A critique of the 2011 IPCC Report on Renewable Energy*.

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This document has been regarded as confirming the widespread belief that renewable energy can replace fossil fuels and more or less meet world energy demand by 2050. It is more than 1000 pages long, has 38 lead authors and input "…from over 120 leading experts from all over the world…", reports on 164 studies, and digests 24,766 comments "...from more than 350 expert reviewers and government and international authorities." (Preface.) The chapters review a great deal of literature and are heavily documented. The Press Release says, "Close to 80 percent of the world's energy supply could be met by renewables by mid-century… a new report shows." (IPCC, 2011b.) The web has statements such as, "The total potential for renewable energy "... is substantially higher than both current and future projected global energy demand, is the message of the Special Report on Renewable .Energy Sources and climate Change Mitigation." (http;//www.evwined.es/noticias.php/id_net=11536)

With these weighty credentials the report is likely to be accepted as an authoritative and definitive statement that transition to renewable is possible, does not require significant social change, and is affordable.

However the following discussion details the reasons for regarding the report as remarkably unsatisfactory and as not establishing the main conclusion attributed to it. Following are the main points.

- The report does not show that renewable sources can meet future energy demand, or a large fraction of it. It is not that its attempt to show this is unsatisfactory; the point is that it does not offer a case; it does not attempt to show what proportion of demand could be met by renewables. It presents much evidence relevant to the issue, but this is not put together into a case which sets out reasoning leading to the conclusion that the necessary quantities could be provided, how they could be provided, and that the difficulties could be overcome. The report merely presents the results of some studies which state conclusions about renewable energy's potential, without attempting to assess their worth. It is argued below that the main such study, on which the WG3 report relies heavily, is deeply flawed, is of little or no value and does not establish its claims.

  The report should be a detailed analysis of the potential and limits of renewable energy, deriving conclusions about what proportion of demand it can meet, and demonstrating these conclusions via evidence and transparent

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*Intergovernmental Panel on Climate Change, Working Group 111, Mitigation of Climate Change, Special Report on Renewable Energy Sources and Climate Mitigation. June, 2011. http:www.srren.ipcc-wg3.de/report assumptions and reasoning that others can work through to assess how well the conclusions follow or are established. The reader should be able to go through the argument to satisfy himself that the conclusion is valid, that it can be seen to follow from the reasoning, (or to decide how well it has been established, what assumptions are weak, where better evidence is needed etc.) The report does not engage in a discussion which enables such an assessment.

The above summary statement about what the Report is supposed to have found is logically akin to a teacher saying "This boy could become President of the US someday." There is a sense in which it is perfectly true. It is an acceptable statement if it is understood as being a statement about a possibility that the speaker is not in a position to rule out. Everything depends on the meaning of the word "could". It is acceptable for the Report to be saying, "As far as we can see given the studies reviewed renewables might be able to provide 80%...", but it is not in order if it is saying "We have established that renewable will in fact be able to provide 80%..." McIntyre (2011) sees this failure to establish the core claim in his commentary, "Junk Science Week: The IPCC's Greenpeace Karaoke",

- The actual conclusion regarding renewable potential the Report's states is as follows.

> "More than 50% of the scenarios project levels of RE deployment in 2050 of more than 173 EJ/y reaching up to over 400 EJ/y in some cases." (SPM, p.20, see also p. 18.) More than half say renewable could provide more than 27% of energy. (Summary for Policy Makers, pp. 4, 15.)

Note firstly that this conclusion is not saying that 80% of 2050 demand can be provided. Note secondly that it is not a conclusion the IPCC's WG 3 has come to; it is a summary of the conclusions the selected studies have come to. The 173 EJ/y median renewable contribution foreseen is around 20% of the 2050 demand we are heading for.

