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The unexpected challenges of using energy intensity as a policy objective: Examining the debate over the APEC energy intensity goal ☆

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HIGHLIGHTS

- APEC adopted, then subsequently revised, an energy intensity reduction goal.
- This is a case study of APEC's use of energy intensity as a policy objective.
- Energy intensity is declining more rapidly than many policymakers realized.
- The definition of energy intensity adopted can dramatically change the incentives.
- Currency conversion methodologies can dramatically change the calculations.

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ABSTRACT

Aims: Energy intensity (energy demand per unit of economic output) is one of the most widely used indicators of energy efficiency in energy policy discussions. Yet its application in real-world policymaking can be surprisingly problematical. This paper aims to provide guidance to governments and organizations considering using energy intensity as a policy objective.
Scope: In 2007 the APEC community adopted, then in 2011 revised, an APEC region-wide energy intensity improvement goal. This paper presents a case study of that experience, focusing on three key 'lessons learned'. These lessons are not original findings. However, none of them have received the recognition they deserve, and consequently, they came as a surprise to many of those involved in APEC's policy discussions.
Conclusions: The three lessons are as follows: (1) Energy intensity improvement is happening surprisingly quickly, but not quickly enough to meet the world's energy challenges. (2) It is difficult to find a definition of energy intensity that can make it suitable for use as an indicator of regional energy efficiency. (3) Whether the GDP's of individual economies are converted to common currency using market exchange rates or purchasing power parity (PPP) can dramatically change regional energy intensity improvement calculations.

1. Introduction

Energy intensity (energy demand per unit of economic output) is one of the most popular indicators of aggregate energy efficiency in energy policy discussions (Schipper and Haas, 1997). Yet its application in real-world policymaking can be surprisingly problematical. This was demonstrated by the recent experience of the APEC community, which adopted, then subsequently revised, an APEC region-wide energy intensity improvement goal. This paper presents a case study of that experience focused on three key "lessons learned", which should be taken into account by any policymaker considering using energy intensity as a policy objective.

These lessons learned will come as no surprise to those steeped in the literature of energy economics, and they are certainly not original findings. However, none of them have received the recognition they deserve in the literature, and consequently, they came as a surprise to many of those involved in APEC's policy discussions. The role of this paper is to highlight their importance by showing their impact on a real world policy decision. Consequently, this paper may provide useful guidance to any other governments or organizations considering the use of energy intensity as a policy objective.

The three "lessons learned" are as follows:

Lesson #1—Energy intensity improvement is happening surprisingly quickly, but not quickly enough to meet the world's energy challenges.

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Lesson #2—It is difficult to find a definition of energy intensity that can make it suitable for use as an indicator of regional energy efficiency.

Lesson #3—Whether the GDP's of individual economies are converted to a common currency using market exchange rates or purchasing power parity (PPP) can dramatically change regional energy intensity improvement calculations.

The most directly relevant previous literature to this paper is Suehiro (2008), who has provided a discussion of some of the general properties of energy intensity as an indicator, focusing especially on the choice of market exchange rates vs. purchasing power parity (PPP), which we will highlight here as Lesson #3. However, the existing literature on the properties of energy intensity is heavily focused on building models to decompose energy intensity improvement into various explanatory factors. Two papers with good reviews of this literature are Wing (2008) and Ma and Stern (2008).

Also relevant to this paper is the literature on a related indicator, *greenhouse gas emissions intensity* (emissions per unit of economic output), which appears to be more abundant (see, for example Pizer, 2005; Herzog et al., 2006; Wing et al., 2006). Some of the properties of emissions intensity also apply to energy intensity. Similar to this paper's Lesson #1, this literature finds that there is a tendency for emissions intensity to decline over time with improvements in economic productivity and shifts away from energy-intensive industry. However, a significant caveat is that emission intensities can decline even as emissions *rise*. This literature also points out that improving emissions intensity is attractive to policymakers as a policy goal because, unlike an absolute emissions goal, emissions under an intensity goal can vary with economic activity. An emissions intensity goal is therefore less likely to be perceived as limiting growth, an especially critical property for developing economies. An energy intensity improvement goal would have this same attractive feature for policymakers.

2. Background on APEC's energy intensity goal

Asia-Pacific Economic Cooperation or APEC is a multi-lateral organization of 21 Pacific Rim economies whose primary mission is to “to support sustainable economic growth and prosperity in the Asia-Pacific region” (APEC, 2013A). APEC member economies have a combined population of about 2.7 billion people and account for about 54% of world GDP (APEC, 2010A, p.2). Unlike some multi-lateral organizations, APEC operates on an entirely voluntary basis—there are no binding commitments and no penalties for non-compliance. Compliance is achieved through “mutual discussion and mutual support in the form of economic and technical cooperation” (APEC, 2010A, p.2). Because APEC is privileged to have the People's Republic of China, Chinese Taipei, and Hong Kong, China as members, APEC refers to its members as ‘economies’ rather than ‘countries’.

APEC promotes regional cooperation in a wide variety of areas related to economics and trade, including energy. One of APEC's key energy initiatives has been an APEC-wide regional goal for energy intensity reduction. This goal was first agreed to at the APEC Leaders’ Meeting in Sydney, Australia in September 2007. The annual APEC Leaders’ meetings bring together the Presidents, Prime Ministers, or other political leaders of each of the APEC economies. In their *Sydney APEC Leaders’ Declaration on Climate Change, Energy Security and Clean Development*, the Leaders announced that they would

> highlight the importance of improving energy efficiency by working towards achieving an APEC-wide regional aspirational goal of a reduction in energy intensity of at least 25% by 2030 (with 2005 as the base year) (APEC, 2007B).

However, at their subsequent meeting in Honolulu in November, 2011, the Leaders adopted a more ambitious goal “to reduce APEC's aggregate energy intensity by 45% by 2035” (APEC, 2011).

Between these two events, there was extended discussion within the APEC community, focusing especially on APEC's Energy Working Group (EWG), as to whether the goal should be revised and, if so, what the revised goal should be. It is this discussion that is the focus of this paper. The author's organization, the Asia Pacific Energy Research Centre (APERC), had the privilege of providing much of the analysis that supported this discussion. APERC is an independent research institute, generously sponsored by the Japanese government, which supports the energy-related activities of APEC through both research and cooperative efforts to promote energy efficiency and low-carbon energy supply.

