Net Energy Analysis – the Fundamental (but Unexamined) Issue in the Climate Change Debate

Adjunct Professor, School of Sustainability,
Murdoch University
jedbarker@iinet.net.au

Summary

The main objective of greenhouse gas abatement strategies is to reduce carbon dioxide (CO2) emissions by reducing carbon-based energy use by one or all of three ways:

- by use of more efficient carbon-burning systems;
- by implementing energy conservation methods and technologies; and
- by shifting to non-carbon-based fuels, such as "renewables" (eg, wind, solar, geothermal) or nuclear.

But, as more than 90% of all energy being used now is carbon-based, the manufacture and operation of the present generation of these new and complex "alternative" technologies will inevitably require the use of materials and services that are mainly carbon-based. Therefore, a basic question regarding *sustainability* arises:

> Will the new energy sources and conservation systems produce or save more energy from the wind, sun, earth and nuclear fuels than the carbon-based energy that they consume in their production, operation and eventual decommissioning?

This question is usually framed as:

> "What is the EROEI- *E*nergy *R*eturn *o*n *E*nergy *I*nvested- of a particular energy source?".

The question is quite simple, but deriving credible answers is difficult. Further, although the direct *process energy* embodied in some materials has been analysed recently, very little has been done about "life-cycle" and "value chain" net energy analysis (NEA) that together give a comprehensive answer to the question. In the meantime, many claims about EROEI are being made by proponents and opponents of each energy source- claims that range from the plausible to the absurd, but none of which is based on data that bears scientific scrutiny.

NEA is important for two reasons: First, even if a globally enforced Emissions Trading Scheme (ETS) were introduced, wrong choices could be made as time-lags may allow the major point of energy consumption to inadvertently shift along the value chain with no net useful effect. Secondly, in the absence of such an ETS, Direct

Action Strategies will certainly require NEA, otherwise "value chain energy shifting" will become endemic, given the community's- and industry's- propensity to "game" any loose policy into a "free-rider" scam.

This paper reviews the problem of (NEA), from which EROEI can be derived. Although there is no substitute for a comprehensive "input-output" analysis on a global level that would require research costing millions of dollars, it may be possible to use a "rule of thumb" method that can guide us while this vital work is being performed. This method, called "average energy intensity" (AEI) indicates that our carbon energy use problems will be very hard to solve, even if we have the resolve to tackle them vigorously and that some of the proposed solutions may even be counterproductive.

If the plausibility of this rule-of-thumb method is accepted, the direction of viable strategies can be proposed.

Net Energy Analysis Explained

NEA is really a fairly simple concept- *it is the methodology for measuring the energy involved with the goods that we make and the services that we provide*. It is important, given that we are concerned about global warming due to excess carbon-based energy consumption. Policymakers need to know about relative energy usage so that public policies can discourage those who use too much carbon energy and reward those who use less. We need to know about this concept for our own personal energy-related choices. It is a simple concept, but how do we measure it? How do we know if we are *really* using less energy by driving a "hybrid" car, or installing a photovoltaic (solar cell) electricity supply on our roof, or funding a wind or nuclear electricity generating system? Just because there's no smoke coming out of the car's exhaust or going up the reactor's chimney, it doesn't necessarily mean that less energy is, has, or going to be, used with these oft-claimed global warming solutions. It's a simple concept that's actually complex to resolve and it's been ignored for almost 30 years. The following is a brief explanation.

The first thing we need to understand is that energy is used in everything we do, and its use begins when we start doing something and its use doesn't stop until we stop doing it. That's what we call the *product life cycle*- literally and metaphorically, the product's cradle-to-grave energy implications. By "product" we mean *both* goods *and* services. Energy is involved in design, development, production, use and final disposal of *everything*- with no exceptions. That's easy enough to understand, but surely some parts of the life cycle use trivial amounts of energy? Like design- isn't that just someone sitting at a low-energy computer, looking at a screen and tapping on a keyboard and maybe chatting to a few people? And production- how much energy *does* it take to make a tonne of steel and half a tonne of plastic? And consumption- isn't that the cost of a tank-full of gas and the monthly electricity bill? And disposal- isn't that the fuel required to drive the trash truck 20 km to the dump- somewhat like the idea of "food miles". All of these responses are correct, but they are only a part of the whole story. To complete the explanation, another fairly simple concept needs to be introduced, called *value-chain-analysis*- VCA for short.

With VCA, we have to consider *all* of the energy that is involved with *each* stage of the life cycle of a particular activity. For example, take the design stage of the product- the total energy involved is much more than just the electricity to power the computer. It's also the energy that it took to *make* the computer (spread out over the number of projects it is used for over its life cycle). The calculation must also include the energy to make the equipment that made the equipment- and so on. It also includes a similar proportion of the energy required to make the design laboratory and its maintenance. It's also the energy used by the designer and the support staff when they buy goods and services with their pay; and so on it goes.

We need to be clear about this calculation: It's not just the energy that is put *into* the product- called *process energy*- like baking bread or smelting an ore- it's also the energy that is inevitably consumed *in association with* the design, production, use and disposal of the product- *energy that would not have been used if the product didn't exist*. To use a metaphor, when we are doing things or making or using things it's like we are paddling downstream and measuring all the water running into the creeks that run into the streams that eventually run into a river that we are paddling on. As this issue is very important, but quite complicated, surely it could be resolved by engaging someone to do the necessary calculations and settle the issue? This task was started almost 40 years ago, and then ten years later, the work stopped before it was completed. To round out the explanation, a short review of the background is useful.

A Short History of NEA

NEA actually has quite a long history. It has gone in and out of fashion several times in the past century and seems to become popular in times of financial uncertainty when people lose confidence in the monetary system and look for more fundamental measures of value. During the Great Depression of the 1930s, the Technocracy Movement in the USA advocated that energy should replace dollars as the basic currency. The Technocrats figured that you can't inflate the laws of physics- a megajoule is always a megajoule even if a dollar's value can be eroded by inflation. Unfortunately, the Technocrats also advocated that scientists and engineers run everything, which, unsurprisingly, did not make them or their ideas particularly popular[1]. With the resolution of the Great Depression and the passing of World War 2, energy became cheap and plentiful and general prosperity dimmed enthusiasm for solving uncomfortable problems like NEA.