- There is no critical examination of the 164 studies. There is no list of the studies enabling their examination. (There is a list which seems to be of 16 research groups carrying them out.) It is not explained how they were selected; it is said that they were not randomly selected. Were only optimistic studies selected? There is no reference to any of (the few) studies that I am aware of as having been published doubting the capacity of renewable energy to meet demand. (These include Hayden, 2004, Trainer, 2007, 2010a, Moriarty and Honnery, 2010.) A satisfactory review would have presented the details from an IPCC working group reporting on their thorough critical examination of all, or a representative selection of, the reports to determine whether their quantitative conclusions were sound or plausible and whether the difficulties had been dealt with. There is no analysis of this kind. In other words the IPCC has not carried out an evaluation of literature in the field; it has only summarised the conclusions of (a select number of) studies, with no apparent effort to check on their validity.

There is no recognition of the great deal of “boosterism” evident in the renewable energy field, driven by the desire of technical people to gain credit and research funding, the wish green agencies have for solutions which do not involve radical social change, and by the desire of politicians, commerce and publics to believe that renewable can save us.

- Several crucial difficulties and problems confronting renewable energy supply are either not dealt with adequately, or not mentioned at all. It is argued below that some of these are not likely to be overcome.

- The report focuses on “scenarios”, i.e., descriptions of imagined future situations, which do little more than allocate a contribution to renewables. For the question at hand there is little value in presenting conceivable future situations; what matters is the derivation of conclusions to do with quantities that are likely to be achievable. There is no discussion in the report as to whether these assumed 2050 situations could be achieved, whether the quantities of renewable energy assumed are realistic, or whether the problems in providing those quantities where and when required can be overcome.

  It is acknowledged that some of the 164 scenarios involve “back-casting”, i.e., they begin with an imagined, preferred greenhouse emission rate, then work back to determine what contributions various renewable sources would have to make to achieve this rate. Again this is of no value unless the question of whether or not those quantities and contributions can be achieved is dealt with convincingly.

- The report depends heavily on one of four selected studies. This is the source of the claim that 80% of energy could come from renewables by 2050. It will be argued below that this study is remarkably superficial, unconvincing, mistaken and misleading.

- Even if the Report’s main claims are accepted, this is of little consolation. Even if renewables could supply 27% of energy by 2050, then catastrophic climate change is very likely. World energy demand is heading towards a doubling by 2050 so if one quarter of it could be met by renewables then the other three quarters would still have to be met by fossil fuels (unless breeders or fusion can deliver about 750 EJ/y by then, and meet all present non-electrical demand.) The IPCC’s graphs (Summary Chapter 1, p. 10) show that CO2e is heading for an average estimate of 65 GT/y by 2050. If renewables cut this by 75% by 2050 we would still have around 50 Gt/y of emissions, far more than the present amount. In 2007 the IPCC 4AR said emissions must be cut to between about 6 and 13 Gt/y. But it is very likely that we will soon recognise that emissions to the atmosphere must be totally eliminated by 2050. (Hansen, 2008, Meinshausen et al., 2009.) If we don’t do this we will go past the emission budget limit. (Carbon Capture and Storage can’t solve the problem, because it is very unlikely that more than only 80 – 90% of emissions from stationary sources can be captured. Metz, 2005, Trainer, 2011, Section.) Therefore even if renewables can provide one quarter of demand as the IPCC says, that would fall far short of solving our energy and greenhouse problems.

After elaborating further on some these points an indication will be given of the reasons indicating that renewable energy sources cannot meet 2050 world energy demand.

Chapters 2 – 7 and 9.

These chapters provide lengthy and valuable compilations of information on the various renewable energy technologies. They do not discuss their combined potential, which is the subject of Chapters 8 and 10.

A concern raised by these chapters is that the focus is on the "technical potential" of the various sources, and this is of little importance. Huge and impressive amounts are documented, in general 40 times human energy use. This information is of little significance; the question is what quantity of it can be reliably provided. In the case of biomass there are estimates which differ by a factor of 50.

Biomass potential.

The biomass chapter offers a detailed and valuable outline of important evidence and issues. It reflects the extensive and confusing diversity among estimates of potential yield, and indicates the dependence of estimates on the assumptions made. Some studies conclude that the biomass potential is very large, for instance 1548 EJ/y according to Smeets and Faiij, (2007) (reported on p.16 of IPCC, 2011, Chapter 2), but the report points out that these might best be regarded as defining theoretical maxima while achievable yields are another matter. It notes that the total net primary productivity of all vegetation on the planet is only about 1550 EJ/y, so a realistic estimate of the amount that might be harvested for biomass energy is likely to be a small fraction of this. The difference between "technical" potential and a realistic figure which takes into account all the social, economic, political and ecological limiting factors is typically very big. For instance Field, Campbell and Lobell conclude that only 27 EJ/y can be obtained, under 2% of the Smeets and Faiij figure.

