Lawrence Berkeley National Laboratory

Title

The "Mine/Yours" method of international comparisons of carbon emissions

Authors
Murtishaw, Scott
Schipper, Lee
Unander, Fridtjof

Publication Date
2000-09-01

The "Mine/Yours" Method of International Comparisons of Carbon Emissions

Scott Murtishaw, Lawrence Berkeley National Laboratory
Lee Schipper, International Energy Agency
Fridtjof Unander, International Energy Agency

ABSTRACT

In previous work (Schipper, Unander & Lilliu 1999), we summarized a new method for comparing energy use and carbon emissions among various countries. We call this the "Mine/Yours" comparison. In this paper, we provide details of the comparisons methodology, and carry out the comparison on a number of IEA countries. We calculate the average energy intensities **I** for a sample of countries ("yours") and multiply them by structural parameters **S** for a particular country ("mine"). Comparing the results with the actual energy use of the country in question gives us an estimate of how much energy that country would use with average intensities but with its own structural conditions. The converse can be calculated as well, that is, average structure and own intensities. Emissions can be introduced through the **F** (fuel mix) term. These calculations show where differences in the components of emissions lead to large gaps among countries, and where those differences are not important.

We show which components cause the largest variance in emissions by sector. In households, home size, average winter climate, and energy intensity appear to be the most important differentiating characteristics for space heating. For other residential energy uses the mix of fuels used to generate electricity (utility mix) is most important.

Because some of the differences are "built in" – geography, climate, natural resources endowment – we conclude by questioning whether uniform emissions reductions targets make sense. Indeed, the "Mine/Yours" tool provides a valuable guide to important ways in which emissions may or may not be flexible.

Introduction

Since the 1992 Earth Summit at Rio de Janeiro, attention has focused on reduction of emissions of carbon dioxide and other greenhouse gases (GHG). With the signing of the Kyoto Protocol and adoption of goals or targets for GHG reduction, interest has grown to understand how each country's economic and human activity is linked to emissions (Schipper 1997). More important for international agreements, questions arise concerning what components underlie differences in emissions, and how and why the differences occur. This paper will chart out preliminary findings from detailed studies of 14 IEA member countries' (which as a group we refer to as the IEA-14) energy-related carbon emissions covering the mid 1990s.[1]

[1] The IEA-14 consist of Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, New Zealand, Norway, Sweden, the U.K., and the U.S. For Germany only data covering the territory of western Germany, i.e. the former Federal Republic of Germany are used. Thus, we designate the country as w. Germany.

Exploring differences in the underlying factors that differentiate CO2 emissions is important for several reasons. First, some differences may be irreducible and consequently, some features of a country's economy may always lead to high (or low) emissions. Some of these "irreducible features" of an economy, such as its winter climate, its size and other geographical features, or its natural resource endowment, may force key parts of the emissions pattern away from the negotiating table. Second, some of the variations in emissions will arise because of differences in energy supply or energy-use technologies, two aspects of the energy-economy link that may be changed. Finally, some parts of the differences in emissions among countries arise because of differences in policies, be they energy, fiscal, or other policies. By understanding how underlying components of emissions differ among countries, these policies, some of which are hidden far from the energy sector, might be unveiled to suggest useful ways of reducing or avoiding emissions.

The per capita energy-related carbon emissions from the IEA-14 countries vary by nearly a factor of four, as shown in Figure 1. Emissions in the services and residential sectors show particular extremes with emissions varying by about 15 and 17 to 1, respectively. This study aims to shed some light on the factors underlying these differences by using a decomposition technique that we refer to as "Mine/Yours." [2]

