CREATING THE RIGHT CLIMATE: THE ECONOMIC SOLUTION

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Abstract
The enhanced greenhouse effect is an economic problem, arising principally from the use of "low-cost" fossil fuels, but creating a risk of significant future costs. Because of these economic dimensions, the polluter pays principle must be applied in accordance with economic theory. In particular, this paper argues that the cost of removing carbon dioxide must be borne by emitters of greenhouse gases. Application of this principle, either by regulation or one of several economic instruments, will provide a least-cost transition to a future of stable climate and sustainable energy. This paper outlines the process by which these goals can be achieved.

Introduction
Burning fossil fuels is a 200 year-old habit. It is a habit which has underscored all the technological progress of the Industrial Age, enabling marvellous improvements in quality of life and personal mobility, and an unprecedented population explosion.

But burning fossil fuels is a habit which must be broken sooner rather than later. We could leave it until later, meaning leave it until the fossil fuels are exhausted. But, as Houghton and Woodwell (1989) have pointed out:

> "Although most modelling to date simulates a doubling of the atmospheric carbon dioxide content ... estimated reserves of recoverable fossil fuels in themselves are enough to increase the atmospheric concentration by a factor of five to ten"

i.e. to between 1500 and 3000 ppm! In the light of present knowledge, this can not be considered a safe scenario. Therefore mankind is faced with a major test of its collective wisdom: how to break the fossil fuel habit soon enough to avoid dangerous anthropogenic interference with the climate system, and long before depletion forces us to do so.

The problem is entirely economic. We have become addicted to fossil fuels because they seem low-cost relative to the sustainable alternatives, and indeed they generally are - to the immediate user. But if, as now appears most likely, climate change will bring significant long-term costs, it becomes a matter of common sense (and in keeping with economic theory) to seek an economic solution so as to avoid or minimise these long-term costs.

The Economic Solution
To be realistic about environmental problems, one must recognise the imperatives of economics - nobody should pay more for energy services than they have to. However the solar solutions which are described later in this paper can not make progress while they have to compete against fossil fuels for which nobody has to pay the cost of creation and storage in the first place, or the other costs of unsustainability, those associated with climate change. The threat of climate change demands, and the solar industries need, an economic playing field which puts a fair value on the fact that solar technologies are not net emitters of greenhouse gases.

The polluter-pays-principle (PPP) is defined by Pearce *et al* (1989) and the OECD (1975). It is becoming increasingly accepted that the PPP must be applied to fossil fuels in order to achieve the objectives of the FCCC. The other term which is used for this is "economic instrument" of which there are two main classes:

- carbon taxes, or charges
- tradeable permit schemes.

In addition to these, there are various renewable energy market stimulation schemes or "targeted measures" being used in different countries, including subsidies, tax credits, and regulations such as mandatory purchase quantities or prices. These are generally not referred to as "economic instruments". Some of them use funds which are "recycled" from carbon taxes.

Since 1988 I have advocated a particular economic instrument or its regulatory equivalent (Henderson, 1990). Stated most simply it is that **the fossil fuel companies be required to ensure (i.e. pay up so that) the CO_2 their product emits is absorbed**. At the time it seemed to be a fairly original idea although Read (1994) was obviously thinking along the same lines. He calls it the tradeable absorption obligation (TAO), a term I will borrow for the purposes of this paper. Other more or less equivalent schemes are:

- tradeable emission permits (TEP's) with absorption credits (TEP schemes are now being designed following the Kyoto Protocol, although it is unclear whether and how absorption credits are being included)
- a two-sided tradeable carbon certificate (TCC) scheme, ie one where absorbers may issue TCC's, as described by Falconer (1996) who concludes that the two-sided scheme will be the most cost-effective.

I advocate the TAO because, being least-cost, **it is the minimum economic instrument necessary to achieve the objective of the FCCC.** Being based on principles of market economics it will also be effective and durable. This is not to say that market stimulation schemes should not be used **as well**. I would readily acknowledge that these can bring about much more rapid creation of a market for renewable energy. However they are also subject to the criticism that they "require governments to pick winners", they create "subsidy-dependency", and they are not "economically optimal". For these reasons they are not going to be politically durable on the sort of timescale required, 50-100 years.