The Report estimates that the median estimate in its selected studies is 250 EJ/y. It says residues might make up 30% of the potential biomass resource, which means that the land area that it assumes could be planted for harvest would be c. 700 million ha at its assumed c. 13 t/ha yield (which it is argued below is too high.) Some analysts say this is possible, but I think it is a technically unlikely figure, and it is ecologically and socially/morally unacceptable, for the following reasons.

- There is already great pressure on all the land on the planet, and it is commonly accepted that food production will have to double. Normal economic growth will deliver an economy in which there is three or four times as much producing and consuming going on in 2050 as there is now, with corresponding increases in resource demand. Rising energy costs will tend to move structural materials from steel, aluminium and cement to timber. Thus the demands on land for other than biomass energy will probably intensify greatly.

- The report notes that water is a problem for very large scale biomass production. It will be removed from ecosystems in the biomass.

- Large quantities of carbon would be removed from soils and ecosysterms. Patzek (2007) argues that over the long term carbon should not be removed and if it is soils inevitably deteriorate.

- The biodiversity effects are probably the most disturbing. The holocaust of species extinction humans are now causing is primarily due to the fact that we are taking so much natural habitat. We take 40% of the land NPP. (Vitousek, 1986.) Obviously we should be returning vast areas to natural habitat, not thinking about taking more.

- The report says that 80% of the present 50 EJ/y harvest of biomass energy is "traditional use" by tribal and peasant people. This is labelled "inefficient" use and the Report anticipates shifting this land to much more productive use characteristic of modern biomass energy systems. In view of the low yield/efficiency, that area is likely to correspond to 750 million ha. However this land provides crucial services sustaining the lives and livelihoods communities of the poorest billions of people on earth, the building materials, food, medicines, hunting, animal fodder, water, products to sell... The greatest onslaught of the global economy on the poorest billion is precisely the taking of the land on which they depend for life. To move this land into modern "efficient" production would inevitably be to transfer the resource from the poor to the rich, if only because the operation would be governed by "market forces", meaning that the rich would get the resource because they can pay more for it. (This is already happening with respect to oil palm plantations.)

For these reasons it is probable that only a relatively small amount of land should be put into global biomass energy production. It is therefore anything but clear how much biomass energy we should attempt to produce, but it would seem that the figure would be a small fraction of the 250 EJ/y the IPCC reports as the average of the estimates reviewed.

Conclusions depend greatly on the assumed biomass growth yield. The common biomass energy yield per ha assumption of c. 13 t/ha/y, also made by the IPCC, is unrealistic. It is easily achieved in good conditions, such as willows on cropland, or forests on good soils with adequate irrigation and fertilizer applications, but very large scale biomass energy will have to use large areas of marginal and/or damaged land. World average forest growth is only 2-3 t/ha/y. A more realistic biomass-energy yield figure might be 7 t/ha/y. Even if 13 t/ha/y is assumed, i.e., 234 GJ/ha/y, a 250 EJ/y harvest would require more than 1 billion ha, which is highly implausible.

Easily overlooked is the fact that the 250 EJ/y figure is for primary biomass energy and this would only yield about 80 – 100 EJ/y of final, useful energy in the form of ethanol, and an even lower quantity of electrical energy. (El Bassam, 1998, reports the average efficiency of biomass electricity generation in the US at 18%. The IPCC Annex 111 gives four figures, averaging around 28%.)

Almost all renewable energy sources other than biomass only produce electricity, but electricity only makes up 25% of rich world use. Biomass is therefore the best source from which to produce the 75% of demand which is in non-electrical form. It will also be needed to plug gaps in wind and solar input. Clearly 80 - 100 EJ/y of biomass energy would not go far towards meeting these needs.