It wasn't until the so-called "OPEC oil crisis" of 1973, when the price of oil more than tripled and inflation became more than 10% per year, that NEA became a popular area of study again- *popular* in that a significant number of mathematicians, economists, chemists, physicists and engineers were writing NEA programs for supercomputers as their day job. Supercomputers were needed then to identify, estimate, calculate and cross-check myriads of energy rivulets, creeks and streams associated with the economy. These technical people were mostly in universities and national laboratories in the USA and the UK and their salaries were met from government grants and contracts. By the time President Jimmy Carter left office in January 1981, the US renewable energy research budget- mainly for solar energy and energy conservation- was about one billion US dollars (almost double that in today's dollars), with many millions of dollars being spent on NEA. And then- the price of energy dropped and newly-elected President Ronald Reagan decimated the energy research budget[2]- as indicated in Fig 1, below. Symbolically, Reagan also removed the solar water heating panels that Carter had put the roof of the White House. So as the grants and contracts ran out in the early 1980s, the boffins lost interest in NEA and followed the money trail to Reagan's Strategic Defense Initiative (aka Star Wars Project). And there the matter of NEA stayed until recently- the issue was ignored but had not gone away.

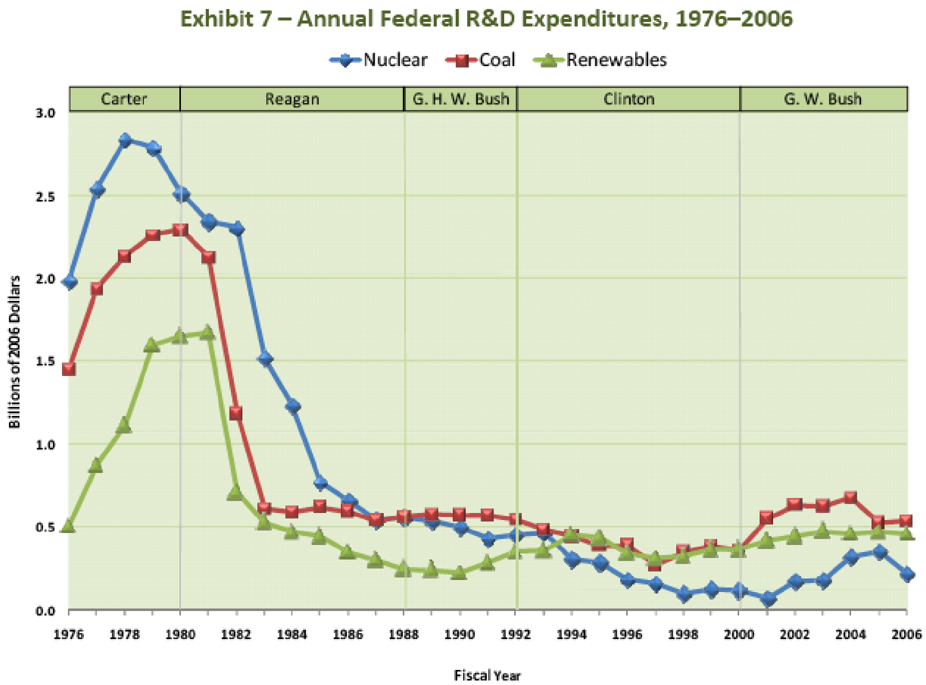


Fig. 1: Annual US Energy R&D Expenditures 1976-2006. (Source: *Analysis of Federal Expenditures for Energy Development.* Report prepared by Management Information Services Inc for the Nuclear Energy Institute, September 2008)

Where Does NEA Stand Today?

A comprehensive review of NEA was published in 2006 called *Life-Cycle Energy Balance and Greenhouse Gas Emissions of Nuclear Energy in Australia*. This 181-page report by ISA, which is mainly a small group of physicists from The University of Sydney, were commissioned by Dr Ziggy Switkowski- who was the Chair of The Australian Nuclear Science and Technology Organisation (ANSTO). Dr Switkowski had been commissioned by the then Commonwealth (Howard) Government to report on the prospects for nuclear power in Australia[3]. The ISA Report is commendable as a very comprehensive review of NEA, although some of its conclusions can be disputed[4]. The important issue for the purposes of this paper is an inspection of its extensive reference list- *it confirms that very few in-depth and impartial studies of NEA have been made since Reagan all-but eliminated research on renewable energy in 1981.*

The few studies undertaken since then have either been reviews of previous work[5], or commissioned by organizations with sectional interests- both pro and con. This work was not cheap or easy 30 years ago: the computer being used to write this article probably has more computing power than the supercomputers in 1980 at the University of Illinois at Urbana, where a lot of NEA work was performed under US Government contracts. It is clear that the analyses were far from complete: For example, according to ISA's review, nuclear fuel fabrication shows a *ten-fold variation* from least to greatest energy requirement in 11 different analyses; reactor construction shows a similar range of results over 35 examples using the available methodologies. Even analyses of the energy embodiment of basic construction materials (such as reinforced steel, stainless steel, copper, aluminium, concrete and cement) display a range of up to four times over the different studies. As the manufacturing processes do not vary widely and the purchase costs are very similar for each process, it is unlikely that these wide variations in energy embodiment do not exist in reality. Nonetheless, that early work was a good start, setting up and trialling new the methodologies, *but we can hardly accept such disparate findings like that as a basis for good decision making*.

Given the acknowledged importance of NEA, one might wonder why a new generation of researchers, equipped with vastly greater computing power than their predecessors in the 'seventies aren't setting about to complete the task. Although there is no ready answer to this question, it is likely that there is insufficient awareness or interest in the issue amongst researchers who have the necessary skills. Further, given the structure of research funding systems and the size of the task, it may be difficult to attract funds against competitors who have immediate commercial backing. As will be explained later, NEA is not quite as important if a global emissions trading scheme (ETS) were adopted. Until the Copenhagen conference, it was widely assumed that ETS would prevail. Since then interest in energy matters has been in a slump, with some parties (such as the Australian Liberal Party) recommending "direct action" programs that tackle particular energy hotspots. In the absence of an ETS, direct action will need to be guided by NEA. As research program funding timeframes are long and uncertain, it is unlikely that concerted effort in resolving NEA issues is going to emerge any time soon.

Simply, nobody seems aware enough or worried enough to pay a new generation of analysts to re-examine NEA. Besides, most of the supercomputers seem to have been allocated to molecular modeling and genomics for Big Pharma, for designing iPods and iPads and cell-phones for Big Telecoms, or for simulating financial innovations for Wall Street. To be fair, a lot of supercomputers are also being used by geophysicists to discover new oil deposits.

NEA Models and the Energy-Money Nexus

Given the unlikelihood of large scale and systematic analysis into NEA in the short term, is there anything that can be done immediately? This paper suggests that there can, but first it is worthwhile to review the progress that was made on NEA in the 70's.