3. Setting the original 25% 2005–2030 intensity improvement goal

The official record is sketchy as to the background of the original 2007 energy intensity improvement goal. The Darwin Declaration of the APEC Energy Ministers of May, 2007 on *Achieving Energy Security and Sustainable Development Through Efficiency, Conservation and Diversity* makes no mention of an energy intensity goal (APEC, 2007A). A review of the Summary Records of APEC Senior Officials Meetings (SOM), where drafts of upcoming Leaders’ Declarations are usually discussed, for the 2nd half of 2006 and 2007 reveals no discussion of an intensity goal. However, this is not surprising as discussions of upcoming Leader's Declarations would usually be done off-the-record. The Summary Records of APEC EWG Meetings for this time period also reveal no discussion of the intensity goal.[1] So where did this goal come from?

According to James Connaughton, who was Chairman of the White House Office of Environmental Policy in 2007, the goal was originally promoted by Australia. The Australian government needed to show that they were doing something meaningful to reduce emissions going into the upcoming election. The United States went along with it because it was something they could live with; in particular, the Bush Administration had set a goal of improving US energy intensity 18% between 2002 and 2012, and the 25% goal was consistent with this rate of improvement projected out to 2030. China also had an intensity improvement goal in their five year plan [specifically, the goal in the 11th Five Year Plan was to improve energy intensity by 20% between 2006 and 2010 (Price et al., 2011), and the proposed APEC goal was also consistent that goal (Connaughton, 2012).

It should be explained that each year one APEC economy plays host to the most senior APEC events including the annual Leaders’ Meeting, Ministerial Meetings, Senior Officials Meetings and a number of other events. As the host economy, that economy nominates a Chair to preside over these meetings (APEC, 2013B). 2007 was Australia's year as host.

Jan Adams, then Australia's Ambassador for Environment, after a review of an earlier draft of this paper, kindly provided the author with the following further explanations regarding the origins of APEC's energy intensity goal:

[1] Summary records for APEC Meetings, including APEC Senior Official Meetings and APEC Energy Working Group Meetings, are available on the APEC website at http://aimp.apec.org/MDDB/Pages/search.aspx.

In 2007 when Australia was APEC chair, there was a great deal of international and Australian focus on climate change. The Stern report was released, the IPCC update, the drought was terrible in Australia, and the upcoming Bali conference of the UNFCCC was a major milestone in terms of Kyoto and post Kyoto negotiations. In that context Australian PM John Howard decided that climate change should be a key focus of the APEC summit. (If you look at other summits that year, they all dealt with climate change—G8; Commonweath meeting; EAS, etc.). Australia conducted a series of consultations among APEC economies on what APEC should do and say about climate change. I was Australia's Ambassador for the Environment, with responsibility for leading negotiations in the UN and elsewhere on climate change. In that capacity I did much of the consultation and preparation of the Sydney Declaration. Mr Downer was Foreign Minister, and Michael L'Estrange was the Prime Minister's special envoy for preparing the Leaders' declarations. Between us, and through our embassies as well, we conducted consultations with APEC economies on climate change. This involved foreign, trade, energy and climate change ministries in the APEC economies, depending on how they organised their internal processes in support of the leaders meeting process.

Australia proposed the energy intensity target with a good understanding of the pros and limitations of such a target, and there was discussion with various member economies on the sorts of issues you discuss in your paper. The actual number was backed up by APERC research at the time. APEC economies including Australia were not inclined to focussing on emissions targets which were under multilateral negotiation in the UNFCCC. Economies agreed on the utility of focussing on energy intensity, given the high energy using economies in APEC and the focus on supporting ongoing economic growth in the region. As you note, economies opposed to emission targets such as US and China already had internal energy intensity targets, so this was an area in which we thought the profile and peer pressure could be raised by elevating it to a regional leaders level issue, without interfering in the multilateral process of the UN. We envisaged that there would be ongoing attention to these issues in the APEC work program through [the APEC] EWG.

So from a process point of view, the declaration was negotiated mainly by representatives of APEC economies with responsibility for climate change negotiations, such as Jim Connaughton and Harlan Watson from the US. It was done in conjunction with representatives from energy ministries and [the APEC] EWG but not as an initiative of theirs (Adams, 2012).

The APERC research referred to by Ambassador Adams would be APERC's *Energy Demand and Supply Outlook 2006*, which projected that APEC's energy intensity would decline 43% from 2002 to 2030 and 33% from 2010 to 2030 (no figures were presented for 2005 to 2030). The assumptions behind these 2006 APERC projections would appear to be business-as-usual, although this is never explicitly stated in the report (APERC, 2006).

4. Lessons learned

The EWG's post-Sydney discussions centered on three significant topics, each of which became a focus of the discussion, at least for a time. Each topic suggests a "lesson learned". This section discusses the three topics and the lessons learned in the chronological sequence in which they arose.

4.1. Lesson #1—Energy intensity improvement is happening surprisingly quickly, but not quickly enough to meet the world's energy challenges

APERC explicitly looked into the question of the adequacy of the 25% goal in its November 2009 *APEC Energy Demand and Supply Outlook 4th Edition* (APERC, 2009). APERC's projections were based mostly on simple econometric models of final demand and expected transformation efficiencies in electricity generation[2]. Consistent with APERC's earlier *Energy Demand and Supply Outlook 2006*, these projections indicated that, assuming energy intensity is defined as primary energy supply per US dollar of GDP at purchasing power parity, the Sydney Declaration goal could be easily be met under business-as-usual assumptions. By 2030, the projections indicated that APEC region primary energy supply will increase by about 45% compared to 2005, while GDP will increase by about 235%. As shown in Fig. 1 below, the net impact will be a decrease in energy intensity of about 38%.

While it may be good news that energy intensity improvement appears to be happening so quickly, the *Outlook 4th Edition* also had some bad news: even with this improvement in energy intensity, over the 2005–2030 time period, APEC's oil imports from outside the APEC region were likely to grow by about 70%, while CO_2 emissions from fuel combustion were likely to grow by about 40%. Hence, the business-as-usual outlook raises serious concerns regarding both energy security and environmental sustainability.

Of course, there was skepticism at first both inside and outside APERC as to whether these projections were really reasonable. Therefore, APERC undertook further analysis focusing on APEC's energy intensity goal, finally published in August 2010 under the title *Pathways to Energy Sustainability*; *Measuring APEC Progress in Promoting Economic Growth*, *Energy Security*, *and Environmental Protection* (APERC, 2010).

The *Pathways* report presented three types of additional evidence which suggested that the conclusions of the *Outlook 4th Edition* were reasonable. It should be noted that energy intensity can be measured in at least two ways: *primary energy intensity* is primary energy (raw fuels before conversion to electricity or refining of crude oil) divided by GDP; *final energy intensity* is final energy (energy in the form it is finally used) divided by GDP. The APEC Leaders did not specify which measure they had in mind, so the *Pathways* Report considered both.