OMISSIONS; THE MAIN CONCERN.

There are a number of very important problems to do with renewable energy supply with which the report does not deal at all, or deals with superficially, or fails to draw significant conclusions about.

Variability, winter, peak demand, etc.

The report does give considerable space to the discussion of intermittency and presents much valuable information. However it does not deal well or at all with some major issues, does not deal with the implications for limits to potential and certainly does not show that the problem can be sufficiently well overcome. Often innocent-looking understatements mask huge difficulties; e.g., "Also of some concern is the possibility of low wind power production at times of high load." (Chapter 8, p. 30.) "An increasing penetration of variable renewable sources implies a greater need to manage variability and uncertainty." (Chapter 8, p, 38.) Such statements are true but misleading but they do not make it clear that these are extremely big and difficult problems for which there are not foreseeable solutions and which will probably prevent renewables making a large contribution.

The Report makes the surprising statement, "...there are few if any technical limits to the planned system integration of renewable technologies across the very broad range of present energy supply systems." (Chapter 10, p. 4.) This could be interpreted to be making a claim that is quite true, i.e., it is possible to integrate renewables to some extent and more than at present, but it is a highly misleading statement because it reads as if it is saying there is no limit to the extent. The following discussion shows that this is seriously incorrect.

There is no discussion of the crucial problem of meeting demand in mid winter, when demand can peak and solar resources can be negligible or non-existent. All discussion seems to follow the common convention of discussing in terms of annual and/or average demand and supply, whereas what matters much more are the figures for maximum demand, e.g., peak quantities, when they coincide with minimum renewable resource availability. Firstly, in order to meet peak demand with a safety margin (e.g., for breakdown of some units) up to twice as much doal-fired generating plant might have to be built as would meet average demand. Secondly the crucial problems for renewable supply are set by winter. Winds are stronger then but solar resources are at their weakest. Central receiver output at the best US sites would average around 50% of summer output (NREL, 2010.)

More importantly still, in a winter month there is significant variation in solar radiation around the average for that month. The climate data from NASA (2010) shows that radiation across a winter month can average 40% below the long term average for that month, meaning that for much of the month it would be much less than 40% of the winter month average. A renewable energy supply system to meet a large fraction of demand would need the surplus capacity to meet peak winter demand when solar radiation was under half the winter average.

Combining these two factors, a peak high in demand and peak low in energy availability, more than doubles the amount of capacity that seems to be required when calculations are based on average demand and average radiation levels. This factor has huge implications for costing, because it means that a renewable power station would need more than twice as much generating capacity than a consideration of average annual insolation and demand would suggest.

The report does not deal with the limits these considerations might impose on future renewable energy supply. There is at times vague reference to problems that will have to be solved, and to (a few special) cases where relatively high integrations have been achieved, but we get no indication or the proportion of the energy that might in the future be integrated from renewable sources, nor that the problems can be solved.

The problem of the big gaps.

However there is a much bigger problem, on which the report does not comment. The greatest challenges set by variability of wind and sun concerns the gaps of several days in a row when there might be no sun or wind energy available across large regions, including continents. Following are cases from the many studies documenting the magnitude and seriousness of these common events.

- Lenzen's review (2009) includes impressive graphs from Oswald et al, (2008) and Soder et al., (2007). The first shows wind energy availability over the whole of Ireland, UK and Germany for the first 300 hours of 2006, i,.e., in mid winter, the best time of the year for wind energy. For half this period, i.e., 6 days, there was almost no wind input in any of these countries, with capacity factors averaging around 6%. For about 120 continuous hours UK capacity averaged about 3%. During this period UK electricity demand reached its peak high for the whole year, at a point in time when wind input was zero. Throughout this period the solar input would also have been negligible.

- Soder et al. provide a similar plot for West Denmark in mid winter, again one of the best wind regions in the inhabited world. For two periods, one of 2 and one of about 2.5 days, there was no wind input at all, and in all there were about 8 days with almost no contribution from wind energy.

- Lenzen's third plot is for the whole of Germany, again showing hardly any wind input for several days in a row. (See also E.On Netz, 2004.)