Furthermore because it is a least-cost scheme, the TAO is almost certain to arise out of any TEP scheme, because emitters will insist on having the option to gain credits for absorption, rather than pay for extra TEP's.

I also advocate the TAO because, unlike any other scheme:

- **it directly addresses the problem of CO_2 accumulation in the atmosphere (this also avoids the criticism that the objective might be to create a market for renewable energy rather than reduce net emissions)**
- **it will bring about major afforestation, being the least-cost[1] method of absorption. This will reverse present deforestation trends and create massive biomass feedstocks for future use**
- **it pushes everything in the right direction providing both a transition to and an ongoing system for a sustainable energy future.**

In this rest of this section I will focus on these last three advantages rather than the purely economic advantages. Figure 1 (following page) shows the train of cause and effect which would follow from the TAO.

An important feature of this "solution" or "vision for the future" is that it does not require an overnight transformation of our present energy infrastructures. Fossil fuel prices would rise gradually for several decades. This is because the land required for afforestation is inherently marginal land, of which most countries have a significant "supply" and several countries have large "supplies". The entry of cash-rich fossil fuel companies onto such a market may drive up the value of such marginal lands, but it is not likely to compete with other productive land uses for several decades. It is, however likely to come head-to-head against unsustainable deforestation practices in many developing nations. The power of market forces should fairly quickly (under a TAO system) **halt and reverse deforestation**, even if deforestation itself does not incur a TAO.

Land Use Implications

One of the issues that are raised about the TAO is that global population densities are already too high for such an allocation of land for afforestation. The average global population density is about 47 per sq.km (0.47/ha). While there are populous countries in the developed and developing world (for example Netherlands 419/sq.km, UK 228/sq.km, Germany 220/sq.km, China 125/sq.km, India 300/sq.km) there are also very large nations which have low population densities (for example Canada 3/sq.km, USA 25/sq.km, former USSR 12/sq.km, Zaire 15/sq.km, Brazil 20/sq.km, Argentina 14/sq.km). These six "countries" (using the term loosely in the case of the former USSR) total 55 million sq.km or 42% of the world's inhabited land area. While they include some desert areas they are all well known as being home (in the present or the past) to substantial temperate or tropical forest areas. In any event, because the TAO is a market-based system, land availability will simply provide a market signal determining the price of fossil fuels, and thus provide a self-limiting brake on the rate of afforestation and hence (absent other cost-effective methods of absorption) the use of fossil fuels.

[1] See for example Fulkerson *et al* (1990) who show it to be the least-cost of several sequestration methods they evaluate (giving only a 10% increase in the cost of electricity for 100% sequestration), and the only one which does not reduce power generation efficiency. And those authors ignore the value of the biomass feedstock which would be created in the process! (By a similar oversight of the economic argument in this paper, they also dismiss afforestation as being "probably impractical because of the huge land requirements".)

This question of land availability also often leads to a criticism of afforestation (or carbon sinks) that it is only a "temporary solution". But this misses an important attribute of the TAO, that it is a **steady-state**, indefinite solution as well as being a **transient** (or temporary) solution. The important difference between the transient and the steady-state situations is that in the former, significant quantities of fossil fuels will continue to be burned, necessitating ever-increasing land areas to be used for meeting the TAO. In the steady-state, biomass fuels will be the primary carbon-based energy source, enabling the area in forestry to remain constant. With sustainable biomass forestry (or any other biomass cultivation, e.g. crops for alcohol fuels) the area in cultivation can stay constant and the fuel output is analogous to the "interest" off a capital investment. Put another way, biomass burning would incur a TAO, just as fossil fuel burning would, but the difference between the two is that biomass can be replanted on land from which last year's crop was harvested.

