of Statistics) provide energy data. J. Sagen of the Central Bureau of Statistics and the Institutt for Energiteknikk provide estimates of floor area.

Sweden:

United Kingdom:
*Digest of UK Energy Statistics* (DUKES).
DTI 1994 Service Sector Energy Model for end-use estimates.

United States:
REFERENCES


Figure 1. Service Sector GDP per Capita in 13 OECD Countries

Figure 2. Service Sector End-Use Energy Intensities for 5 OECD Countries

Note: For France, electric equipment includes all electric end-uses, and the breakdown between water heating and cooking was estimated. For the UK, the breakdown between space heating and water heating was estimated.
Figure 3. Results of Decomposition of Service Sector Carbon Emissions in the U.S. from 1970-1994

Figure 4. Distribution of Service Sector Floor Area by Building Type, 1990
Figure 5. Service Sector Electricity Intensity for 10 OECD Countries, 1970-1995

Figure 6. Service Sector Fuel Intensity for 10 OECD Countries, 1970-1995
Figure 7. Service Sector Electricity Intensities by End-Use and Fuel Intensities, 1990

Note: Electric heating includes HVAC and water heating. For Japan, lighting includes other electric end-uses.

Figure 8. Service Sector Final Energy Intensities for Building Types, 1990

Note: Values are weighted averages based on floor area in the U.S., Japan, Canada, France, Denmark, and Sweden.
Figure 9. Service Sector Final Energy
Intensities for Building Types, 1990

Denmark 1972-1995
Finland 1970-1994
Sweden 1970-1995
Norway 1970-1994
Netherlands 1980-1995

Germany 1970-1995
United Kingdom 1970-1995
France 1975-1995
Italy 1972-1995
Japan 1970-1995

United States 1970-1994
Canada 1981-1995
Australia 1974-1995

- Electricity
- District Heat
- Biomass
- Coal, Coke
- Gas
- Oil, LPG
Figure 10. Carbon Release per Unit of Delivered Electricity for 13 OECD Countries

Figure 11. Service Sector Electricity Price Estimates for 13 OECD Countries
Note: For Finland, there is a high level of uncertainty for service sector energy use in the 1970's, so this figure may overestimate Finland's service sector carbon intensity.
Figure 14. Average Carbon Release per Unit of Final Energy Used in the Service Sector

- Australia
- Denmark
- USA
- UK
- Germany
- Italy
- Japan
- Holland
- Finland
- Canada
- France
- Sweden
- Norway


Figure 15. Service Sector Per Capita Carbon Emissions for 9 OECD Countries

- Fuels and District Heat
- Electricity

Figure 16. Electricity Use and Service Sector GDP

Figure 17. Fuel and District Heat Use and Service Sector GDP