1. *The energy intensity of the APEC region has historically declined at a rate exceeding 25% over the 25 years prior to 2005*. Between 1980 and 2005, the primary energy intensity of the region excluding Russia and Viet Nam (for which comparable data are unavailable prior to 1990) declined by 31% (1.5% per year). Over the same period, the final energy intensity of the region declined by 39% (1.9% per year). From 1990 to 2005, when data for all APEC economies is available, the primary energy intensity of the region declined by 20%. Final energy intensity

[2] More specifically, APERC estimated simple least-squares regression models of final demand for each of 10 sub-sectors (iron and steel, chemicals, other industries, road transport, other transport, agriculture, household, commercial, non-specified other, and non-energy) for each of four fuel types (coal, petroleum products, natural gas, and electricity) for each economy. The models were driven by projections of macro-economic variables including GDP, population, crude oil prices, industrial value-added, and automobile ownership, which were obtained from a variety of published sources for each economy. Demands for each type of primary energy for electricity generation were based on data on the existing generation fleet by primary energy type, including capacity, transformation efficiencies, and utilization, combined with APERC's assessment of likely future generation fleet additions and retirements by 2030 based on published studies for each economy.

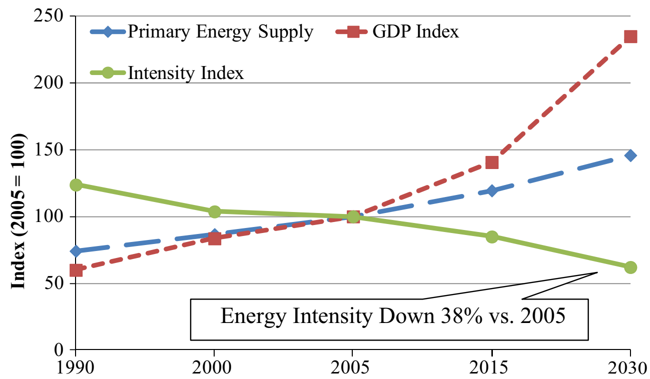

Fig. 1. Projected APEC business-as-usual primary energy demand, GDP, and energy intensity (APERC, 2009, Fig. 1.5).

declined by 25%. A continuation of these 1990 to 2005 rates of decline over the next 25 years would bring a decline in primary energy intensity of around 31% and a decline in final energy intensity of around 38%. Both declines comfortably exceeded the APEC Leaders' goal.

2. *Since 2005, energy intensity of the APEC region has continued to improve*. At the time the *Pathways* report was published, data were available only for 2006 and 2007, but they indicated an average annual reduction in primary energy intensity of 2.2% per year and an average annual reduction in final energy intensity of 2.3% per year, well above the historical trends discussed above. Subsequently, data for 2008–2010 have become available. They indicate that, with the onset of the economic crisis, the rate of APEC energy intensity improvement slowed in 2008, essentially stopped in 2009, and resumed slowly in 2010. Therefore, over the 2005–2010 time period, primary energy intensity declined at an average rate of 1.4% per year, while final energy intensity declined at an average rate of 1.8% per year.[3] Even at these rates, the 25% goal would be exceeded by 2030, and the 2008–2010 results are probably anomalous in any case.
3. *A comparison of APERC's projections with those of other modeling efforts indicates a remarkable degree of similarity*. Projections of APEC energy intensity based on the results in the International Energy Agency's *World Energy Outlook 2009* (IEA, 2009A) indicated a 38% intensity improvement, almost exactly matching APERC's independent *Outlook 4th Edition* projection.[4] A comparison with the United States Energy Information Administration's *International Energy Outlook 2009* model results indicated a slightly larger 40% intensity improvement.[5] Hence, there are three independent modeling efforts that have arrived as essentially the same conclusion about APEC's projected business-as-usual intensity reduction.

It should be emphasized that these findings are not unique to the APEC region. The IPCC's Fourth Assessment Report, Working Group 3: Mitigation of Climate Change found that energy intensity globally declined by 1.2% per year between 1970 and 2004 (Fisher et al., 2007, Section 1.3.1.2), a 33% decline in 25 years (IPCC, 2007, Section SPM B). Nakicenovic (1997) concluded that the historical rate of decrease in energy intensity appears to have averaged about 1% per year since the mid-nineteenth century and about 2% per year in some countries since the 1970s, with large and persistent variations between countries.

Looking ahead, the IPCC's Fourth Assessment Report, Working Group 3 analysis of 286 ‘non-intervention’ scenarios to the year 2100 from the literature found that in all scenarios, energy intensity improves significantly across the century, with a mean annual intensity improvement of 1%. The 90% range of the annual average intensity improvement is between 0.5% and 1.9%, which they note is fairly consistent with the historical variation (Fisher et al., 2007, Section 3.2.1.5). It should be noted that many of these scenarios compared GDP values across countries using market exchange rates (Fisher et al., 2007, Section 3.2.1.4). As discussed under Lesson #3 below, they may thus understate the actual improvement in energy intensity.

The *Pathways* report also outlined an example of how a more sustainable scenario for energy development in the APEC region could be achieved. The scenario shows how the energy sector in the APEC region could contribute towards limiting global warming to 2 °C by limiting greenhouse gas concentrations in the atmosphere to 450 PPM of CO_2-equivalent. This scenario would require a roughly 50% improvement in primary energy intensity by 2030, along with other measures to promote non-fossil energy as well as carbon capture and storage.[6]

An early draft of the *Pathways* report was published on the website of the APEC Energy Ministers meeting in Fukui, Japan, prior to the meeting in June 2010. At that meeting, the Ministers decided that a reconsideration of the 25% goal was needed. In their Fukui Declaration, the Energy Ministers directed the EWG to:

> Assess the potential for reducing the energy intensity of economic output in APEC economies between 2005 and 2030, beyond the 25 percent aspirational goal already agreed by the APEC Leaders, with assistance from APERC, EGEDA [the APEC Expert Group on Energy Data and Analysis], and EGEEC [the APEC Expert Group on Energy Efficiency and Conservation] (APEC, 2010B).

4.2. Lesson #2—It is difficult to find a definition of energy intensity that can make it suitable for use as an indicator of regional energy efficiency

The Ministers directed the EWG to reassess the goal, but what should the new goal be and exactly how should it be measured? Measurement turned out to be a surprising difficult question. As noted above, there are two commonly-used measures of economy-wide energy demand: primary energy and final energy. The two differ by the losses in energy transformation processes, especially electricity generation and refineries, which are included in primary energy but not included in final demand.