- Coppin and Davey (2003) make the same point for Australia with its much more favourable wind resources than Germany, for instance indicating that for 20% of the time a wind system integrated across 1500 km from Adelaide to Brisbane would be operating at under 8% of peak capacity.

- Mackay (2008, p. 189) reports data from Ireland between Oct. 2006 and Feb. 2007, showing a 15 day lull over the whole country. For 5 days output from wind turbines was 5% of capacity and fell to 2% on one day.

- Similar documentation on lengthy gaps is given by Coelingh, 1999, Fig. 7, and Sharman 2005.

Clearly these lengthy periods of calm are not rare or of minor significance. For several days in a winter month in good wind regions there would have to be almost total reliance on some other source. The considerable capital cost implications of having a back up system capable of substituting for just about all wind capacity (noted by Lenzen, 2009) are rarely focused on.

This problem is usually discussed in terms of “capacity credit” and “loss of load probability”, but these terms can obscure the central issue. “Capacity credit” refers to “...the fraction of average capacity that is reliably available during peak demand.” (Lenzen, 2009, p. 92.) The south Australian electricity supply agency estimates that for its wind supply system this value is only 3-4%. However ”reliably” in this context means 95% probable and the crucial point concerns what can happen in the remaining 5% of the time, which is 17 days of the year. As the above cases show it is very likely that what can happen is the occurrence of long periods with negligible wind. Thus the probability of a loss of load event might be very low, but if and when it happens the entire wind contribution would have to be made up by some other source, and as Lenzen notes the capital cost of this provision should be accounted to the wind system.

A similar problem associated with higher penetrations of wind and solar is to do with periods of over-supply and dumping. Lenzen (2009, p, .94) reports Hoogwijk et al., 2007 as finding that “...the amount of electricity that has to be discarded grows strongly for penetrations in excess of 25-30%.” If wind and PV were to contribute 25% and 30% of electricity then on sunny and windy days they would be generating more than twice average demand. Some degree of system “over-sizing” will probably make sense but the capital cost implications are easily overlooked. System capital costs should be divided by electricity delivered, not generated, to arrive at a realistic system capital cost per kW.

The usually overlooked need for redundancy.

Optimistic claims re the potential of renewable energy (e.g., Stern, 2006, The World Wide Fund for Nature, 2010, Zero Carbon Britain, 2007, Greenpeace International and European Renewable Energy Council, 2010), typically fail to recognise the need for large scale redundancy in generating capacity, caused by the fact that often one or more component systems will not be contributing much if anything. For instance, when the availability of solar energy is low, enough wind capacity (or some other source) would have to have been built to make up that deficiency. When there is little wind there would have to be on hand sufficient solar generating capacity to meet the deficit. Thus total system capital cost might be several times what at first seemed to be required.

This shows that the crucial questions regarding renewable energy supply are not clarified by information on the “levelised cost” of 1 kWh from the various sources, nor by figures on their average annual contributions. What matters most is the capital cost of the quantity of plant required to cope with a) periods of minimal or zero energy availability, b) periods of maximum demand, and c) the required amount of plant redundancy to cope with variability which at times reduces or totally eliminates contributions from one or more components of the total system.

The issue is illustrated by Stern's Fig. 9.4 (2006) which attributes 8% of future energy supply to wind. The typical procedure is to multiply such a quantity in kWh by a levelised cost for 1 kWh of wind energy, and to regard the result as the cost of the wind component in the proposed total supply system. What this fails to recognise is that there will be times when there is little wind and then there will have to be enough extra solar or other capacity to compensate for this, and there will be times when solar input is low and there will also have to be enough extra wind (or other) capacity to plug that gap. The total system will therefore need much more wind plant than would be sufficient to generate 8% of total annual demand.

Thus the common practice of focusing on levelised costs in estimating total system capital costs leads to serious underestimation of system costs. Attending to peak capital costs kW(peak) are similarly misleading. Some expect the capital cost per peak kW for coal and solar thermal electricity plant to be about the same by 2030 (e.g., Jacobson and Delucci, 2011a, 2011b.) However a coal fired power station averages an output that is about .8 of its peak capacity, whereas for a solar thermal power station the figure is around .2. In other words for each to deliver at a constant 1 kW rate the solar thermal plant would have to be four times as large as one capable of delivering 1 kW at peak insolation, so the capital costs in relation to average or constant energy delivery are not well indicated by the commonly quoted peak ratings. They refer to a peak output which the solar thermal plant achieves only for a small fraction of the time, but coal-fired plant achieves it all the time.