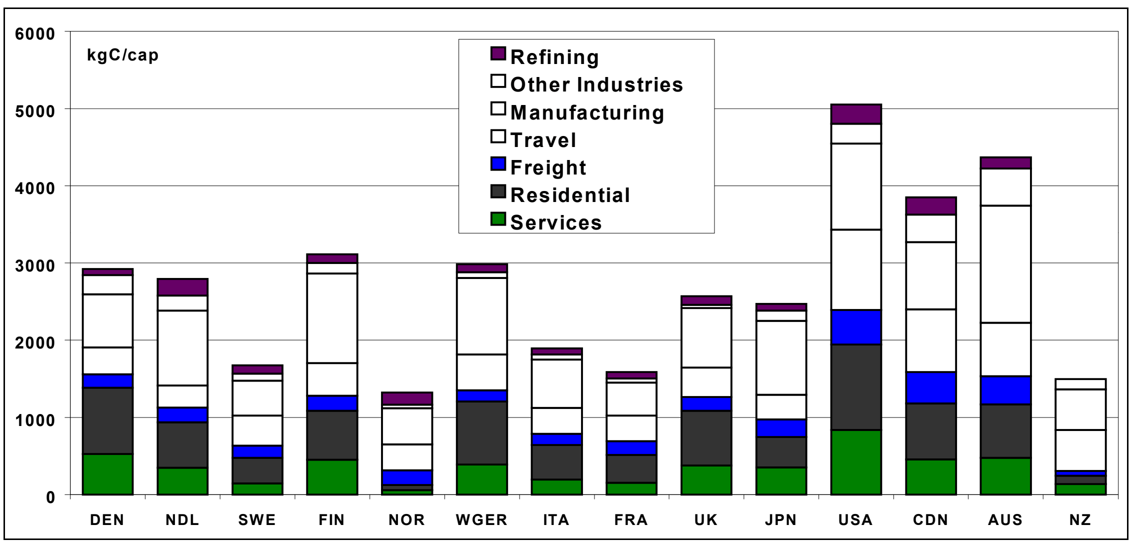

Figure 1. Total 1994 Emissions per Capita, by Sector

Methodology

The Mine/Yours method grew out of our work using decomposition methods to examine changes in energy use and carbon emissions over time (Greening, Davis & Schipper 1996; Greening et al. 1997; Schipper et al. 1997). In these decompositions, changes in total energy use for each sector are disaggregated into activity, structure, and intensity terms

---

[2] The data used for this study are drawn from an International Energy Studies database of international energy and economic statistics at the Lawrence Berkeley National Laboratory. This database relies on raw data from official national energy balances where possible. For economic indicators OECD accounts are used. All economic indicators are converted to 1999 U.S. dollars, adjusted for purchasing power parity.

(hence "STRINT"). Depending on the sector, activity is measured either as value added, passenger-kilometers (pkm), tonne-kilometers (tkm), population, or built area. Intensity is simply a measure of how much energy is consumed per unit of activity. Generally, structure is defined as the composition of subsectoral shares of sectoral activity. In the manufacturing sector, for example, structure is defined as the relative shares of each industry branch in total manufacturing value added. For carbon emissions decompositions we include two additional terms: one to account for changes in end-user fuel mix (fuel mix) and another for changes in the utility fuel mix (utility mix). Changes in energy use or carbon emissions are attributed to the underlying decomposition factors to determine the direction and magnitude that these effects have had over time.

Mine/Yours analysis uses the same decomposition terms[3] but rather than tracking changes over time they are used to compare values across countries for a single year. We calculate an average substitution factor for each term and that value is substituted for each country's own value while holding the other terms constant. When a comparison is made between one country and the group average, that country's own share in the average is left out. This approach prevents large countries like the U.S. and Japan from exerting a strong pull on the averages to which they are compared.

The "GASIF" Identity: $\mathbf{G} = \mathbf{A} * \mathbf{S}_i * \mathbf{I}_i * \mathbf{F}_{ij}$

In simple terms, the comparison starts with the **GASIF** identity for a single country, where **G** equals the emissions from a given sector and the other terms correspond to the STRINT components described above. Sectoral activity is represented by **A** while $\mathbf{S}_i$ and $\mathbf{I}_i$ indicate the activity share (structure) and intensity of subsector *i*. Fuel shares for each fuel *j* in each subsector are represented by the **F** term. To evaluate the importance of each term in differentiating emissions, we measure the ratio of $\mathbf{G}_a$ (actual) to $\mathbf{G}_{m/y,c}$ where we have substituted the Mine/Yours average value of **GASIF** component *c* for that of the first country. Making this substitution does not imply that the country in question could achieve the resulting level of emissions, but the results show how much the overall difference in emissions between one country's emissions and another emissions profile is due to component *c*. The operation can be restricted to one sector, or summed over all sectors.

The residential sector is in some ways the most complicated for mine-yours analysis. Unlike the manufacturing sector where all subsectors can be compared using value added as a common metric, all of the residential end-uses have more distinct characteristics. For this reason, structural calculations are not performed for this sector. Moreover, due to definitional differences in the measure of activity, separate activity per capita terms are determined for each major end-use. Energy use is adjusted according to floor area per capita for space heating, air conditioning, and lighting; number of occupants per household (i.e. dwellings per capita) for water heating and cooking; and ownership per capita for appliances.