As noted above, the Sydney Declaration did not specify what measure of energy demand was to be used to calculate energy intensity. Nor does there appear to be any standard set by the International Energy Agency (IEA). The IEA's *World Energy Outlook 2012* (IEA, 2012, see, for example, Fig. 2.4) discusses intensity based on primary energy. However, another IEA publication specifically devoted to the topic of energy indicators focuses throughout on energy intensity calculated using final energy (IEA, 2008, see, for example, p. 15).

[3] These results are APERC calculations based on historical energy data from IEA (2011A, 2011B) and historical economy GDP data from IHS (2012).

[4] Additional non-published data on individual economy model results were provided by the IEA to APERC to facilitate these calculations. The raw data is © OECD/IEA, 2009, calculations by APERC.

[5] These results are APERC calculations based on projections of energy demand and GDP published in United States Energy Information Administration (2009).

[6] See Chapter 5 of APERC (2010). The Sustainable Scenario in the Pathways report was based on model results from the 450 Scenario of the International Agency's *World Energy Outlook 2009.* Additional non-published data on individual economy model results were provided by the IEA to APERC to facilitate these calculations. The raw data is © OECD/IEA, 2009, calculations by APERC.

It is natural to assume that primary energy is the best measure to use for calculating energy intensity improvement, since it is the broader measure that can reflect improvements in electricity generation and refinery efficiency, as well as end-use efficiency. However, since various types of electricity generation have different levels of conversion efficiency, changing the mix of electricity generation can change the apparent overall efficiency of electricity generation (Percebois, 1979), and such changes do not always align with the ultimate objectives of the APEC energy intensity goal.

This message was clearly driven home to the author several months after the Fukui Declaration in a discussion with an energy policy analyst from Hong Kong, China. The analyst explained that Hong Kong was considering a proposal to build a nuclear power plant. He explained that Hong Kong, as a member of APEC, wanted to help APEC meet its energy intensity improvement goal, but when they did the calculations for the impact of the nuclear power plant, they showed that it would make Hong Kong's energy intensity increase, that is *get worse*. This did not seem right to him, since the nuclear plant would reduce Hong Kong's greenhouse gas emissions and reduce Hong Kong's dependence on imported fossil fuels, both goals that the APEC Leaders presumably wished to encourage with their energy intensity improvement goal. He asked me if his calculations were correct.

The answer is that his calculations are indeed correct, at least if primary energy is used to calculate energy intensity and primary energy is calculated using the 'physical energy content' methodology employed by the International Energy Agency and Eurostat (IEA et al., 2004). There are actually at least three methodologies used in the literature to calculate primary energy (Moomaw et al., 2011, Section A.II.4; Macknick, 2009). All of them agree that, for fossil fuel generation plants, primary energy is the fuel burned, and the efficiency of the plant is the electrical energy output divided by the fuel energy input. However, for a nuclear plant, the definition of 'efficiency' is not so obvious, since the heating value of the nuclear fuel cannot be clearly established. In the IEA/Eurostat methodology, primary energy for a nuclear plant is defined to be the energy content of the steam leaving the reactor for the turbine, implying that the efficiency of the plant is the electrical energy output divided by the steam energy input (see IEA et al. 2004, p.22).

Using this methodology, the efficiency of a nuclear plant is typically relatively low. In 2009, the worldwide average efficiency of nuclear plants was about 33%.[7] Since many countries do not even keep statistics on the energy content of the steam produced in nuclear plants, the IEA/Eurostat methodology for estimating it in these cases is to impute it from the electricity output at an assumed efficiency rate of 33% (IEA et al., 2004, p. 138).

For geothermal plants, the principle under the IEA/Eurostat methodology is the same: the energy in the geothermal steam is the primary energy and the electricity produced is the final energy. However, for geothermal plants, because of the relatively low temperature of most geothermal steam, the worldwide average efficiency turns out to be an even more dismal 11%.[8] Again, since many countries do not keep statistics on the energy content of the geothermal steam produced, the standard approach for estimating it in these cases is to impute it from the electricity output at an assumed efficiency rate of 10% (IEA et al., 2004, p. 138).

Fossil fuel plant efficiencies are typically much higher—the worldwide averages were 36% for coal plants and 49% for natural gas plants in 2009.[9] Hence, when an economy converts from fossil fuel to nuclear or geothermal electricity generation, their generation efficiency under the IEA/Eurostat methodology will *decrease* and their primary energy intensity will increase (*get worse*). Note that this anomalous result does not apply to non-thermal types of renewable energies that are converted directly to electricity without the intermediate step of producing steam or heat, such as hydro, wind, and solar photovoltaics. For non-thermal renewables, the primary energy input under the IEA/Eurostat methodology is defined to be the same as the electricity output, effectively counting them as 100% efficient (IEA et al., 2004, pp. 118 and 137). Since one might assume that low-carbon, non-fossil electricity generation, such as nuclear and geothermal, is something that the APEC Leaders would be seeking to promote, or at least not to discourage, it is apparent that using primary energy to measure energy intensity, at least following the IEA/Eurostat methodology, does not align with their ultimate objectives.

As noted above, there are at least two alternatives to the IEA/Eurostat 'physical energy content' methodology used in the literature to measure primary energy (Moomaw et al., 2011, Section A.II.4) from non-fossil sources. First, BP (2011, p, 44) uses the 'substitution method', which counts the primary energy used to produce nuclear and renewable electricity as if they had been produced from fossil fuels. Specifically, a 38% conversion efficiency is assumed for all nuclear and renewable electricity. The United States Energy Information Administration applies a similar methodology to electricity from hydro, geothermal, solar thermal/photovoltaic, and wind, currently assuming a conversion efficiency of 35%, but follows a methodology more similar IEA/Eurostat for nuclear[10].

Second, UN Statistics (2012) use the 'direct equivalent method', which simply counts one unit of electricity generated from nuclear or renewables other than biomass as one unit of primary energy, effectively assuming generation from these renewables to be 100% efficient. The 'direct equivalent method' has also been used in various IPCC reports (Moomaw et al., 2011, Section A.II.4).