The mistake easily made here is to assume that renewable sources can be regarded as additive, when they should be seen as alternative. It is in order to regard Stern's diagram as indicating the proportions of annual energy supply that (you hope can) come from the various sources, but it is a serious mistake to regard it as indicating the amount of plant and therefore capital cost involved in achieving this contribution to supply.

Integration limits.

The IPCC discusses integration at some length and its summaries seem to align well with Lenzen's review (2009, p.19) which confirms the previously generally understood conclusion that wind cannot contribute more than 25%, probably 20% of electricity required Beyond that point integrating this highly variable source into systems which must deliver precise and relatively stable amounts of power continually becomes too difficult. Lenzen believes the limit for PV might be somewhat higher, but this is questionable. A system in which storage enabled PV to continually contribute 30% of annual demand would be generating about 150% of that amount in the middle of a summer day, requiring half its output to be dumped even if all other generating systems are idled, because peak PV output is about 5 times as high as its 24 hr continuous average.

What does not seem to be generally recognised is that these integration limits mean that wind plus PV might contribute at best only 55% of electricity, i.e., only 14% of all energy. The Report does not deal with the question of from which sources the other 86% is to come, apart from biomass. (Economies could however be radically restructured to use much more electricity, but this would reduce the proportion intermittent sources could contribute, (as the IPCC notes, Chapter p) and set other significant challenges, most obviously regarding storage. The difficulties in the most commonly given response, hydrogen, are considered below.

The storage problem.

Again there is discussion of this issue, reviewing (superficially, some) options, but it does not help much in assessing the possibility of a global renewable energy supply system. Such a system would have to rely heavily on very large scale storage of electricity, which is not possible at present and is not foreseen. The report does not contradict this view. The formidable difficulties are recognised briefly (Chapter 8, p. 41), in a sentence which actually says it is questionable whether solutions will be found. Again the seriousness of the issue is not brought out; if very large scale storage of electricity is not possible (or affordable) then it is difficult to imagine how utopian renewable energy scenarios could be achieved.

Following are two statements typical of the reassuring tone evident throughout the Report where huge problems are made to look as if answers are around the corner.

> "By storing electric energy when renewable energy is high and the demand low, and generating when renewable output is low and demand high, the curtailment of renewable energy will be reduced." (Chapter 8, p. 40.)

> "Battery technology is an area of active research, with costs, efficiencies and other factors such as life time being improved continuously..." (Chapter 8. p. 40.)

Obviously again what matters is whether there is reason to think that the improvements will be sufficient.

The most promising storage options are subject to critical evaluation in Trainer, 2011, Section, but brief reference to the significant difficulties in solar thermal and hydrogen storage should be made here.

Solar thermal systems are planned to have 17 hr storage. If a solar thermal power station was to b e cap able of maintaining supply through four cloudy days it would need 96 hour storage. The IEA says the cost of present solar thermal storage capacity, usually c. 6-7 hours, makes up about 9% of plant cost, so a 96 hr storage capacity would add more than the cost of another 1/5 solar thermal power stations.

However the key question here is whether solar thermal heat storage capacity could enable an entire electricity supply system to continue delivering through a four day period of no wind or sun. If wind, PV and solar thermal were each delivering one-third of supply then the storage task for solar thermal would have to correspond to 3x96 hours, multiplied again by the additional capacity to deal with peak demand. In addition solar thermal power blocks would have to be three times normal size, adding to capital costs.

Similar formidable multiples lie in wait if storage via hydrogen is envisaged, due to the implications of the low energy efficiency of this path. The future energy efficiencies of a) producing hydrogen from electricity, b) compressing, pumping and distributing it, and c) re-generating electricity via (expensive) fuel cells are, optimistically, .7, .8 and.5, meaning that for each kWh the wind turbines generated this path would deliver .28 kWh for use. (Plausible assumptions could make this less than .2 kWh.) Again the implications for capital cost are significant. In effect the plant cost to generate the electricity needed for 1 KWh to be delivered via hydrogen would be 3.6 times that of the plant needed to supply 1 kWh/y directly.