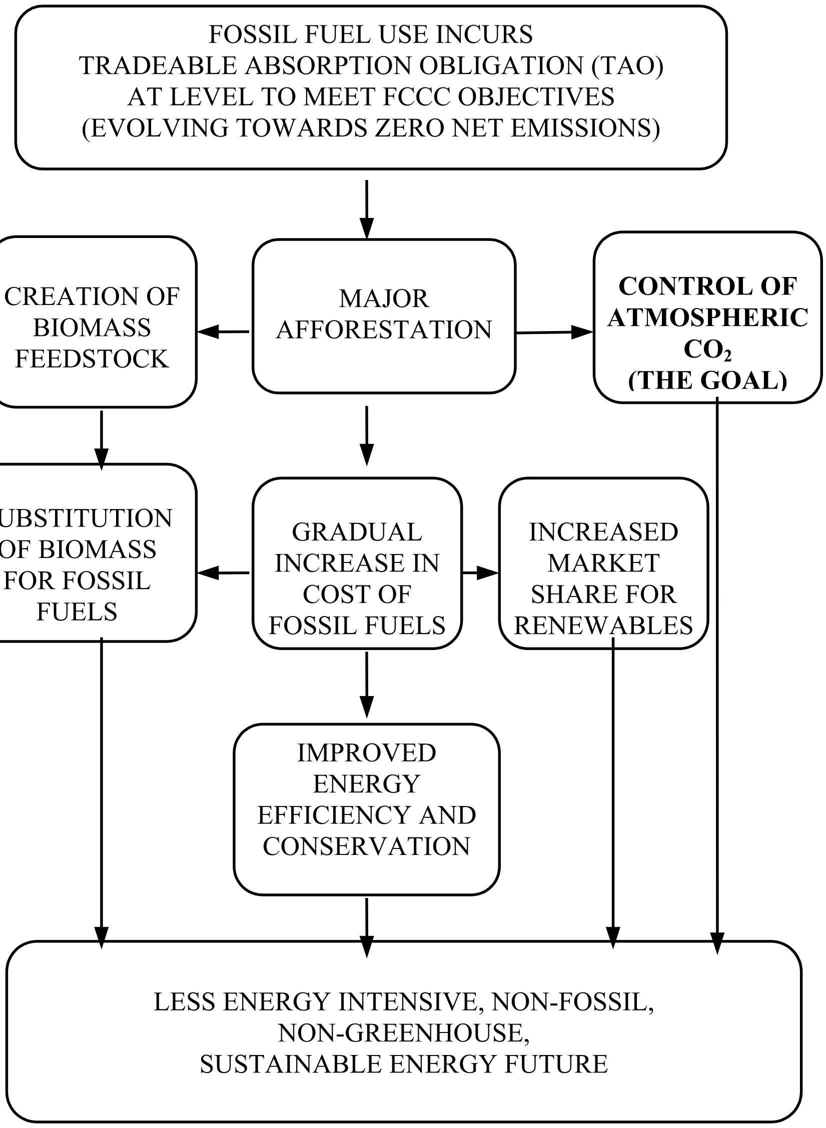
In short, in a TAO-based sustainable energy future land availability will simply determine:

- the market share of biomass fuels
- the cost path for fossil fuels and hence the rate at which they are phased out and energy efficiency improves.

In this context it is important to note the relative land intensity of other solar-based energy forms. Biomass can produce about 5 kW/ha. (N.B. In this paper I use watts as a unit of rate of energy use, meaning average year-round watts). By comparison:

- average global energy use is presently about 1 kW/ha (2.2 kW/person times 0.47 persons/ha)
- average global energy use is likely to rise to 4.5 kW/ha (5 kW/person times 0.9 person/ha)
- wind power produces about 1000-2000 kW/ha (based on actual land taken out of grazing)
- hydro produces about 50-100 kW/ha (based on typical land flooded for reservoirs)
- solar thermal produces about 500 kW/ha
- rooftop PV and solar hot water inherently take up no land, thus are infinitely good by this measure.

Figure 1: The TAO pushes everything in the right direction.



Thus biomass could conceivably provide all our present energy needs on about 20% of global land area, but probably could not meet future energy needs. However it is the **most land-intensive of the solar-based alternatives, by a factor of between 10 and 400 (or infinity in the case of rooftop applications).** The corollary of this is that **land availability**, while it will limit the market share of biomass, **will not be a limiting factor** for a

TAO-based sustainable future, because the associated market signal will stimulate the less land-intensive options (wind, hydro, direct solar).

The Transition to Sustainability

As mentioned above, the TAO provides a transient and a steady-state solution to sustainability. Figure 1 showed the train of cause and effect which the TAO would initiate. The figures on the following two pages show how the transition will take place. The following gives a brief commentary on Figures 2-5 and 7, and a more extended discussion of Figure 6.