The EWG did consider using the 'direct equivalent' methodology to measure energy intensity improvement, which would have avoided the anomalous effects of increased nuclear and geothermal generation on primary energy intensity discussed above. The main argument for this methodology was that fossil fuel plant losses result in greenhouse gas emissions and fossil energy imports, while nuclear and geothermal losses are more benign and should be ignored in calculating energy intensity. This methodology would also standardize the treatment of most non-fossil energy, since nuclear and geothermal generation would effectively be counted as 100% efficient just like hydro, wind, and solar photovoltaics. However, within the EWG there were objections that this methodology was not commonly used in policy analysis, and would therefore be confusing to policymakers. Also, some EWG members felt that this definition would cause the

[7] This figure is the author's calculation based on worldwide statistics from IEA (2011A), which show that nuclear plants had a primary fuel input of 703.2 mtoe, and an output of 2696,765 GW h, or 231.88 mtoe, of electricity plus 0.52 mtoe of marketable heat for a total output of 232.4 mtoe.

[8] This figure is the author's calculation based on worldwide statistics from IEA (2011A), which show that geothermal electricity and CHP plants had a primary fuel input of 55.931 mtoe, and an output of 66,672 GW h, or 5.73 mtoe, of electricity plus 0.23 mtoe of marketable heat for a total output of 5.96 mtoe.

[9] These figures are the author's calculations based on worldwide statistics from IEA (2011A), which show that coal electricity and CHP plants had a primary fuel input of 2041.13 mtoe, and an output of 8110,286 GW h, or 697.36 mtoe, of electricity plus 43.96 mtoe of marketable heat for a total output of 741.32 mtoe. Natural gas electricity and CHP plants had a primary fuel input of 918.98 mtoe, and an output of 4301,367 GW h, or 369.85 mtoe, of electricity plus 76.92 mtoe of marketable heat for a total output of 446.77 mtoe.

[10] The United States Energy Information Administration methodology for estimating primary energy is explained in the entries for 'Primary Energy Consumption' and 'Primary Energy Production' in their on-line Glossary available at ⟨http://205.254.135.7/tools/glossary/index.cfm?id=P⟩. The actual conversion rates used are shown in United States Energy Information Administration (2011, Table A6).

APEC energy intensity reduction goal to look a bit too much like an emission intensity reduction goal, an alternative the APEC Leaders had already rejected.

An alternative to using primary energy to measure the APEC energy intensity goal would be to use final energy. This approach would give a clear measure of end-user energy efficiency, which is the focus of energy efficiency improvement efforts in many economies. However, it would not reflect any improvements an economy makes in the efficiency of its electricity generation, which in many economies represents a major opportunity to improve energy efficiency.

Fortunately, all of the analysis of projected energy intensity improvement indicated that it made little difference whether one used primary energy or final energy to calculate energy intensity—for any given set of assumptions, the projected APEC-wide improvement always seemed to work out about the same either way (Samuelson, 2011). So, from the perspective of setting a numerical goal, the measure selected did not matter that much in the end. Perhaps for this reason, the EWG has still never taken a position on which definition should be used (APEC Energy Working Group, 2011).

However, from the perspective of incentives to APEC economy policymakers, the measure of energy demand selected does matter. Using primary energy intensity calculated according to the IEA/Eurostat methodology, policymakers seeking to contribute to the APEC-wide energy intensity goal should avoid nuclear and geothermal generation. Using final energy intensity, they should not concern themselves with generation efficiency at all. Neither seems right to the author.

4.3. Lesson #3—Whether the GDP's of individual economies are converted to common currency using market exchange rates or purchasing power parity (PPP) can dramatically change the energy intensity improvement calculations

Discussions within the EWG of APEC's energy intensity improvement goal took a surprising turn as the deadline approached for recommending a new goal in time for consideration at the APEC Economic Leaders' Meeting in Honolulu, Hawaii in November 2011. One EWG participant, who was skeptical of APEC's ability to meet a more ambitious energy intensity goal, cited a recent study of the ASEAN+6 economies by the Economic Research Institute of ASEAN and East Asia (ERIA), which concluded that their energy intensity would improve in the 2005–2030 time period by only 9.9% under business-as-usual, and only 26.7% under an "Alternative Policy Scenario" (APS) incorporating additional goals and action plans (Kimura, 2010).

The ASEAN+6 economies are not the same as the APEC economies. However, 12 of the 21 APEC economies are also in the ASEAN+6, so the results of this new study appeared to be difficult to reconcile with the results of other studies, discussed under Lesson #1 above, which suggested a much higher 2005–2030 business-as-usual improvement in energy intensity.

It turns out that the major explanation for the difference between the ERIA results and other model results lies in the way GDP's for each economy were converted to US dollars. ERIA used year 2000 market exchange rates (MER), while the other models and the historical results cited under Lesson #1 above used Purchasing Power Parity (PPP) rates with a 2005 base year. If the ERIA results are recalculated using PPP's, the results become consistent with those other models.

To see why this is the case, we have to look at the underlying data. Table 1 below shows the business-as-usual ERIA results economy-by-economy using their original year 2000 market exchange rates. The 2005–2030 primary energy intensity improvement would be 4.2% for the ASEAN+6 economies that are also members of the APEC and 9.9% for all the ASEAN+6 economies.

At first glance, the individual economy improvements in Table 1 appear to be broadly consistent with the results of the modeling work discussed under Lesson #1 above, especially considering the large projected improvements in energy intensity in the two largest energy-consuming economies, China and India. What seems odd are the *total* values for the APEC ASEAN+6 economies and for the entire ASEAN+6. For example, the 4.2% BAU case total improvement for the APEC ASEAN+6 economies is smaller than the corresponding figure for every individual economy. How can this be?

The answer lies in the fact that there is a disconnect here between GDP and energy demand. It can be seen that more than 53% of the total 2005 GDP of the ASEAN+6 is contributed by Japan. On the other hand, 48% of the total 2005 energy demand of the ASEAN+6 is contributed by China. Between 2005 and 2030, Japan's economy is projected to grow slowly, while China's economy is projected to grow quickly. Hence, total ASEAN+6 GDP growth tends to be pushed down by Japan, while total ASEAN+6 energy demand tends to be pushed up by China. Since energy intensity is energy demand divided by GDP, this would explain why total primary energy intensity improvement for the ASEAN+6 economies that are also members of APEC is a meager 4.2% and why total primary intensity improvement for all ASEAN+6 economies is only 9.9%.