There are essentially three different methodologies that have been employed to try to determine the total energy expended in producing goods and services. They are

- Process Chain Analysis (PCA)
- Input/Output Analysis (I/OA)
- Average Energy Intensity (AEI)

Process Chain Analysis (PCA): PCA essentially looks at the sequence of events that have occurred in producing the item. For example, producing a stainless steel kitchen sink would involve exploration for the minerals involved (say iron, chromium, nickel), mining of these minerals, transporting them from the mine to shipping ports, transport to the smelter, smelting, rolling and treatment, fabrication of the product, transport to warehouses and retail outlets and transport by the kitchen outfitter to the house and finally fitting of the new kitchen sink using drills, saws and screwdrivers. PCA essentially meters the energy used in each of the activities- the fuel used in exploration vehicles, mining blasting, train and ship fuels, smelting gas, coal and electricity and petrol and diesel in distribution vehicles. What is missing from this analysis is the energy that was used in making the exploration vehicles, the haulpak trucks, the railway carriages, ships, smelters and other transport vehicles. Also, it does not take into account the energy involved with the purchases made by people employed along the process chain. For example, the exploration geophysicist might be paid, say $100,000 per year, with which she buys a car, food, clothing and repayments on her house in the suburbs. When she is out in the field the company provides accommodation and food, all of which required energy to produce that is not captured by the "meters" on the cars, trucks, ships and smelters that are more obvious along the chain. Of course, more sophisticated PCA can take these energy expenditures into account and then take into account the energy involved when the brickie, who built the geophysicist's house, spends his money on the usual range of goods and services. The net result of this analysis is that energy trails are "truncated" or simply ignored. Little wonder there is such a wide range of estimates for energy embodiment using this method.

Input/Output Analysis: I/OA recognises that energy is used across all economic activity. For example, the analysis used by the University of Illinois in the 1970s adopted the 426 economic sectors used by the US Dept of Commerce for econometric analysis. and estimated the energy used by each of these sectors. Any good or service could therefore be seen as a combination of activities from these sectors. Essentially, in each case, an amount of energy was assigned to the activity in each sector. Computation of very large matrices of inputs required state of the art supercomputers at that time. The results were mixed and have not been reworked in light of sectoral shifts and significant energy efficiencies that have occurred since the '70s.

Average Energy Intensity (AEI): AEI is at once the simplest, but most contentious methodology. It basically assumes that most goods and services are the result of complex chains and matrices of events that use energy in proportion to the money spent (ie value-added) to that stage. A basic measure for a whole economy is used- the total energy used in the country divided by total dollars spent in the country's economy- ie MJ/$. The same quotient is used for kitchen sinks and ice creams.

Even though there is some argument as to the validity of this method, it is clear that in all three methods there is a strong correlation between the cost of a good or service and the energy consumed by providing it, ie

If it costs more, it is highly likely that more energy is used in it and around it.

This paper proceeds using this assumption.

Does it mean that a $1000 suit takes as much energy to make as a $1000 sheet metal shed? Yes. That's what the models point to. And a $1000 digital camera that weighs 500grams has the same energy implication as a $1000 8kg trail bike? Yes, most likely. And the carbon footprint of those $5/kg organic tomatoes from that little farm just outside of town is greater than those indestructible genetically modified $2/kg luminous red orbs from the other side of the country? Yes again. And what of the "hybrid" car, such as the Prius? A comparable-sized Corolla costs $15,000 less than the Prius, but we are being sold exclusively on the Prius' fuel consumption….. but as stated above- one has to take into account *all* of the value chain and *all* of the life cycle energy uses. *And the money-cost added at each stage of the chain is a close reflection of the energy used to that stage*. Moreover, the life cycle doesn't finish until the worn-out product has been sustainably disposed of- which is pretty costly in the case of toxic chemicals and nuclear power. We can't leave the so-called "negative externalities" of waste and pollution out of the total energy calculation any more.

How can this be the case? Try to think about parallel creeks and streams of money and energy. Both of these flow-systems cover most of the socio-economic landscape. I say *most* because there are free energy inputs from the sun via photosynthesis into plants and keeping us warm and drying our washing and making the wind blow and so on. And we do a lot of things without charging a fee, like time with family and friends and volunteer work. But every time we exchange money, we are recognizing past effort or promised future *effort*- and *effort* is another way of saying *energy* is being consumed. Services are not excluded, as people who render services use their money to buy cars, pay the rent on their offices, buy homes and other material things that take energy to make. Think- we can't all get rich by singing to each other.

Supporting the Case for the (Money/Energy) Nexus

It is hard to argue explicitly about this proposition. At one level it is intuitively obvious, but it can only be verified by measuring the flows in *all* of the streams, which is very tedious. Consider these supporting arguments: For twenty years *The Economist* magazine has been conducting an annual measurement of its "Big Mac Index"[6]. The BMI is a measure of the PPP- the Purchasing Power Parity- across 120 countries that sell McDonalds Big Macs. The PPP is essentially a cross-check on the exchange rate[7]. Why a big Mac? Because the goods and services that go into making it are extensive and reflect the economy as a whole. A Big Mac is more than bread, meat and salad- it is people and buildings and machines and everything else along that whole value-chain that I mentioned before. In a stable economy the price paid for all of these things reflects their total cost for their whole life cycle. The Big Mac Index is very close to more detailed econometrically modeled PPP indexes- that is why *The Economist* continues to use it. Another example: about 30 years ago an old sage told me that it was worth reflecting on the fact that the cost of a man's suit, the market price of an ounce of gold and the average weekly wage were about the same and had been so for many years. As I write, a reasonable quality suit, an ounce of gold and the average weekly wage are all about $1,200-$1,400. Why? For the same reason- each is a microcosm of the whole economy, crossing most streams in the socio-economic landscape. As the money goes, so does the energy. Sound reasonable?

A third example, which may be more convincing: It is well known- even universally accepted, that gold is the best available measure of fundamental wealth- probably because of the reason mentioned above- its production cost is a reflection of our basic productivity. On the other hand, oil prices *seem* to be wildly fluctuating. But when we bring the two together and make a graph of the ratio of the gold price to the oil price, we find that, although it has fluctuated, it has remained around the same value for the past 50 years. Over the last 50 years or so, gold and oil have generally moved together in terms of price, with a positive price correlation of over 80%. During this time, the price of oil in gold ounces has averaged about 15 barrels per ounce. That is, an ounce of gold has been able to buy about 15 barrels of oil since 1958. (In the past several years there has been a divergence to about 7:1 ($150/barrel), which now appears to have been a market "bubble" as the price at time of writing (27/311) is 14:1. That doesn't *prove* the connection, but strongly suggests that money and energy are highly correlated.