Figure 2 - Population

Typical projections for global population by the year 2100 range from 8 to 14 billion (stabilised). See for example Hinrichsen (1987). The graph uses mid-range figures from Keyfitz (1989) through to 2025 and extrapolates to a stabilisation level of 11.6 billion. Keyfitz (1989) gives a figure of 1.2 billion for the population of the developed world, which he says will increase by less than 0.2 billion by 2025.

Figures 3 and 4 - Per-capita and total energy usage

Davis (1990) gives 170 million barrels of oil equivalent per day as 1990 world energy usage. This converts to 12 TW. EECA (1995) gives OECD average energy usage as 4.53 tonnes of oil equivalent per capita per year. This converts to 6 kW per capita, which is used as a developed world average. Combined with Figure 2 data, the developing per-capita and other figures can be calculated to give the starting points for Figures 3 and 4.

The end point of 5 kW/capita is an assumption (discussed below). Estimated trajectories have been fitted to the curves in Figure 3, and the curves in Figure 4 follow from these.

Note that, compared to some estimates, the 16% reduction to 5 kW/capita is a modest improvement in energy efficiency for developed nations. But note also that several direct solar technologies (see Figure 6) are in a "grey area" as to whether they are supply-side or demand-side (energy efficiency) technologies. For example passive solar architecture, solar hot water, solar drying and even rooftop PV can be treated as demand-reduction. However the analysis in Figures 3 and 6 implicitly treats them more as supply substitution. Thus the 5 kW/capita represents a judgement as to what is an acceptable "energy services" supply in a developed nation. Regarding the potential for other types of energy efficiency, hybrid cars are an excellent example of the potential to make this 5 kW/capita a considerable over-estimate. **Hybrid cars which halve fuel consumption are on the market in Japan (since December 1997) for about NZ$31,000.**

Figure 5 - New afforestation and the price of fossil fuels

The afforestation curve follows an S-curve, starting from zero and levelling off at 30 million sq.km (about 23% of every inhabited nation or 55% of the six large sparsely populated nations mentioned above). Because the cost of fossil fuels will include the cost of this afforestation, their price will increase gradually at first and then very rapidly as the land available for afforestation becomes increasingly scarce. Fossil fuel interests may initially find such a prospect horrifying, but from a commercial and technological point of view they should be well-placed to convert their operations to biomass fuel supplies, especially if they secure harvesting rights to the new energy forests for which they will have paid.

Figure 6 - Changing patterns of energy supply

Figure 6 could also be labelled "The Technical Solution", because it describes how the technology will respond to the economic signals created by the TAO. The thinking underlying this projection is admittedly radical, as is the TAO itself. However it is also based on an engineer's knowledge of **1990's-proven** technologies and an energy specialist's understanding of the ability to substitute energy supply options. **And it is not an overnight change projection**, except for the need to introduce the TAO sooner rather than later.

The start and end points of this process are set out in the Table 1, where "Other" includes nuclear and geothermal. The 1990 figures for fossil, biomass, hydro and other are taken from Davis (1990). For wind power the global installed capacity was about 2 GW (rated) in 1990, corresponding to an average output of 0.4 GW (at 20% capacity factor). Direct solar is estimated to be about one-quarter of this, although this neglects traditional drying and passive solar technologies in the developing and developed world.

Figure 2: Population in the developing and developed world - the primary demand driver.