To these energy costs we would need to add those of constructing the hydrogen producing and storage plant. If the strategy is to store in hydrogen for the regeneration of electricity then as much generating capacity would be needed in the form of fuel cells as in the form of wind turbines, and Harvey states the dollar cost per kW of fuel cell generating capacity at up to $5,000/kW, maybe three times the cost of wind generators. (Harvey, 2011, p. 133.)

Jacobson and Delucci assume that liquid fuel for aircraft and other uses would be provided via liquid hydrogen. Again due to the energy cost of transforming hydrogen gas into a liquid the energy costs would increase by another 40%, i.e., I kWh of wind would provide less than .18 kWh of energy in liquid form, and we would have to add the embodied energy cost of the plant to do the liquefying, plus that of the pressure tanks (four times as big as for storing the same amount of petrol) and other equipment to keep the liquid hydrogen very cold.

In fact if a thorough embodied energy accounting was carried out it would be surprising if storing energy in the form of hydrogen had any net positive energy return. On other words we might end up with as much energy in the form of liquid hydrogen as it took to produce and provide it.

Inadequate consideration of embodied energy costs.

The report sets out estimated embodied energy cost figures in a table, but does not discuss their status or implications. This field remains to be clarified and confident estimates regarding the amount that should be deducted from gross lifetime energy output do not seem to be possible. The main issue is as Lenzen points out that studies to date typically take into account only the energy cost of fabrication plus materials and do not include the “upstream” energy costs of, for instance producing the steel works that makes the steel. The energy cost of PV modules is commonly taken as c. 3-5% of lifetime output but Lenzen et al. (2006) report that when a thorough accounting is carried out the real cost is actually 30% of lifetime output. (The need for confirmatory studies is evident.) It seems likely that in general 10% should be deduced from renewable energy output to cover this cost. A thorough study would have clarified theissue, but the IPCC does not discuss it.

Embodied energy calculations for a renewable energy world should include the costs of hundreds of very long distance HVDC lines from deserts to demand centres, e.g., from North Africa to the UK. One line might be needed for each three 1000 MW solar thermal farms. Czisch (2004) estimates these would add 33% to solar thermal electricity supply costs (although DESERTEC proposals assume relatively short lines, not to NW Europe.). Harvey reports a lower probable cost, in the region of 10+%. (2011, p. 149.)

Conclusions on neglected and omitted issues.

The Report reviews evidence on several of these issues, without drawing implications for the question of limits to potential. This is especially so regarding wind integration limits where the discussion focuses on the ability to cope with integrating up to 20+% of electricity from wind farms (and there is reference to special cases where the figure is much higher at times, such as Denmark, along with the special conditions making that possible.) However if renewables were to meet high proportion or all of energy demand then penetration by wind would have to be far higher than 20% and whether that could be achieved is not discussed.

Embodied energy costs are not discussed. The problem of large gaps in solar and wind energy availability and the associated problem of redundancy is not discussed. Some crucial issues are considered but not in a way that leads to conclusions re the load renewable can carry. Some of these issues are capable of disqualifying renewables from meeting a significant proportion of demand if solutions to them cannot be found.

THE HEAVY RELIANCE ON THE GREENPEACE REPORT,

THE ENERGY (R)EVOLUTION.

Chapters 2 to 7 and 9 review a great deal of valuable evidence and discussion, including on the nature of technologies and the quantities of energy these "could/might" provide. However the crucial chapters for the purpose of assessing the potential of renewables are 8, "Integration of Renewable Energy into Present and Future Energy Systems" and 10, "Mitigation potential and costs." The discussion in these is, to put it mildly, quite unsatisfactory, and it is especially difficult to understand why the rationale for Chapter 10 was chosen. The preceding chapters consider the renewable sources separately but what matters is the extent to which they can be combined to meet what proportion of future demand reliably, and at what cost. Chapters 8 and 10 are of little value in answering these questions.