So- we knew that time was money, now we're told that energy is money- and vice versa. Well, we're actually saying that the amount of energy consumed *correlates* closely with the amount of money spent. All expenditures have an energy consumption consequence. We can't paddle down the river if there's no water in it.

Getting Down to Numbers

OK- how much energy? We can easily derive the approximate energy correlation figure: It's called Average Energy Intensity- or AEI. AEI- which is calculated on a national basis by dividing *all* the energy expended by *all* the money spent in the nation- to give a figure of megajoules per dollar. It's no surprise that the values for all of the OECD countries are very similar- about 10 megajoules per US dollar (10MJ/$)- given that their production systems are also similar. The value for non-OECD countries is about 15MJ/$- suggesting less efficient production systems[8].

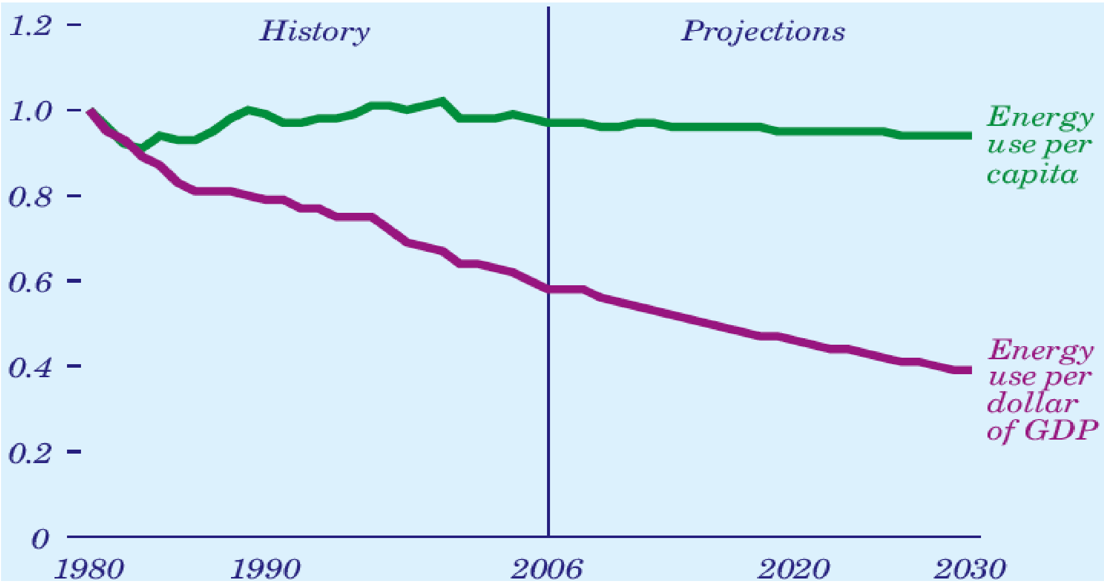


Fig2: Energy use per capita (Energy Intensity) and per dollar of gross domestic product, 1980-2030 (index, 1980 = 1) (Source: US Energy Information Agency World Energy Outlook 2008)[9].

Despite the US Energy Information Administration's (EIA) smooth graphs on AEI (Fig.2), there must be a bit of latitude with currency fluctuations. Nonetheless, the figures are robust and the important thing is that money and energy are inextricably connected. The good news from these graphs is that AEI show a decline over time- we are getting more efficient in our energy use. The bad news is that our GNP and GNP-per-person are increasing even faster- meaning that the *total* energy use is increasing, along with the associated greenhouse gases.

Some Examples

What can we infer from this rather extraordinary conclusion about the nexus between money and energy? We'll use a few examples. First, take the Prius vs Corolla debate. I mention this because there seems to be a widespread assumption that because so-called hybrid cars use less petrol, then they are the answer to the transportation part of the energy question. You will see from the following that the situation is really quite different.

To start- the basic Prius costs about $15,000 more than the basic Corolla, and has almost twice the fuel efficiency. For the average 15,000km/yr driver it would take about 20 years of savings at the bowser to make up the difference in purchase price. But that's not the whole story. The NRMA of NSW publishes annual lists of the total life cycle costs of buying and maintaining many kinds of motor vehicles, including

Corollas and Prius[10]. By their calculations, the basic Prius costs about $200 per week, all up, compared to about $150 per week for a basic Corolla. The life cycle was taken to be all of the estimated costs over five years for fuel, tyres, licence, insurance, repair, servicing, depreciation, etc. So over five years the Prius would cost about $13,000 more to have and keep than a Corolla. As to what happens for the next 15 years is anyone's guess, but it is hardly likely that a complicated Prius is going to cost less to run than a Corolla. In many cases, the car owner will trade in for a new model, therefore keeping to a five-year effective life cycle.

So the Prius *never* catches up *financially* with the Corolla and, according to AEI theory, it will *never* catch up *energetically*, either. What happened? Well, simply, the complexity of the Prius means that more people spent more time with more buildings and equipment *making* the Prius and consuming more energy as they worked and lived. Maintaining the Prius has a similar story- the only difference is that less energy is consumed while the Prius is on the road. It may be hard to believe, but it's even harder to disprove. It seems that the only solution to our energy consumption associated with transport is to have cars with a lower *total* value chain and *total* life cycle financial cost. Because the purchase cost of a car is such a large proportion of the total cost, and therefore a large proportion of the associated energy, *it is essential that cars are cheaper to buy, as well as more economical to run.* "Cheaper" doesn't mean government subsidies, as they just mask the real cost. I will discuss subsidies again below.

This example also highlights the fallacies of the recent Australian debate on luxury car taxes. The Prius is a nice car, but at $40,000 is hardly a luxury car. A Lexus hybrid, for example, at $100,000 to $150,000 that has about the same fuel consumption as a Corolla is hardly going to entail the same total life cycle and value chain energy consumption as a car that costs one quarter or one sixth as much to have and hold. In fact, by this analysis, the ownership of the more expensive car is likely to involve about four to six times the energy than the cheaper car. That's not a good feeling!

Food Miles

While we're at it, let's talk about those tomatoes. A lot has been said and argued about the virtues of buying locally grown food, with the focus of the debate being on the transport costs from farm gate to plate- the so-called "food-miles" debate. Most certainly, other things being equal, food produced locally will involve less transport energy than food grown on the other side of the country or the world. But other things aren't necessarily, or usually, equal. It is possible that food produced by dollar-a-day farmers on large farms in China that is shipped by the container-load each day, might take less energy per kg along its value chain than an edge-of-town organic farmer with half a hectare, taking two boxes of veges to the growers market on Fridays in the back of his ute. There are two big factors counting against the local farmer- economies of scale and cheap labour. Economies of scale are just that- the more that is produced, the smaller fixed costs per unit will be, so long as you're producing at close to full capacity. And along with lower costs, we assert, is lower per unit energy consumption. Cheap labour means that the workers aren't taking home lots of money to buy things that take energy to make- after work they are sitting in their small huts eating small meals then going to bed when the sunlight fades. No giant plasma TVs, no McMansions, no Corollas, let alone Priuses. So if we don't mind social inequality, then the Chinese are doing us both a financial favour and saving the planet from excess energy consumption. These are very uncomfortable thoughts.