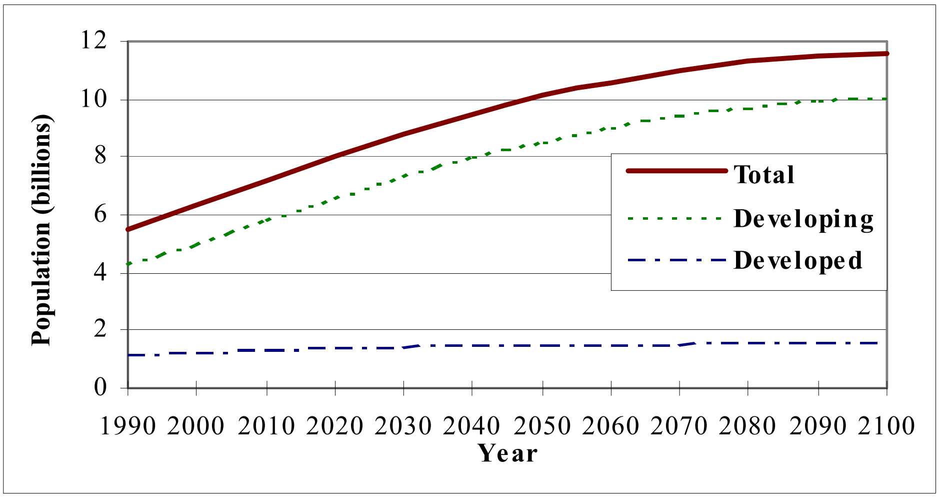


Figure 3: Energy per capita in the developing and developed world -
modest energy efficiency improvements and a convergence on a "developed" standard of living.

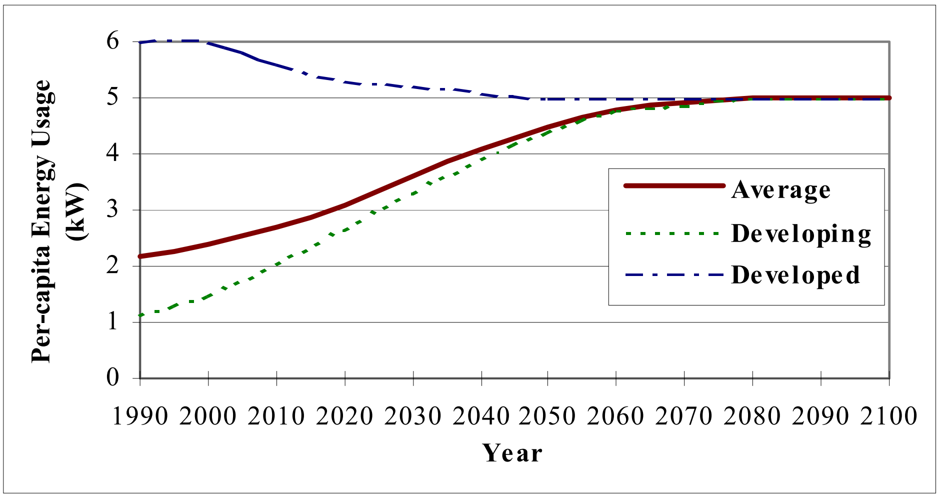


Figure 4: Total energy demand in the developed and developing world - the product of Figures 2 and 3.

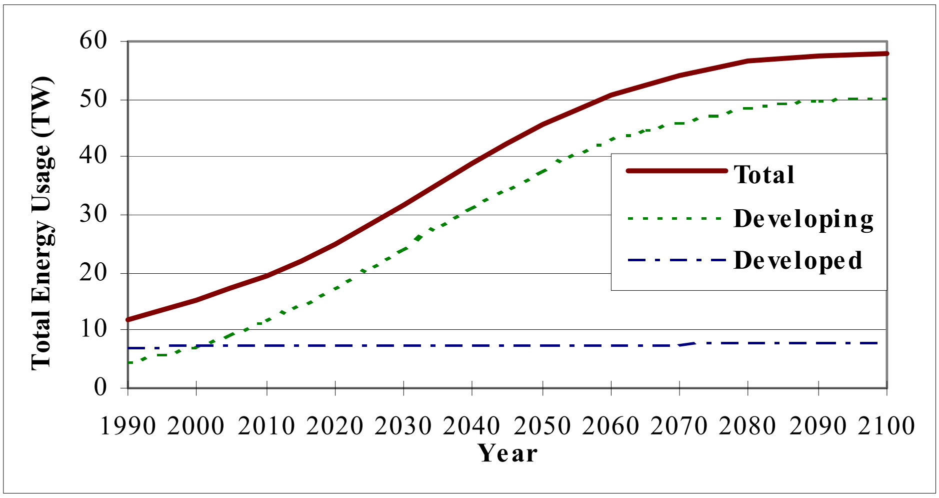


Figure 5: New afforestation and the price of fossil fuels - a market-driven interrelationship.