More specifically, the activity-adjusted level of energy consumption for space heating and lighting equals own energy consumption times the average area per capita times own population. The space heating calculation is further modified to adjust for climate by

[3] The activity term, per se, is not used. It would not be helpful to ask, "How much carbon would Norway have emitted if it had the same manufacturing output as w. Germany?" Instead each country's activity is scaled to its population and differences in the ratios of activity per capita are used to calculate Mine/Yours results.

multiplying the ratio of average degree-days to own degree-days.[4] The activity substitution for cooking and water heating is performed by multiplying own energy use by the square root of the ratio of own number of occupants per dwelling to average number of occupants per dwelling. This is based on observed trends in per household energy consumption for these end-uses. For appliances the own unit energy consumption (UEC) per appliance is multiplied by the number of appliances the country would have at average ownership rates. This can only be calculated for the major appliances[5] for which there are disaggregated UEC and ownership data. To estimate the activity effect for all appliances the ratio of the average total appliance energy consumption to average major appliance energy consumption is multiplied by the country's activity-adjusted major appliance energy consumption.

Average intensity substitutions for space heating and lighting are based on the energy consumption per unit of floor area. To determine the hypothetical energy consumed, the average energy per floor area is multiplied by own floor area. Cooking and water heating terms are found by multiplying the average energy per capita by own population. Note that these figures are structure-corrected by multiplying the results by the square root of the inverse of the occupants per dwelling ratio described above. For the mine-yours appliance substitution, we sum the products of the average UECs for each appliance and the own number of appliances. Similar to the structure substitution, total intensity-adjusted appliance energy demand is estimated by multiplying the major appliance intensity result times the country's own ratio of total appliance energy use to major appliance energy use.

The fuel mix substitution adjusts the country's own fuel mix to reflect the average shares of fuels in the sector. The formula for each fuel is the average share of fuel times own final energy times that fuel's carbon coefficient (a measure of carbon released per unit of fuel consumed).[6] The carbon coefficients for coal, oil, and gas are constant, but district heat and electricity coefficients must be determined for each country based on that country's inputs into the generation mix. Each country's own district heat and electricity carbon coefficients are used for the fuel mix calculation. Average utility coefficients are used in the utility mix substitution, which holds own emissions from end-user combustion of fuels constant while multiplying own district heat and electricity consumption times their average carbon coefficients.

One final caveat must be added. The substitutions in this calculation assume that all of the Mine/Yours terms are separable. In reality they are not entirely separable, as we note in certain cases. Above all, low energy intensities, which may be associated with low energy costs, may stimulate activity levels, while high intensities may inhibit growth in activity levels. This kind of "rebound effect" is probably small for most sectors, but could be large for energy-intensive sectors like non-ferrous metals, heavy chemicals, or air travel (Schipper & Grubb 2000). Thus it is important not to assume that the substitutions implied by the calculations, even if carried out, would give the resulting energy use implied by multiplying one country's intensities by another's activities. For carbon, however, the matter is more complex, since carbon does not have any real value (Birol & Keppler 2000). Since the carbon

---

[4] We would also like to adjust for the percent of dwellings with central heating systems since they use more energy for comparable heating requirements, but meaningful data are not available for two countries.

[5] The major appliances include freezers, refrigerators, washers, dryers, dishwashers, and air conditioners.

[6] We use the simplified carbon coefficients for fossil fuels recommended by the Intergovernmental Panel on Climate Change (IPCC 1996). The IPCC carbon factors are 21.1 kilotons carbon per petajoule (ktC/PJ) for petroleum products, 15.3 ktC/PJ for natural gas, and 25.8 ktC/PJ for coal.

emissions here are tied to energy use, however, it is better not to assume that such a substitution would automatically give the emissions level implied by no interaction.

Results of Mine/Yours Analysis for the Residential Sector

Emissions from the residential sector have been divided into two separate operations for the Mine/Yours analysis. We analyze space heating separately since it is such a large component of residential energy use and emissions (accounting for one quarter to three-quarters of sectoral emissions in most countries). Actual per capita carbon emissions from space heating vary widely with a factor fifteen difference between the highest and lowest countries. Average home size and climate are the most important factors affecting emissions. This is mostly due to the fact that this term has the largest impact on U.S. emissions. At the others' per capita floor area and climate U.S. emissions would fall by approximately 20%.

Energy intensity is the second most important factor in terms of variance in the results, and it is the predominant term for France, w. Germany, Denmark, and the Netherlands. The remaining three terms all yield approximately equal levels of variance in their results and have considerably less impact. Utility-mix, however, had substantial effects on certain countries, particularly Norway, whose emissions would increase nearly ten-fold. This is due both to the high share of electricity used for home heating (65% of delivered energy) and the almost negligible carbon coefficient associated with electricity production there. Sweden and New Zealand also would experience more than a doubling of emissions at the average utility mixes for similar reasons. In these three countries, electricity use is high in part because electricity is inexpensive. Were these countries to generate electricity from the thermal mixes of the others, costs would doubtless be higher, and thus usage lower. This is an example of how two terms, in this case fuel mix and intensity, interact.