While the "food miles" debate is a minor distraction, it does embody a lot of the principles that apply to the "biofuels" initiatives. The enthusiasm in the USA for fermenting corn to make liquid transport fuels has been driven by two factors- Brazil's success with sugarcane alcohol and the power of the already-heavily-subsidized US corn growers. Alcohol is widely used in Brazil and sells for as little as half the cost of gasoline. This can be done because the sugarcane is grown on fertile soil with plentiful rain and labour costs are low. Further, they have been researching this area for many years. None of these factors pertain in the US, where corn-alcohol costs much more than gasoline. Higher costs because the cost of inputs is higher. And as the cost of gasoline increases, the input costs will also increase. Subsidies are fine if they enable new systems to be developed and trialled and given a level playing field in new markets. The problem with corn-alcohol is that the energy balances will never work on those soils in that climate with those labour costs. And the same situation pertains in Australia as in the USA.

NEA and Electricity Generation

So far, I have only looked at goods and services that *consume* energy. What about the net energy of systems that *produce* energy in the form of electricity? The outcomes are just as unsettling. If we first consider a life-cycle-and-value-chain approach, then we see three major stages (see Fig.3 for an example). The first- the design and construction stage, which is pure energy input. At the operational stage, we have energy input for fuel and maintenance and energy output, then at the decommissioning stage we return to pure energy input. Only renewables, by definition, have no fuel input at the operational stage- others have coal, gas, uranium or biofuels, and all have operational maintenance. Unfortunately, much of the debate on energy supplies has focused almost exclusively on the energy *production* stage, ignoring the energy costs of design and construction and later decommissioning.

As we have said, AEI takes into account *all* the money spent or committed at *all* stages. What we do know is that on a pure financial basis, nuclear and wind-power have similar costs per unit of produced energy and coal and gas are a bit cheaper, but not actually much cheaper. Wind and nuclear are more capital intensive but coal and gas have much higher fuel and maintenance costs. What can we make of this? Simply, it means that we finish using about the same amount of energy to produce our electricity, no matter which energy source we chose.

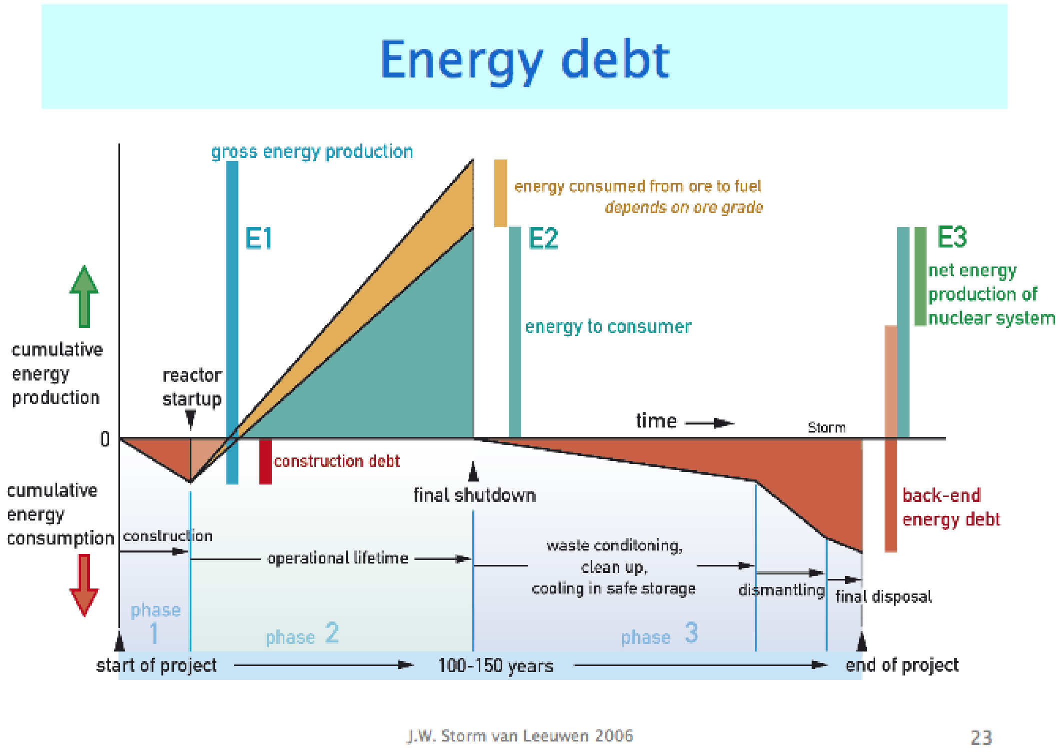


Fig. 3. Energy usage across the life cycle of a Nuclear power station. Similar graphs can be drawn for all power generators, with differing energy consumption and production at each stage. (Source: Storm van Leeuwen 2006[11])

The most worrying part of this analysis is that at present, almost all of the energy inputs at all three stages to these energy sources are fossil fuel. I say *almost*, because a very small component might be from nuclear or hydro- at most about 6%.