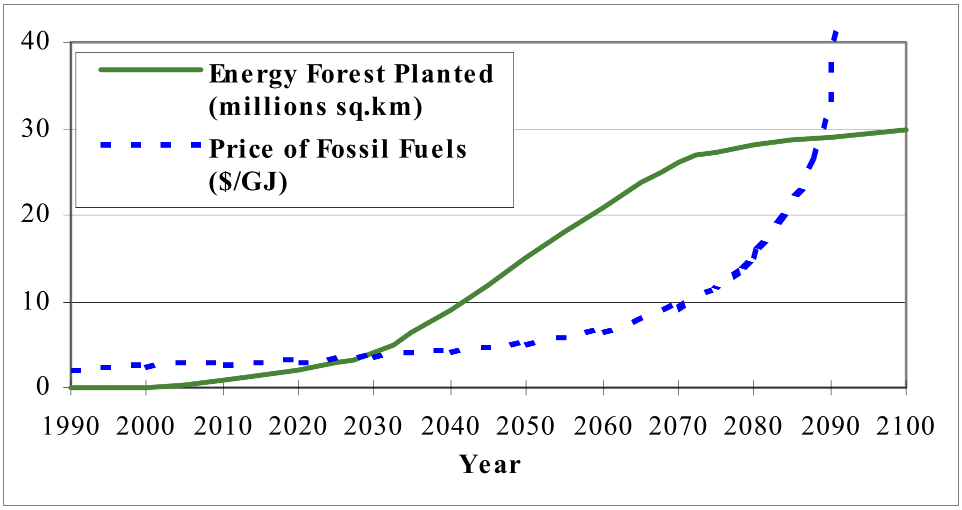


Figure 6: Changing patterns of energy supply - increasing fossil fuel use to meet developing nation expectations, then phasing out as the solar options take over.

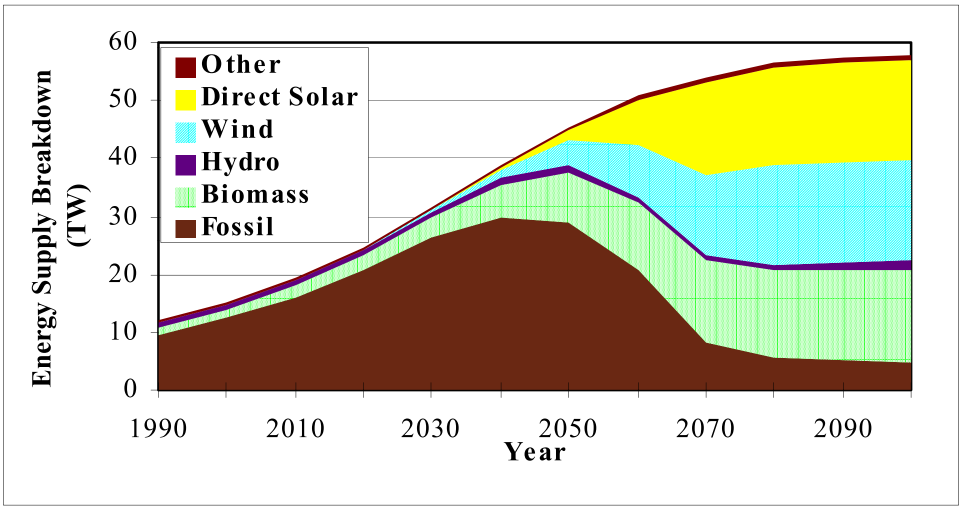


Figure 7: Atmospheric CO_2 concentration - increasing with fossil fuel use but moderated by afforestation, and stabilising!