Other home emissions arise mostly through the consumption of electricity for cooking, water heating, and running other appliances. Electricity accounts for about 60% of the delivered energy for these end-uses in the IEA-14. However, natural gas for cooking and water heating is a significant fuel source in some countries, and it accounts for most of the remaining energy demand.

Since electricity comprises such a large share of the total energy for these end uses, the utility mix is by far the predominant effect. The hypothetical per capita emissions from substitution of this term generate about three times the variance of any of the other factors. Norway is the extreme outlier for this substitution, as Figure 2 shows. With Norway removed, the variance would fall by more than half, but utility mix remains the most important effect. The other terms are approximately equal in their impacts.

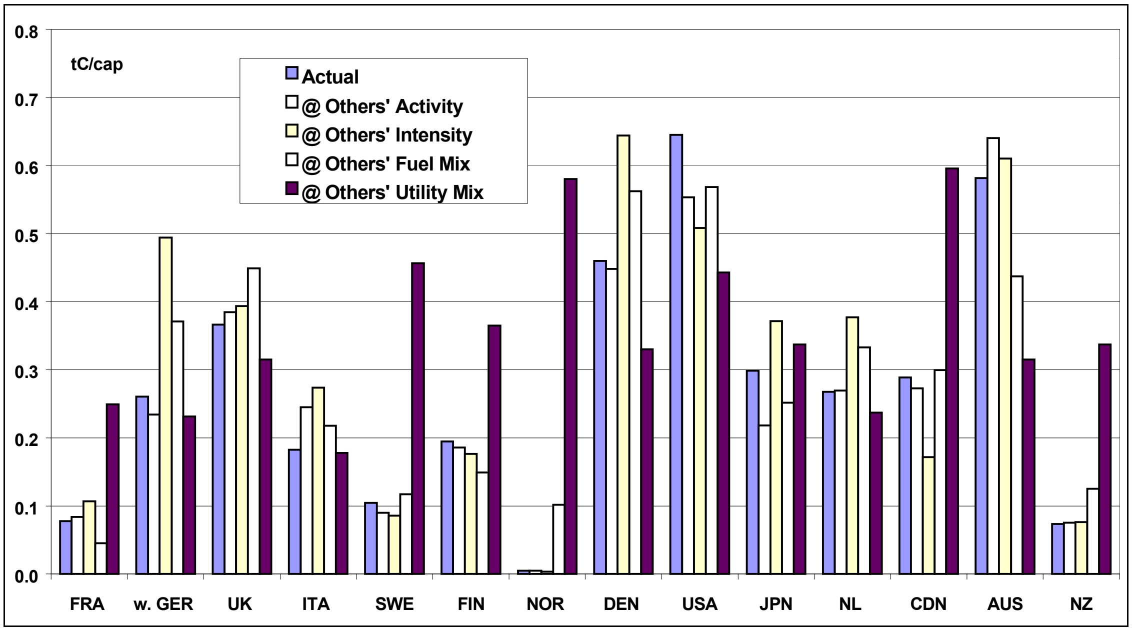

Figure 2. Mine/Yours Substitutions for Non-Space Heating Residential Emissions

Intensity is the next most important factor and is the predominant effect in w. Germany, Italy, and the Netherlands. The largest variations in end-use efficiencies are in water heating and cooking. We would expect more variation in these end-uses than in lighting or appliances because delivered energy demand is also partly a function of fuel mix. Much of the delivered energy content of natural gas and oil is lost through waste heat and incomplete combustion.[7] Thus, it requires more delivered energy to get a unit of "useful" energy from these fuels than it does from electricity. Lighting, not surprisingly, shows little variation in energy use per floor area, while appliance intensities fall somewhere in between.

Activity differences have the greatest impact only in Japan. Saturation adjustment for the major appliances accounts for some of this, since Japan has relatively high saturation levels for these products. However, the large drop stems mostly from the high share of electricity not accounted for by the major appliances. Recall that in our activity calculation, the sum of the saturation-adjusted consumption for the major appliances is multiplied by the ratio of the others' total appliance energy to major appliance energy to estimate the effect for all appliances. Since this ratio is much lower for the other countries this calculation significantly diminishes Japan's total appliance energy consumption.