Table 2 shows Table 1 recalculated using 2005 PPP's, to make them comparable to the models discussed under Lesson #1. To make this table, the 2005 GDPs of each economy in 2005 PPP US dollars were obtained from the World Bank,[11] and were substituted for the original 2005 GDP values. A currency conversion factor was also calculated, equal to each economy's 2005 GDP in 2005 PPP US dollars divided by the economy's original ERIA 2005 GDP at market exchange rates. Each economy's 2030 GDP was then multiplied by this conversion factor to obtain a projected 2030 GDP in 2005 PPP US dollars. Note that this currency conversion did not change either the 2005–2030 percentage growth of each economy's GDP nor the individual economy improvements in energy intensity. It did, however, dramatically change the absolute energy intensities (energy/GDP) for some economies.

In Table 2, GDP's are much better aligned with energy use, with China and other fast-growing economies making a much larger contribution to total GDP compared to Table 1. As a result, total energy intensity improvement is much larger: 32.5% for the ASEAN+6 economies that are also members of APEC and 37.2% for all ASEAN+6 economies. A similar recalculation of ERIA's Alternative Policy Scenario (APS) would give a 2005–2030 primary energy intensity improvement of 44.3% for the ASEAN+6 economies that are also members of APEC and 48.8% for all ASEAN+6 economies. These results are generally consistent with the results of the other models discussed under Lesson #1.

Tables 1 and 2 demonstrate in a practical way why PPP is the superior approach for calculating aggregate energy intensity improvements across economies for use in policy analysis—as noted, the GDP's calculated using PPP are much more closely aligned with energy use than the GDP's calculated using exchange rates. But there are good theoretical reasons to favor PPP as well.

In fact, there has been much discussion in the literature on the merits of using PPP vs. exchange rates in multi-economy modeling (see Van Vuuren and Alfsen, 2006, for a literature review). Much of this debate is well beyond the scope of this paper. Our concern here is simply with how to best aggregate the results of individual economy models to produce an aggregate energy intensity

[11] World Bank (2008, pp. 23–28). This publication did not provide PPP figures for Myanmar, so Myanmar's GDP values in Table 2 were left unchanged.

Table 1
Original ERIA business-as-usual primary energy intensity improvement results by economy[a].

	2005 GDP (billion 2000 US$)	2005 Energy (mtoe)	2005 Energy/GDP	2030 GDP (billion 2000 US$)	2030 Energy (mtoe)	2030 Energy/GDP	2005–2030 Improvement (%)
APEC members							
Australia	468.4	122.0	0.260	898.4	184.0	0.205	−21.4
Brunei	6.6	2.6	0.394	16.8	5.4	0.321	−18.4
China	1893.0	1505.2	0.795	11,996.0	5011.6	0.418	−47.5
Indonesia	207.9	135.1	0.650	937.3	544.5	0.581	−10.6
Japan	4980.0	517.8	0.104	6,984.0	503.5	0.072	−30.7
Korea	639.6	218.5	0.342	1,449.6	323.7	0.223	−34.6
Malaysia	112.5	62.8	0.558	347.1	120.1	0.346	−38.0
New Zealand	61.7	15.2	0.246	100.9	18.5	0.183	−25.6
Philippines	94.5	33.8	0.358	395.4	120.4	0.305	−14.9
Singapore	114.7	27.7	0.241	296.4	45.1	0.152	−37.0
Thailand	157.0	98.9	0.630	419.9	247.7	0.590	−6.4
Viet Nam	44.8	27.3	0.609	280.1	156.8	0.560	−8.1
Total—APEC	**8780.7**	**2766.9**	**0.315**	**24,121.9**	**7281.3**	**0.302**	**−4.2**
Non-APEC members							
Cambodia	5.7	1.3	0.228	35.0	8.6	0.246	7.7
India	645.0	379.9	0.589	4,513.0	1346.9	0.298	−49.3
Lao PDR	2.4	0.5	0.208	15.0	6.2	0.413	98.4
Myanmar	13.3	5.8	0.436	131.1	22.4	0.171	−60.8
Total—all	**9447.1**	**3154.4**	**0.334**	**28,816.0**	**8665.4**	**0.301**	**−9.9**

[a] Results were calculated from the primary energy and GDP figures given in Annex 1 to Kimura (2010). In some cases, the figures differ slightly from the figures given in Table 5 of that report due to rounding errors.

Table 2
ERIA business-as-usual primary energy intensity improvement results by economy recalculated using 2005 purchasing power parities (PPP).

APEC members	2005 GDP billion 2005 PPP US$	2005 Energy (mtoe)	2005 Energy/GDP	2030 GDP billion 2005 PPP US$	2030 Energy (mtoe)	2030 Energy/GDP	2005–2030 Improvement (%)
Australia	671.5	122.0	0.182	1,287.9	184.0	0.143	−21.4
Brunei	17.6	2.6	0.148	44.8	5.4	0.121	−18.4
China	5,333.2	1505.2	0.282	33,796.7	5011.6	0.148	−47.5
Indonesia	707.9	135.1	0.191	3,191.5	544.5	0.171	−10.6
Japan	3,870.3	517.8	0.134	5,427.7	503.5	0.093	−30.7
Korea	1,027.4	218.5	0.213	2,328.5	323.7	0.139	−34.6
Malaysia	299.6	62.8	0.210	924.4	120.1	0.130	−38.0
New Zealand	100.7	15.2	0.151	164.7	18.5	0.112	−25.6
Philippines	250.0	33.8	0.135	1,046.0	120.4	0.115	−14.9
Singapore	180.1	27.7	0.154	465.4	45.1	0.097	−37.0
Thailand	444.9	98.9	0.222	1,189.9	247.7	0.208	−6.4
Viet Nam	178.1	27.3	0.153	1,113.5	156.8	0.141	−8.1
Total—APEC	**13,081.3**	**2766.9**	**0.212**	**50,981.1**	**7281.3**	**0.143**	**−32.5**
Non-APEC members							
Cambodia	20.1	1.3	0.065	123.4	8.6	0.070	7.7
India	2,341.0	379.9	0.162	16,379.7	1346.9	0.082	−49.3
Lao PDR	10.2	0.5	0.049	63.8	6.2	0.097	98.4
Myanmar	13.3	5.8	0.436	131.1	22.4	0.171	−60.8
Total—all	**15,465.9**	**3154.4**	**0.204**	**67,679.1**	**8665.4**	**0.128**	**−37.2**

indicator, not how to build aggregated models of multiple economies. Nevertheless, the conclusions from the literature are relevant. And the conclusions seem generally to favor using PPP's when one wishes to compare income levels between economies.

For example, the IPCC's Fourth Assessment Report, Working Group 3: Mitigation of Climate Change (Fisher et al., 2007 Section 3.2.1.4) concluded that:

> On the question of whether PPP or MER [market exchange rates] should be employed in economic scenarios, the general recommendations are to use PPP where practical. This is certainly necessary when comparisons of income levels across regions are of concern ….