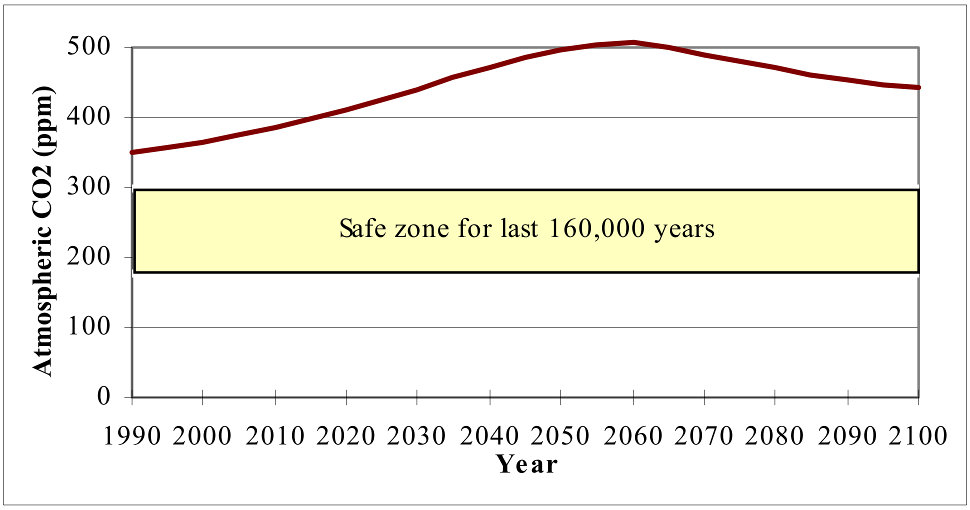


Table 1: Energy Supply Breakdown (TW), 1990 and 2100

Year	Fossil	Biomass	Hydro	Wind	Direct Solar	Other	Total
1990	9.3	1.6	0.7	0.0004	0.0001	0.4	12
2100	4.9	16.0	1.4	17.4	17.4	0.9	58

In summary the present day situation (dominated by fossil fuel usage with biomass being the largest other source) is projected to be replaced by a situation whereby biomass, wind and direct solar dominate supply. Hydro, nuclear and geothermal are projected to double their present contribution, but, being already well-established, are not expected to have the growth prospects of biomass, wind and direct solar.

In particular:

- the fossil fuel figures are calculated as providing the balance of supply (to meet the demand of Figure 4) once all the other contributions have been calculated
- the biomass figures are calculated as being the 1990 supply plus an increased supply (at 4.8 kW/ha) from the new energy forests of Figure 5
- the hydro and "other" figures are calculated as increasing in a straight line at 10% of the 1990 supply per decade. The underlying assumptions are that these are relatively mature technologies, facing significant resource and/or environmental constraints, which have already been overtaken economically by the other renewable options, in particular (in the 1990's) by wind power. In spite of these constraining factors, they will be stimulated by the TAO and thus will see some uptake in the developing world.
- the wind power and direct solar figures are calculated as increasing by a factor of five every decade, until 2040 for wind power and 2060 for direct solar. Thereafter wind power trebles by 2050, doubles by 2060 and then stabilises at 30% of demand. Similarly direct solar stabilises at 30% of demand after 2060. Note: wind power has increased by a factor of four already in the 1990's. It will have increased five-fold by 2000.

While it is impossible to crystal-ball the exact market share of biomass, wind and direct solar technologies, I have projected a roughly equal market share for the three because of the following countervailing factors:

- present economics rank them generally as wind, biomass, direct solar (in that order)
- land use considerations rank them as rooftop solar, wind, other direct solar, biomass (in that order)
- biomass provides combustion fuel with solid (wood), liquid (alcohol) and gaseous (methane) forms all proven in the 1990's. This has the important attribute of providing transportability and storage on an annual time-scale. In addition the sequestration aspect during the transition away from fossil fuels will create such a large biomass feedstock that it will become obvious that it must be used as a fuel
- by contrast wind power is limited primarily to electricity generation. In order for its economic and land-use virtues to over-ride this limitation, one needs to project (not unreasonably) that electricity's market share will increase significantly in the 21st century, in particular:
    - for electric vehicles (individual or mass-transit)
    - for battery-charging for electric and hybrid vehicles (providing the storage wind power lacks)
    - for hydrogen generation (providing storage and an alternative combustion fuel to biomass).
- rooftop solar options (hot water and PV), while expensive in terms of supply-side economics, have the advantage of delivering energy on the customer's side of residential meters. (This is not generally so for wind power because people do not tend to build their homes in exposed windy places.) Depending on retail pricing arrangements, this can significantly increase their attractiveness and hence potential market share. Furthermore, as with wind power, battery charging for electric and hybrid vehicles may prove to be a major demand-driver and storage provider for PV
- in a TAO-based future with correct pricing of energy, load management strategies should become more widespread. These include:
    - use of dedicated electrical and thermal energy storage technologies (e.g. batteries, flywheels, hydrogen, hot water stores)
    - timing domestic and industrial batch processes according to wind/sunshine forecasts (a humble example being clothes washing and drying).