The U.K. is the only country for which the fuel mix effect is predominant. This is due to the large share of natural gas used for water heating and cooking. Other than the Netherlands, the U.K. is the only country that provides more than half of its non-space heating home energy from gas.

The comparison suggests where carbon emissions might be reduced in this sector. First, substitution of gas for oil or coal in space and water heating and cooking is one avenue. Second, reduction in the carbon emissions from utilities would have an important impact on the household sector because of the high electricity share. Finally, improvements in end-use

---

[7] To calculate the useful energy we multiply the delivered energy from fuels by the following coefficients: oil and gas (0.66), coal (0.55), and wood (0.55).

efficiency, particularly for electric appliances, would have an important impact in most, but not all, of the countries studied.

Results of Mine/Yours Analysis for the Services Sector

The services sector accounts for energy used in most buildings not represented in the manufacturing and residential sectors (see Krackeler, Schipper & Sezgen 1999). Internationally compatible data for the services sector by main end use or by subsector do not exist; hence it is difficult to study the details of this sector. Instead, structure in this study is defined as the amount of floor space used per unit of services value added, which is the main difference between countries we can measure. Intensity is defined in terms of energy per unit of floor area.[8]

In the Mine/Yours comparisons for this sector, the structural and per capita value added components emerge as the most important of the terms. Although half of the IEA-14 countries' services area per services value added are clustered around 1.5 to 1.6 m^2/\$1000 the spread among the remaining countries is quite large. Finland and Sweden top the list with 2.0 and 1.8 m^2/\$1000 respectively, while Italy, France, and Japan have ratios ranging from 0.7 to 1.1 m^2/\$1000. One likely explanation for this range is climate: the cold northern climate means there is little outdoor space that can be used in this sector compared with what is done in the aforementioned warmer countries.

Given the high share of electricity used in the services sector, the utility mix substitution is, not surprisingly, a close third in terms of the variance generated. The pattern is the same here as it is in the other sectors: emissions in Australia, Denmark and the U.S. would fall, while those of Norway, France, Sweden, and New Zealand would increase.

Intensity and fuel mix effects are relatively less important in differentiating emissions in this sector. The intensity substitution is only significant in reducing emissions for Finland and Canada and only significantly increases them for Australia and New Zealand. Without reliably disaggregated data, it is not possible to say with certainty what end-uses are responsible. It is likely that these countries are the most and least intensive due to space heating requirements, considering that these are the coldest and warmest countries respectively. Fuel mix effects decreased emissions for Finland and Australia. For Finland this is a result of oil and high-carbon district heat being shifted to gas and low-carbon electricity. Australia's services, which utilize an unusually large share of (high-carbon) electricity would consume relatively more gas and oil. Norway, the Netherlands, and Sweden all experience increases from this substitution. The Netherlands, would consume less gas and more oil and electricity at average fuel shares. In Sweden emissions increase primarily because low-carbon district heat would be replaced mostly by gas. As in other sectors, Norway relies on a very large share of electricity that would at average shares be replaced by gas.

Differences in Total Emissions.

Summing the Mine/Yours results across all sectors, including industries and transportation, offers a sense of which terms play the greatest role in differentiating total

[8] The exceptions are w. Germany and the Netherlands, for which the floor space data are not available: for these two countries we have to assume that the ratio of floor area to service sector GDP is the average of all countries. Intensity is defined as energy used per unit of sectoral value added.

energy-related emissions. The results of this technique for a subset of IEA-14 countries are depicted in Figure 3. In regard to what drives demand for energy services, the activity term clearly predominates over the structure term, although the fact that the structure results for the residential sector are set equal to the actual emissions partly explains this. Activity levels in both manufacturing and services are driven by their respective value added, while activity levels in freight, travel, residential buildings are measured by other indicators. However, these indicators are driven to some extent by GDP. Hence the importance of the activity term is predominantly, but not totally, a function of GDP.