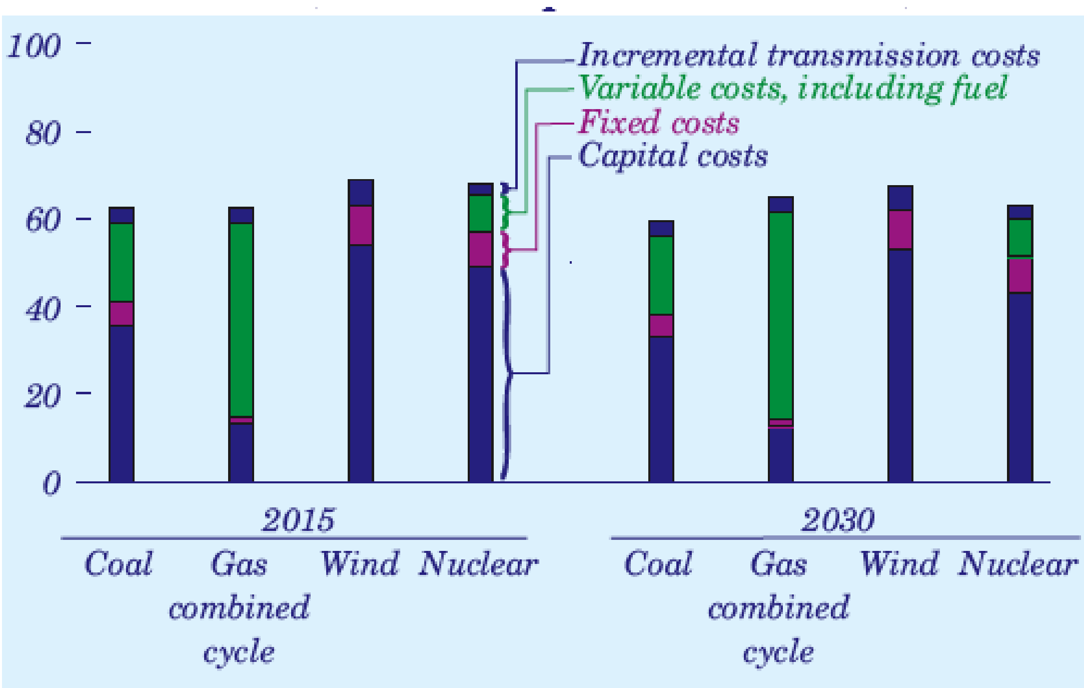


Fig 4: Estimated levelized electricity costs for new plants, 2015 and 2030 (2006 mills per kilowatthour) (Source: US Energy Information Agency World Energy Outlook 2008)

There is a popular thought experiment that says why not put a ring-lock fence around the electricity source and use the electricity to reproduce the next generation of power stations? That is, to use the electricity to make the concrete, steel, turbines and other component materials of the power station and, of course, all the office buildings and factories that make the component materials. Will it work? Probably not. Why? Because our power stations are not just made from goods and services that just use electricity. Concrete and steel, which are a large part of the materials, use large amounts of coal and gas, which are much cheaper than electricity (about 5-10 times cheaper)[12]. Over all the economy, about one-third of the total energy goes to making electricity.

In fact (or perhaps in well-founded theory), *it is likely that all of our electricity supplies consume more energy in their construction, maintenance and disposal than they produce*. This may seem absurd, but consider this: the cost per unit of electricity is usually based on an assessment, by the power authorities, of all of the costs involved over the life cycle of the station, which usually involves borrowing money on a 25-year loan. That is, the power station will repay the money borrowed to design, build and operate it over 25 years. That implies a very narrow margin – about 2.5% between inputs and outputs. If all of the inputs were based exclusively on electricity, the costs would go up significantly- certainly much more than 2.5%. *A power station is really a way of turning an inconvenient source of energy, such as coal into a convenient source of energy- electricity*. There is no rule of the universe that says that the amount of electric energy produced should be more than the total life cycle energy inputs for construction, maintenance and disposal from all sources. So long as we have oil and gas and coal to do most of the energy "heavy lifting" then we can (energetically) afford to have net-loss electricity. To help us think through this apparently paradoxical situation, let's take an extreme example- think of a solar-powered resource-mapping satellite, where solar cells are very expensive, so the cost per unit of electricity is very high. But the cost is justified, because the satellite identifies new sources of coal, oil and gas, which are used, ultimately, to make the solar cells of the next generation of satellite as well as fuel our cars, make our steel and so on. Earth-bound electricity generators aren't quite as expensive, but the principle is the same. They are a kind of a "loss-leader". Think about it.

Some (Present) Solar Myths

What else? We can say with some confidence that photovoltaic electricity, at *its current cost* of at least 25 cents/kWh[13]- about two to three times fossil fuel-based electricity- is unlikely to be a net-energy producer. That is not to discourage its use, as there are now many off-grid situations where 25cents/kWh is a good price. But unless, and until, the price is less than about 10cents/kWh, it will be energy net-negative. Subsidies will increase demand, and thereby drive down costs, but until then, it only spreads the financial and energy costs over everybody. It would make more sense to seek out applications where it is cost effective now, rather than confuse suburban people with arbitrary and artificial prices.

A similar criticism can be leveled at much of passive solar building design. Certainly, it is possible to design a house with little extra cost that takes less energy to heat and cool with windows placed so that they capture the winter sun and exclude the summer sun. However, we must bear in mind that the major energy cost of a house is embodied *in the house itself*. This is like our Prius/Corolla issue discussed previously. For example, comfort energy in temperate Australia is about $1,000 per year for heating and $500 for cooling. This is about 0.5% of the cost of an average house and even less for a McMansion. As with the automotive example, *the best way to reduce the expenditure of energy associated with housing is to have cheaper houses*. A similar argument applies to offices, where it is now assumed that so long as there is plenty of vegetation and natural lighting, the per-square-metre construction cost is irrelevant. I don't think so.

…And Some Nuclear Myths

As I have given solar some specific and perhaps discomfiting attention, I shall be even-handedly specific and discomfiting about nuclear energy-derived electricity. There are two major issues to consider with nuclear- *total life cycle cost* and *sustainability*.

There has been many claims that the real cost of nuclear power stations has been masked by unaccounted government subsidies. Reference 2, published in September 2008, provides extensive details of all US Government support for all energy sources and energy conservation since 1950. In summary, total nuclear subsidies amount to about $US80 billion (2006 US$), with a resultant 100 GW of power output. Much of this expenditure was for R&D. With an estimated replacement cost of $2 billion/GW, this could be interpreted as a 40% subsidy, to date. As much of this expenditure occurred before 1985, and no new reactors have been commissioned since the early 1990s, it is hard to estimate the level of support that would be required to sustain the nuclear industry. Present claims that disposal only requires about 5% of total life cycle costs do not take into account the fact that guaranteed safe disposal is yet to be achieved. Given that nuclear electricity amounts to only 6% of total US energy (20% of electricity), nuclear power stations, like solar panels, are mainly "congealed fossil fuel", with a life cycle energy implication of about 50% more than fossil fuel-based power stations. This means, paradoxically, that less fossil fuels would be expended by making coal and gas- powered electricity than nuclear.