Figure 7 - Stabilising Atmospheric CO_2

This follows from the graph of fossil energy usage (Figure 6) combined with the effects of sequestration during the establishment phase of the new forests (Figure 5). The sequestration figures are based on a coppicing model given

by Ford-Robertson (1995) and are much lower than sequestration figures for conventional forests. However this is consistent with the biomass harvesting assumed in Figure 6.

The projected outcome is lower than most projections for the 21st century but still 25% higher than the present level, which in turn is already 25% higher than the highest naturally occuring level in recent geological times. The critical question for international policy-makers remains: what is a safe level?

Note: the energy usage and supply breakdowns in Figures 3, 4 and 6 and the afforestation projection in Figure 5 are simply one person's "crystal ball" view of a sustainable, prosperous and globally equitable outcome for the population projected in Figure 2. Flowing from this is the atmospheric CO_2 outcome of Figure 7. Ultimately the actual outcomes are all inter-dependent and, in a TAO-based future, could vary significantly from these projections. As the TAO is an effects-driven, market-based process, attempting to predict the inherently unpredictable outcomes in Figures 3-6 does not matter so much as the fact that the TAO provides a way to achieve any required stabilisation curve for Figure 7.

Also questions such as the socially and environmentally acceptable mix of conservation forest, traditional production forest and coppicing plantation are not so much ignored as left to "the market" (which includes democratic planning processes and their associated costs) to decide.

Conclusion

The tradeable absorption obligation (TAO) is an effective, least-cost method of avoiding or minimising the costs of climate change while achieving a transition to a sustainable energy future. It incorporates the polluter-pays-principle in the most direct way appropriate to climate change - pay to absorb emissions. Because tree-planting is the least-cost method of absorption, the TAO will lead to major afforestation. Trees planted today to absorb CO_2 will become the biomass feedstocks of future generations. Because of the cost implications for fossil fuels, energy efficiency and all the non-fossil options will be stimulated. These include:

- biomass (which will also incur a TAO but without the ever-increasing areas needed to meet fossil TAO's)
- wind power, direct solar and hydro
- nuclear and geothermal power.

Market forces will determine the final mix, but biomass, wind power and direct solar are expected to have the largest growth, providing 90% of energy by 2100 when demand is likely to be five times the 1990 demand.

The land-use implications are significant in the case of biomass fuels, but they are a necessary consequence if:

- we are to continue burning carbon-based fuels (fossil in the transition and biomass in the steady-state), and
- we are to control atmospheric concentrations of CO_2.

The land-use implications are significantly less (by two or more orders of magnitude) for the contribution by wind power, and direct solar (especially rooftop solar) to the final mix of supply options. Thus the overall land-use implications are major but not physically impossible, and in any event they are economically self-limiting.

References

Davis G.R. (1990). *Energy for Planet Earth.* Scientific American, September 1990.

EECA (1995). *Energy-wise Monitoring Quarterly.* EECA, Wellington, September 1995.

Falconer W. (1996). *Climate Change and CO_2 Policy: A Durable Response.* the Discussion Document of the Working Group on CO_2 Policy, Ministry for the Environment, Wellington.

Ford-Robertson J. (1995). *Plantation Forestry as a Carbon Sink.* In Proceedings of "Trees as Carbon Sinks" workshop, Massey University, Palmerston North.

Fulkerson W., Judkins R.R. and Sanghvi M.K. (1990) - *Energy from Fossil Fuels.* Scientific American, September 1990.

Henderson G.M. (1990). *The Economic Solution to the Greenhouse Effect.* Unpublished paper, London.

Hinrichsen D. (1987). *Our Common Future: A Reader's Guide*. Earthscan Publications Ltd, London.

Houghton R.A. and Woodwell G.M. (1989). *Global Climatic Change.* Scientific American, April 1989.

Keyfitz N. (1989). *The Growing Human Population.* Scientific American, September 1989.

OECD (1975). *The Polluter Pays Principle: Definition, Analysis, Implementation.* OECD, Paris.

Pearce D., Markyanda A. and Barbier E.B. (1989). *Blueprint for a Green Economy.* Earthscan Publications Ltd, London.

Read P. (1994). *Responding to Global Warming: The Technology, Economics and Politics of Sustainable Energy.* Zed Books Ltd, London.