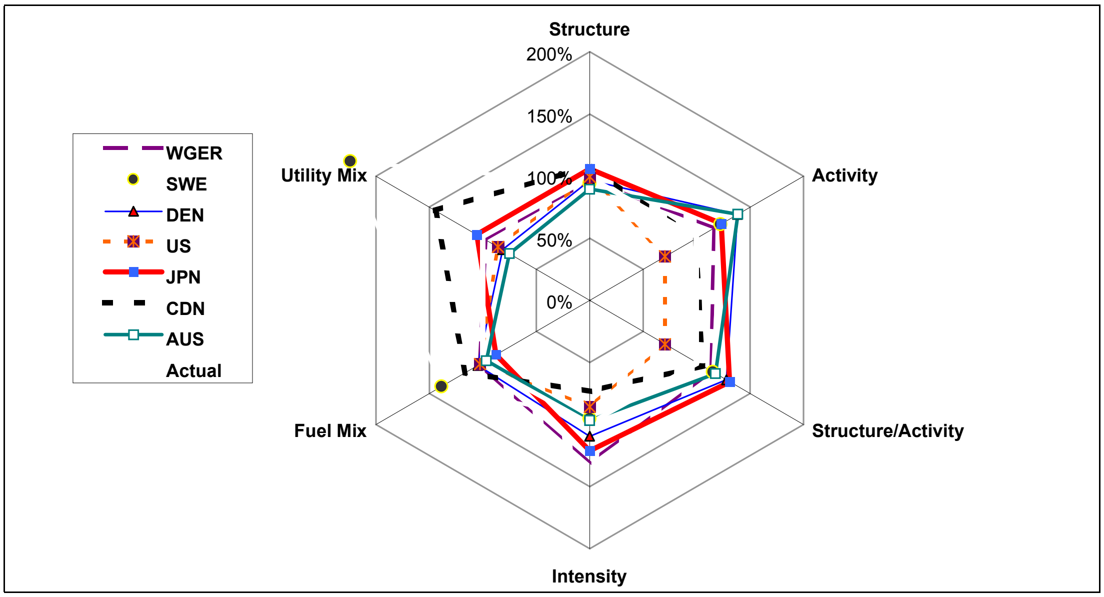

Figure 3. Total Mine/Yours Results for All Sectors, Selected IEA-14 Countries

If variances in the $\mathbf{G}_a$ to $\mathbf{G}_{m/y,c}$ ratios are weighted by emissions, the activity term is the most important term leading to differences in per capita emissions, largely due to the impact of this term on the U.S. For the U.S. the activity adjustment yields major decreases for the services, freight, and travel sectors. The activity substitution increases emissions for every European country, with increases for most countries coming in every sector. This is because the average for each sector is raised by the important U.S. term. The largest differences occur in the transportation sectors, particularly freight. This is mostly due to the large gaps in pkm and tkm per capita between the large and small countries.

Fuel mix effects on a country's emissions are generally small. Important exceptions are Sweden and Norway, which both use large shares of low-carbon electricity. Fuel mix also has an appreciable effect on the emissions from Canada and New Zealand. Canada's emissions increase at others' fuel shares because Canada uses a relatively high share of natural gas and low-carbon electricity, while biomass and electricity shares in New Zealand would be shifted to more oil and natural gas. For Japan, emissions would decrease as the high shares of oil and coal are displaced to considerably more natural gas use.

In contrast to the fuel mix effect, utility mix has a profound impact on the carbon emissions of most of the IEA-14 countries. As Figure 3 shows, total emissions from Sweden would more than double, and Canadian emissions would increase about 50%. Increases in

Norway's emissions would be even greater. The large utility mix effects result from the tremendous range of carbon released per unit of delivered energy in electricity. Norway, with its hydropower resources emits 0.06 ktC/PJ compared to Australia, which emits 73 ktC/PJ.

The Outliers: Extremes of Driving Factors

We noted at the outset that it is dangerous to push the comparisons of energy intensities and carbon intensities too far. Still, the list below outlines some of the extremes of conditions among countries that affect emissions from buildings.

- Heating degree-days (base 18°C) vary from 900 in Australia, 1,600 in New Zealand, and 1,800 in Japan to over 4,500 in Canada and Finland.
- Home size varies from over 155 square meters/home (or roughly 60 square meters/capita) in the U.S. to less than 90 square meters/home (closer to 30 square meters/capita) in Japan.
- Service sector value added varies by more than two-to-one, with the U.S. having the highest and Finland the lowest.
- Consideration of services structure reveals an almost two-to-one difference in ratio of built area to population or to service-sector GDP, with the U.S. having both the most space per capita and per GDP, and Japan and Italy having the least.
- The average carbon content of a megajoule of primary energy varies from a low of 6.8 gC in Norway to a high of 20.3 gC in Australia.
- People per dwelling varies from a low of approximately 2.25 in the Nordic countries to above 2.8 in Japan, which affects per capita residential energy use.
- Finally, GDP per capita varies by 1.75 to 1 across the countries considered, all compared using purchasing power parity, with the U.S. at the high end and New Zealand at the low end.