Nordhaus (2007, pp. 351–352) puts it in stronger terms:

> The basic answer is clear: In principle, PPP measures are superior to MER measures for representing relative incomes and outputs …. It should be emphasized that the use of MER is not a fine technical detail. Incomes estimated at MER are fundamentally wrong ….

More precisely, Nordhaus argues (see his Fig. 3) that the best approach is to use PPP values to establish the GDPs of various countries for a single base year, then use national accounts growth rates of real GDP for each economy to extrapolate country data forward and backward in time. He calls this the "Superlative PPP" technique. This is the approach used here in Table 2.

A good short summary as to why PPP is superior is offered by Castles and Henderson (2005). They argue that the PPP approach can be thought of as facilitating cross-economy comparisons of GDP in the much same manner that converting nominal GDP to real GDP facilitates time series comparisons of GDP for a single economy. In order to compare GDP over time, one must adjust for changes in price level over time. Similarly, to compare the 'real' GDPs of various economies, one must adjust for the differences in the price level between the economies, which is what PPP does.

Market exchange rates, on the other hand, have no necessary relationship to the 'real' value of an economy's GDP—that is, how much it will buy locally. The PPP approach ensures that if two economies have the same physical outputs, they will have the same GDP, whereas market exchange rates provide no such assurance. Since it is this real GDP that should drive to energy demand, it is clear why economy GDPs and energy demands are much more closely related in Table 2 than in Table 1.

The fact that the market exchange rates used in Table 1 result in understatement of the GDP of China relative to Japan and to understate energy intensity improvement is probably a robust result. The "Harrod–Balassa–Samuelson effect" hypothesizes that GDPs calculated using market exchange rates will systematically understate the GDPs of low-income economies (Nordhaus, 2007; Suehiro, 2008). The literature on the Harrod–Balassa–Samuelson effect is reviewed in Tica and Družić (2006). To the extent that low-income economies tend to have the fastest growing GDPs, using market exchange rates to calculate energy intensities will tend to understate regional GDP growth and thus downward-bias projections of aggregate future energy intensity improvement.

A practical reason to favor energy intensities calculated using PPP values in policy analysis is that market exchange rates can fluctuate dramatically over time. Even if the exchange rate for a single base year is applied to all years, as in Table 1, energy intensities based on market exchange rates will depend heavily on the base year selected. This will not be true of energy intensities based on PPP. PPP conversion rates for any two economies should, in principle, change over time only in response to changes in their relative levels of inflation, as measured by their GDP deflators. Of course, in the real world, there will always be some data inconsistencies, but these are generally small (see Nordhaus, 2007, p. 357).

An objection sometimes raised to using PPP rather than market exchange rates is that PPP's must be estimated based on surveys, whereas market exchange rates are always precisely known market values. While this is true, Nordhaus (2007) notes, "in this area it is better to be imprecisely right than precisely wrong".

For all these reasons, the EWG concluded that the PPP approach should be used (APEC Energy Working Group, 2011).

5. Conclusion

This paper has highlighted three significant lessons related to energy intensity calculations in the analysis of the APEC energy intensity improvement goal. These lessons may be of interest to anyone who is studying international trends in energy efficiency improvement, or who is seeking to define international indicators of energy efficiency improvement. The three lessons are as follows:

Lesson #1—Energy intensity improvement is happening surprisingly quickly, but not quickly enough to meet the world's energy challenges. Large reductions in energy intensity, on the order of 35–40%, can be expected between 2005 and 2030. However, because of expected rapid economic growth, these improvements in energy intensity will not stop the growth of energy demand, with its associated threats to the environment and the stability of the world economy.

Lesson #2—It is difficult to find a definition of energy intensity that can make it suitable for use as an indicator of regional energy efficiency. Energy intensity, if calculated based on primary energy demand using the IEA/Eurostat methodology, will increase (get worse) if an economy uses more nuclear and geothermal electricity generation. Energy intensity, if calculated based on final energy demand, will not reflect improvements in electricity generation efficiency at all.

Lesson #3—Whether the GDP's of individual economies are converted to common currency using market exchange rates or purchasing power parity (PPP) can dramatically change the energy intensity improvement calculations. The literature suggests that PPP is the more correct approach because it is the actual purchasing power of each GDP that will drive an economy's energy use. Energy intensity improvement for a group of economies will typically be downward biased if calculated using market exchange rates rather than purchasing power parities. Because of exchange rate fluctuations, energy intensities calculated using PPP's will also be less dependent on the base year selected than energy intensities calculated using market exchange rates.

Although the lessons discussed here relate specifically to the 21 APEC member economies, it may be hypothesized that similar lessons would apply to the entire world and to other regional groupings of economies. Further research is needed to verify this hypothesis.

References

Adams, J., 2012, E-mail to the Author Dated 17 December, 2012.

APEC, 2007A. Darwin Declaration on: Achieving Energy Security and Sustainable Development Through Efficiency, Conservation and Diversity. ⟨http://www.apec.org/Meeting-Papers/Ministerial-Statements/Energy/2007_energy.aspx⟩.

APEC, 2007B. Sydney APEC Leaders' Declaration on Climate Change, Energy Security and Clean Development. ⟨http://www.apec.org/Meeting-Papers/Leaders-Declarations/2007/2007_aelm/aelm_climatechange.aspx⟩.

APEC, 2010A. "APEC at a Glance" Brochure. ⟨http://publications.apec.org/publication-detail.php?pub_id=1077⟩.

APEC, 2010B. Fukui Declaration—Low Carbon Paths to Energy Security: Cooperative Energy Solutions for a Sustainable APEC. ⟨http://www.apec.org/Meeting-Papers/Ministerial-Statements/Energy/2010_energy.aspx⟩.

APEC, 2011. The Honolulu Declaration—Toward a Seamless Regional Economy. ⟨http://www.apec.org/Meeting-Papers/Leaders-Declarations/2011/2011_aelm.aspx⟩.

APEC, 2013A. Mission Statement. ⟨http://www.apec.org/About-Us/About-APEC/Mission-Statement.aspx⟩.

APEC, 2013B, APEC Website Frequently Asked Questions Page, ⟨http://www.apec.org/FAQ.aspx⟩.

APEC Energy Working Group, 2011. Statement Regarding the APEC-Wide Energy Intensity Reduction Goal—EWG Recommendation to Senior Officials. ⟨http://aimp.apec.org/Documents/2011/SOM/CSOM/11_csom_003.pdf⟩.