Perhaps an even bigger issue is the *sustainability* of the nuclear power industry. Present uranium reserves up to $130/kg are about 5 million tonnes. According to the Nuclear Energy Agency[14] "based on the 2006 nuclear electricity generation rate and current technology, the identified resource base will remain sufficient for 100 years". Present consumption levels (given by NEA) of 66,000 tonnes/year would mean about 75 years of supply. However, if nuclear energy is to become a more significant energy source, then this time period shrinks proportionally. For example, at 20% of energy supplies (about 50% of all present electricity supplies), the reserves will last only about 25-30 years- which is about the lifetime of a nuclear reactor. The Nuclear Energy Agency is confident that ".. undiscovered resources, i.e. uranium deposits that can be expected to be found based on the geological characteristics of already discovered resources, have also risen to 10.5 million tonnes." This might stretch the time horizon out to 50-70 years. However, as the price increases, so does the energy involved in mining and refining, which reduces the net energy available for other purposes. As discussed above, most of this mining energy is presently fossil fuel. As the cost of fossil fuel increases and as the cost of uranium increases and the proportion of nuclear power increases, the price of nuclear electricity will also increase. These issues have not been thoroughly exposed or debated to date[15].

NEA and the ETS Debate

In principle, an emissions trading scheme (ETS) could eliminate the need to consider net energy analysis. If emissions are capped by regulation and the market then trades the limited rights, then emission levels cannot increase. As the government progressively reduces rights, the emissions must decrease correspondingly. However, this scheme will only work if all suppliers of goods and services that involve fossil fuel use are included in the scheme. For example, "hybrid" cars purchased in Australia might reduce local emissions, but if the cars are made in a non-complying country, the major energy expenditure will simply be re-located from the bowser to the manufacturer, ie back along the life cycle. Similarly, if sectors of the energy use are exempt from emissions caps, then emissions reductions will be weakened by the extent that these sectors contribute to the GNP. For example, transport accounts for about one-third of Australia's energy consumption and there has been intense lobbying for its exemption from an ETS. The effectiveness of the ETS would be reduced by at least this proportion. While a universal cap would, by definition halt the *rise*, the likelihood of an ETS actually achieving *reductions* will depend on purchasers of goods choosing lower life cycle emitters.

The Garnaut Report[16] has recommended that 20%, or $3 billion/year of the carbon tax should be allocated to emissions reduction R&D. This would amount to about 20% of Australia's present R&D budget. Although R&D targeted specifically to efficiency may be more effective than R&D overall, we should note that our present R&D levels accompany a 1% per year improvement in energy intensity- or productivity. On the face of it, an extra $3 billion might improve productivity by about 0.25% per year, with a similar improvement in energy intensity.

Some Conclusions

I could go on with examples, but the intention of this paper is only to illustrate how the idea of how NEA works. Where does this leave us? What can we do? To start, one should adopt lower total-life-cycle-*cost* options when purchasing goods and services. This applies to cars, houses, fridges- whatever. It's no point having a five-star fridge that costs so much that its life cycle cost is greater than a fridge with fewer stars, or, as we have explained at length, a car with better fuel economy but much higher purchase and maintenance cost.

Secondly, and in the same vein, we can adopt energy conservation measures like housing insulation, but we have to take care there too- there has been plenty of research on optimum energy conservation levels, ie, finding the point at which more energy/money is spent in the conservation measure than what is saved.

Thirdly, and perhaps unpleasantly, we need to consume less goods and services. It is no point just improving the national average energy intensity (MJ/$) if we increase the total production, and therefore the total megajoules. This needs a slight qualification. If productivity (which includes a measure of energy intensity) improves at 2% per year and population increases by 2% (these are the actual Australian figures), then expenditure per capita must remain constant to avoid an increased overall energy consumption. Does this mean a stagnant standard of living? Yes, by definition. Does it mean a reduced quality of life? Not necessarily. Do luxury cars (or V8 utes for that matter), McMansions with only two occupants, $10,000 home entertainment systems, etc really add *that* much to our happiness?

However, if we were able to increase productivity to 3% and hold our population constant, then we could increase our consumption by 1% per year while halving our energy consumption in 35 years. That's possible and fits with the best practice international goals. These numbers for population, productivity and expenditure can be mixed and matched, so long as we don't increase the quotient of population multiplied by expenditure divided by productivity. It doesn't seem like a big stretch.

Fourthly and most importantly, intense efforts have to be made in system-efficiency R&D. As noted above, the effort has to be commensurate with the problem- which means that it probably should be at least $10billion/year in Australia. An accompanying issue is that new systems (both products and processes) invariably involve “switching costs” ie the total cost is usually higher in the early days of new systems as we learn how to use them and exploit their full potential. Given that, more analysis of total life cycle benefits is required so that we can more clearly determine the real benefits.

The forgoing may be in error, but it will need some serious work by a team of economists, mathematicians, engineers and scientists to definitively determine the energy implications of our activities. Until then, I think that it’s probably a good rule of thumb to live by.

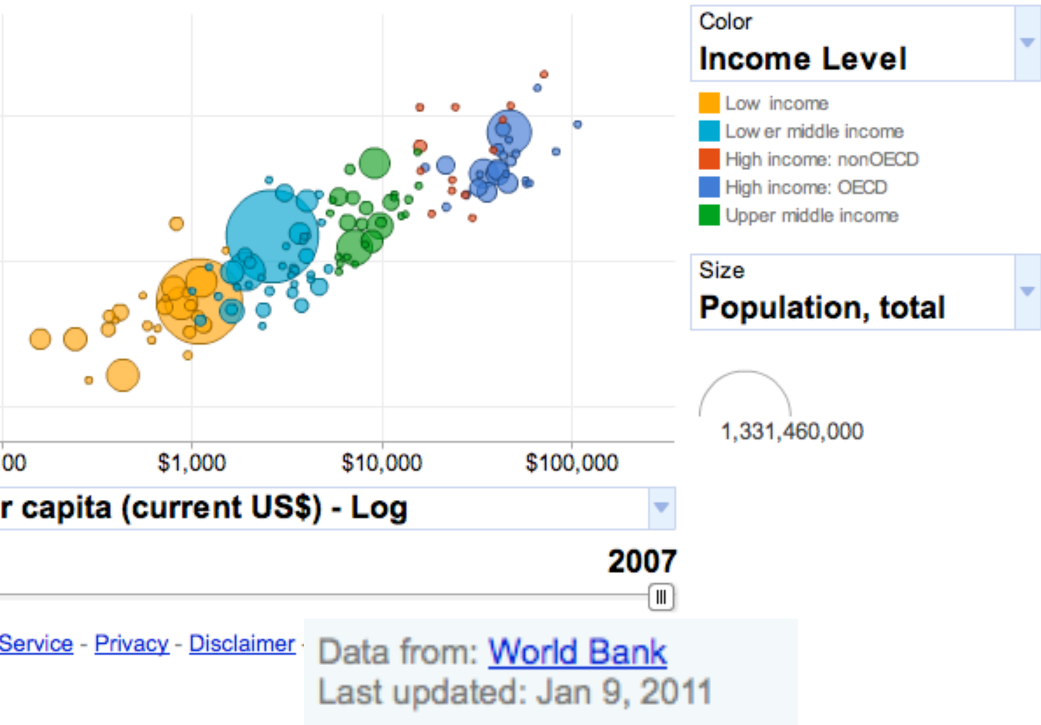
Energy use

Power slide

Jan 19th 2011, 15:14 by The Economist online

Energy intensity is converging across the world

THE energy required to produce a unit of GDP is falling in most countries around the world. As countries industrialise, energy-intensive businesses make up a bigger share of the economy. Peaks generally correlate to the high point of heavy industry, before lighter industry and higher value-added businesses (such as services) begin to replace old-fashioned smokestack manufacturers. This often coincides with gains in energy efficiency, too. According to BP’s "Energy Outlook 2030", published on January 19th, globalisation will lead to a similar level of "energy intensity" across the globe by 2030, despite wild divergence in the past, as energy is traded freely and consumption trends and technologies spread.