Broadest Conclusions: What Matters

The foregoing shows how key components underlying carbon emissions vary among industrialized countries. How much of this variation is natural versus how much is caused directly by differences in incomes and prices is a subject for debate. The same is true for energy intensities, which, as we have shown, also vary significantly. In broadest terms, per capita activity levels are the most important factors driving a wedge among countries' emissions per capita.

Manufacturing and services output make up typically 85% or more of any country's GDP, and these in turn drive emissions in those sectors. To a certain extent GDP may be said to drive the other measures of activity, but as noted above, other factors are important as well. While home area growth is coupled strongly to GDP, there is a wide range in area per capita at a given GDP per capita. Normalizing our results by a uniform division of GDP may add as much distortion as information. Thus we adhere to the per capita indicators but point out that GDP per capita has a strong influence on every sector and must be considered a key factor lying behind differences in per capita emissions.

For a few countries, a key structural feature (such as a few very carbon-intensive industries in the Netherlands or Australia) boosts emissions significantly, but in the main this is not an important effect. After activity, intensity is the most important factor. In a few countries, a particular set of energy or carbon intensities boosts emissions (high average carbon intensity of manufacturing branches in the U.S., Australia, or the Netherlands; high carbon intensity of automobile travel in the U.S. or Canada). And in some countries the presence of large hydro or nuclear resources, biomass, or the absence of coal leads to a low-carbon fuel and utility mix. Conversely an electric power sector dominated by coal and a high dependence on coal and oil in industry (e.g., w. Germany) raises emissions.

Looking at all of these countries, we can identify those that lie at the extremes. These countries are identified in Table 1. For each factor, the country whose emissions change the most is the outlier in either sense. If emissions are raised are raised by a Mine/Yours substitution, then that country has the least carbon-intensive characteristics for the property shown, and conversely, if the emissions are lowered the most, that country has the most emissions-intensive characteristics for that particular property. Where two or three countries lie close to each other and well away from the rest, all are given. This list is not meant to imply "better" or "worse", only relative position.

Table 1. Countries whose Total Emissions are Raised or Lowered the Most by Mine/Yours Factor Substitution

Component	Least Carbon-Intensive	Most Carbon-Intensive
Sectoral Activity	Italy, France	U.S.
Structure	Italy	Sweden, Finland
Activity and Structure	Italy	U.S.
Energy Intensity	w. Germany, Italy, Japan	Canada, Finland, Norway, U.S.
Fuel Mix	Norway, Sweden	Japan
Utility Fuel Mix	Norway, Sweden, New Zealand	Australia, Denmark

If we examine the structural and activity differences, several points come to mind. First, the "average" of the IEA countries shown is dominated by the U.S., hence most countries' substitutions move in the opposite direction of those for the U.S. Note for the U.S. that every substitution but fuel mix reduces its emissions. This is both because of the U.S. emissions-intensive structure (primarily transportation), but also the high GDP per capita. But Japan, with a high GDP/capita, shows an increase in emissions from all substitutions. Like the U.S., the largest changes for Japan occur in the household and transportation sectors. This is important, because it implies that transportation contributes highly to variability of per capita emissions among countries, followed by the household sector. If we were to normalize by GDP the role of transport and households would stand out even more.

A little consideration of the structure and activity components explains why Italy and Norway come out with the lowest values. For one thing, Norway's extremely energy or electricity-intensive industry is not necessarily carbon-intensive, and it is small in terms of per capita output. And while Norway is cold, its space heating is almost entirely based on hydro-electricity or wood, hence counts very little towards emissions. The same is true for Italy, but this time the reason is both the mild climate and the low share of automobiles, for Europe, in total travel. Sweden and Finland have the most carbon-intensive structures because they have relatively energy-intensive industrial mixes, with considerably more fossil fuels than does Norway, they are cold, and they are relatively transportation-intensive. If activity alone is considered, the U.S. is the most carbon-intensive country, mainly because of the very high values it has for transportation activities, but also because of the large home sizes and relatively high services value added per capita.

Conclusions for CO2 Policies

If we ascribe most of the variation in emissions per capita to activity levels, then we are forced to conclude that much of this variance is caused by differences in GDP per capita. Overall it appears that energy intensities drive the next greatest differences in carbon emissions, and therefore drive the largest differences in emissions per unit of GDP. Not all of these "intensities" are technological, as many have behavioral components such as hours of heating, car size, load factors, etc. After that primary energy supply has the biggest influence on carbon emissions, and in a few countries (notably Sweden, Canada, and Norway) it is more important than energy intensities and may to some extent offset high intensities. Fortunately for policy makers, these are factors that can be influenced by technology and policy. But what drives these factors?