APERC, 2006, APEC Energy Demand and Supply Outlook 2006, ⟨http://aperc.ieej.or.jp/publications/reports/outlook.php⟩.

APERC, 2009. APEC Energy Demand and Supply Outlook 4th Edition. ⟨http://aperc.ieej.or.jp/publications/reports/outlook.php⟩.

APERC, 2010. Pathways to Energy Sustainability; Measuring APEC Progress in Promoting Economic Growth, Energy Security, and Environmental Protection. ⟨http://aperc.ieej.or.jp/publications/reports/other_reports.php⟩.

BP, 2011. BP Statistical Review of World Energy 2011. ⟨http://www.bp.com//statisticalreview⟩.

Castles, I., Henderson, D., 2005. International comparisons of GDP: issues of theory and practice. World Economics 6, 55–85.

Connaughton, J., 2012. Interview with the Author, 14 July 2012.

Fisher, B.S., Nakicenovic, N., Alfsen, K., Corfee Morlot, J., de la Chesnaye, F., Hourcade, J-Ch., Jiang, K., Kainuma, M., La Rovere, E., Matysek, A., Rana, A., Riahi, K., Richels, R., Rose, S., van Vuuren, D., Warren, R., 2007. Issues related to mitigation in the long term context. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York.

Herzog, T., Baumert, K.A., Pershing, J., 2006. Target: Intensity, An Analysis of Greenhouse Gas Intensity Targets. World Resources Institute Report. 〈http://pdf.wri.org/target_intensity.pdf〉.
IEA, Organisation for Economic Co-Operation and Development, and Eurostat, 2004. International Energy Statistics Manual. 〈http://epp.eurostat.ec.europa.eu/cache/ITY_PUBLIC/NRG-2004/EN/NRG-2004-EN.PDF〉.
IEA, 2008. Worldwide Trends in Energy Use and Efficiency: Key Insights from IEA Indicator Analysis. 〈http://www.iea.org/publications/freepublications/publication/Indicators_2008.pdf〉.
IEA, 2009A. World Energy Outlook 2009.
IEA, 2011A. Energy Balances of Non-OECD Countries 2011.
IEA, 2011B. Energy Balances of OECD Countries 2011.
IEA, 2012. World Energy Outlook 2012.
IHS, 2012, IHS Global Insight World Industry Service Database, Downloaded 9 May 2012.
IPCC, 2007. Summary for policymakers. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York.
Kimura, S. (Ed.), 2010. Analysis of Energy Saving Potential in East Asia Region. ERIA Research Project Report 2010, Number 21. 〈http://www.eria.org/publications/research_project_reports/analysis-on-energy-saving-potential-in-east-asia-1.html〉.
Ma, C., Stern, D.I., 2008. China's changing energy intensity trend: a decomposition analysis. Energy Economics 30, 1037–1053.
Macknick, J., 2009. Energy and Carbon Dioxide Emission Data Uncertainties. International Institute for Applies Systems Analysis Interim Report IR-09-032. Laxenburg, Austria.
Moomaw, W., Burgherr, P., Heath, G., Lenzen, M., Nyboer, J., Verbruggen, A., 2011. Annex II: methodology. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C. (Eds.), IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press, Cambridge and New York.
Nakicenovic, N., 1997. Freeing energy from carbon. In: Ausubel, J.H., Langford, H.D. (Eds.), Technological Trajectories and the Human Environment. National Academy Press, Washington, DC, pp. 74–88.
Nordhaus, W., 2007. Alternative measures of output in global economic-environmental models: purchasing power parity or market exchange rates? Energy Economics 29, 349–372.
Percebois, J., 1979. Is the concept of energy intensity meaningful? Energy Economics. 1, 148–155.
Pizer, W., 2005. The Case for Intensity Targets. Resources for the Future Discussion Paper 05-02. 〈http://www.rff.org/news/features/documents/rff-dp-05-02.pdf〉.
Price, L., Levine, M., Zhou, N., Fridley, D., Aden, N., Lu, H., McNeil, M., Zheng, N., Quin, Y., Yowargana, P., 2011. Assessment of China's energy-saving and emission-reduction accomplishments and opportunities during the 11th Five Year Plan. Energy Policy 39, 2165–2178.
Samuelson, R.D., 2011. APEC's Potential for Reducing Energy Intensity: The Research Evidence (PowerPoint Presentation), APERC Workshop at EWG 41, 9 May 2011, 〈http://apecenergy.tier.org.tw/database/db/ewg41/PresentationMaterialsAPERC/APERC_Workshop/EWG41_Workshop_Energy_Intensity_Research_20110505.pdf〉.
Schipper, L., Haas, R., 1997. The political relevance of energy and CO_2 indicators—an introduction. Energy Policy 25, 639–649.
Suehiro, S., 2008. Energy intensity as an index of energy conservation: problems in international comparison of energy intensity of GDP and estimate using sector-based approach. IEEJ Energy Journal 7, 58–71 〈http://eneken.ieej.or.jp/en/data/pdf/400.pdf〉.
Tica, J., Družić, I., 2006. The Harrod–Balassa–Samuelson Effect: A Survey of Empirical Evidence. University of Zagreb Faculty of Economics and Business Working Paper No. 06-07, Zagreb, Croatia. 〈http://web.efzg.hr/RePEc/pdf/Clanak%2006-07.pdf〉.
United Nations Statistics, 2012. Energy Balances and Electricity Profiles—Concepts and Definitions. 〈http://unstats.un.org/unsd/energy/balance/concepts.htm〉.
United States Energy Information Administration, 2009. International Energy Outlook 2009. 〈http://www.eia.gov/forecasts/archive/ieo09/index.html〉.
United States Energy Information Administration, 2011. Annual Energy Review 2011. 〈http://www.eia.gov/totalenergy/data/annual/〉.
Van Vuuren, D.P., Alfsen, K.H., 2006. PPP versus MER: searching for answers in a multi-dimensional debate. Climatic Change 75, 47–57.
Wing, I.S., Ellerman, A.D., Song, J., 2006. Absolute vs. intensity limits for CO_2 emission control: performance under uncertainty. In: Tulkens, H., Guesnerie, R. (Eds.), The Design of Climate Policy. MIT Press, pp. 221–252.
Wing, I.S., 2008. Explaining the declining energy intensity of the U.S. economy. Resource and Energy Economics 30, 21–49.
World Bank, 2008. Global Purchasing Power Parities and Real Expenditures: 2005 International Comparison Program. 〈http://siteresources.worldbank.org/ICPINT/Resources/icp-final.pdf〉.