Color
Income Level
Low income
Lower middle income
High income: nonOECD
High income: OECD
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Size
Population, total
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2007
Service - Privacy - Disclaimer
Data from: World Bank
Last updated: Jan 9, 2011

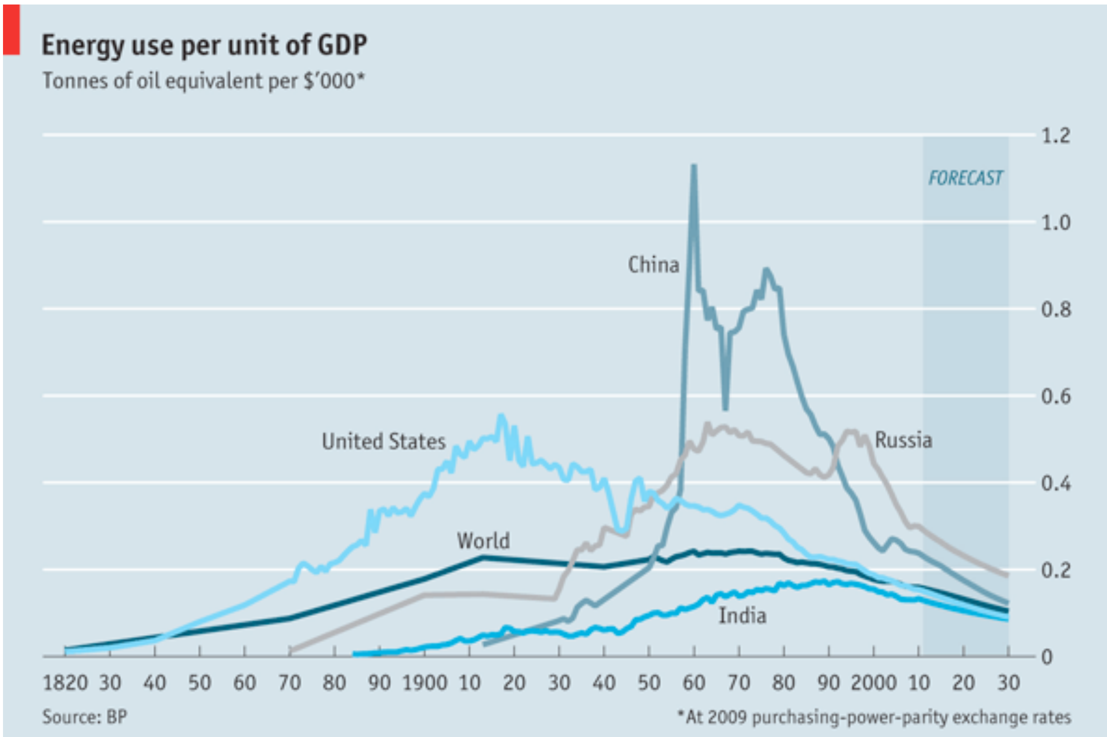
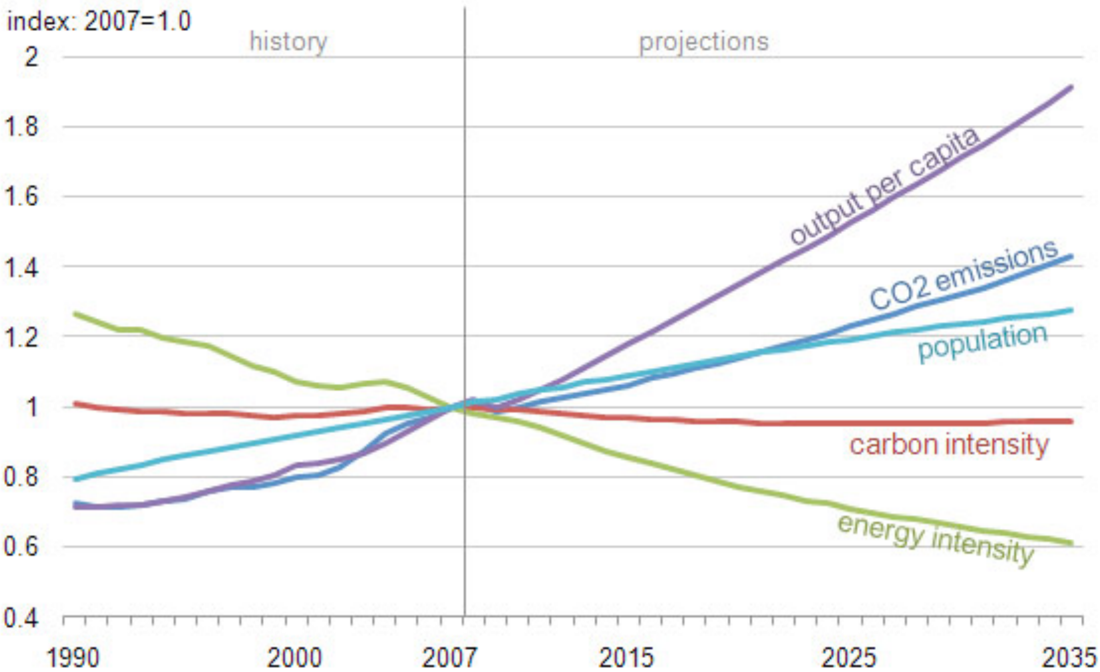


Figure 11. Impacts of four Kaya factors on world carbon dioxide emissions



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[13] http://solarbuzz.com/SolarPrices.htm. Sighted 30 September 2008.

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[15] For a very detailed analysis, see Storm van Leeuwen, Ref 12.

[16] Ross Garnaut, *The Garnaut Climate Change Review, Final Report*, Cambridge University Press, 2008.