GDP itself is a driving factor, in the reverse sense, as higher incomes are clearly associated with lower carbon/GDP ratios (Schmalensee, Stoker & Judson 1998; Galeotti & Lanzo 1998). We freely admit that our linearization of the emissions picture with GDP in many examples is a simplification, but it is a necessary simplification as a first step towards an even deeper understanding.

It is hard not to give energy prices an important role in the answer to that question. These shape fuel mix and make improved energy efficiencies and more efficient practices more – or less attractive. One must debate the strength of this role, i.e., the price elasticities, and the time lags before changes in energy prices affect both behavior and the choice of equipment. But it is difficult to deny that role and hard to foresee a successful carbon restraint program that does not somehow raise the price of carbon.

Finally, there are other factors as well. We pointed to the natural endowments and geography of a country, as well as some examples of the countless policies outside of the energy sector that influence activity and structure. Many of these endowments, such as the availability of raw materials for energy-intensive processing, raise carbon emissions, while others, such as the presence of hydro resources, lower them.

Given the wide variation in both "controlled" driving factors (e.g., incomes and prices) and "natural factors" (e.g., climate, geography, and natural resources), many countries want their special situations to be "differentiated", so that their own carbon reduction targets take these natural factors into account. Which of the various factors we have isolated can be taken "off the table" as grounds for CO2 restraint? That is, could any one country with that component claim the right to decarbonize at a slower rate than others? The high emitters could claim a certain dependency on carbon-intensive activity and high carbon intensities. The latter could either claim that they have little carbon to save (Norway) or that they already underwent significant decarbonization in the 1970s and 1980s (France, Sweden).

In sum, we estimate that roughly 75% of per capita emissions differences are driven by rigid factors. By this we mean those factors that carbon restraint policies are either unable or unlikely to address: GDP/capita, climate, geography, home size, and economic structure. Perhaps as much as half of the differences arise from factors such as energy intensities and utility mix that could be subject to reducing emissions over the next ten to twenty years.

What is clear is that transparent systems of analysis and an informative set of indicators will be needed to guide future carbon restraint negotiations.

References

Birol, F. and J.H. Keppler. 2000. "Prices, Technology Development And The Rebound Effect." *Energy Policy* (June, in press).

Galeotti, M. and A. Lanza. 1999. *Desperately Seeking (Environmental) Kuznets*. Fondazione ENI Enrico Mattei, Nota di lavoro N.2/99.

Greening, L., W. B. Davis, and L. J. Schipper. 1996. "Decomposition of Aggregate Carbon Intensity for the Manufacturing Sector: Comparison of Declining Trends from Ten OECD Countries for the Period 1971 to 1991." *Energy Economics* 20 (1): 43-65.

Greening, L.A., W.B. Davis, L.J. Schipper, and M. Khrushch. 1997. "Comparison of Six Decomposition Methods: Application to Aggregate Energy Intensity for Manufacturing in Ten OECD Countries." *Energy Economics* 19 (3): 375-90.

[IPCC] Intergovernmental Panel on Climate Change. 1996. IPCC Guidelines for National Greenhouse Gas Inventories: Greenhouse Gas Inventory Reference Manual. Geneva: Intergovernmental Panel on Climate Change.

Krackeler, T., L. Schipper and O. Sezgen. 1999. "Carbon dioxide emissions in OECD service sectors: The critical role of electricity use." *Energy Policy* 26 (15): 1137-52.

[OECD] Organization for Economic Cooperation and Development. 1997. *Indicators of Energy Use and Efficiency: Understanding the Link between Energy and Human Activity*. Paris: OECD.

Schipper, L. 1997. *Indicators of Energy Use and Efficiency: The Link Between Energy Use and Human Activity.* Paris: International Energy Agency.

Schipper, L. and M. Grubb. 2000. "On the Rebound: The Interaction of Energy Use and Energy Efficiency." *Energy Policy* (June, In press).

Schipper, L.J., M. Ting, M. Khrushch, and W. Golove. 1997. "The Evolution of Carbon Dioxide Emissions from Energy Use in Industrialized Countries: An End-Use Analysis." *Energy Policy* 25 (7-9): 651-72.

Schipper, L., F. Unander, and C. Lilliu. 1999. "One Man's Carbon is Another Man's Bread." In *New Equilibria in the Energy Markets*, proceedings of the 22nd IAEE International Conference. Cleveland, Ohio: International Association for Energy Economics.

Schmalensee, R., T. Stoker, and R. Judson. 1998. World Carbon Dioxide Emissions: 1950-2050. *Rev. Ec. Stats*. LXXX: 15-27.