Firstly, Chapter 8 does not provide anything like a satisfactory discussion of the overall integration/storage/redundancy problem. It provides considerable evidence on present integration experience, but provides almost no evidence or discussion on what the future limits might be. The importance of this issue and the apparent savage limits have been emphasised above.

However the most remarkable feature of the whole report, and its most objectionable aspect, is the focus in Chapter 10 on four selected studies, one of which is very optimistic and is the source of the claim the Report is identified with, i.e., that 80% of world energy in 2050 can come from renewables. It is puzzling why this was done. What is the point of selecting one highly optimistic scenario, not attempting to assess its worth, giving it so much attention, and allowing it to be taken as representing the findings of the entire IPCC WG3 Report re he potential of renewable energy?

The crucial point here is that the study in question, the 2008 Energy (R)evolution, by Greenpeace, is, to be as polite as possible, extremely challengeable. (I have written a somewhat detailed critique of it, available at , It is quite similar to this critique of the IPCC Report.) In my view it too fails to deal with several crucial issues, makes implausible and poorly supported or not supported assumptions, and above all simply presents a desired/imagined 2050 scenario which is not derived and not shown to be possible.

Despite the glaring inadequacies in the Greenpeace Report the IPCC offers no critical or evaluative comment on it. As the title of Macintyre's brief critical response says, the IPCC has in effect chosen simply to sing the song written by Greenpeace. ("Junk Science Week: The IPCC's Greenpeace Karaoke", Special to Financial Post June 16, 2011.)

CAPITAL COSTS

The report's conclusions regarding the capital costs of mitigating climate change are also unsatisfactory, highly challengeable and in my view, very misleading. Again the Working Group does not attempt to work out costs but quotes those stated in the four selected studies selected in Chapter 10. In the Summary for Policy Makers a total is briefly given without derivation or discussion, and is apparently taken from Greenpeace. It is said that the most optimistic of the four studies focused on in Chapter 10 is $12.28 trillion between 2010 and 2030. (SPM, pp. 7, 22, 24.) It is stated that this would be for the power sector alone. However the 2008 version of the Greenpeace document does not seem to include any comment on the total capital cost. The 2010 version by Teske et al. does give a figure, but it is $17.9 trillion to 2030, and no derivation or references are given. It is not explained that an investment cost would have to be paid every year into the future, as plant requires constant reconstruction or replacement at about 25 year intervals.

Following are crude approaches suggesting the reasons for thinking that the investment costs for renewable energy supply are likely to be far higher than $12 trillion or $600 billion p.a. (A more detailed estimate is derived in Trainer 2010.)

1) Firstly, power or electricity is only 25% of final energy use, so if meeting that demand is to cost $12 trillion (or $18 trillion) over 20 years, i.e., c. $6-700 billion p.a. this suggests that the investment cost of providing all energy will be at least $2.8 trillion dollars pa. (It would be far more than this because apart from biomass all significant renewable sources only produce electricity, and that remaining 75% of energy in non-electrical form would probably have to come via hydrogen. Note that in the early 2000s total world energy investment was $450 billion p.a. (Birol, 2003.)

2) Here is another approach. Let us assume that by 2050 business as usual demand has risen to 900 EJ/y primary (the IPCC Summary Chapter shows the average estimate is higher than this, although estimates vary widely), and 630 EJ/y final, and that conservation and efficiency effort cuts this by one-third to 420 EJ/y. By 2050 the Report says (the studies it reviews say) renewables will provide 27% of energy, so the investment cost of $700 billion p.a. is being claimed to provide plant capable of providing 113 EJ/y, or 9.42 EJ/month. Because integration problems limit wind +PV to contributing around 15% of energy demand let us assume for simplicity that solar thermal meets all this demand.

   Trainer 2011 derives the estimate that in winter at the best Australian location a central receiver solar thermal power station would deliver (at distance and net of embodied energy cost, transmission losses and dry cooling energy cost) about 54 MJ/m2/ month. The anticipated <u>future</u> plant cost derived from NREL (2010) and the review by Hearps and McConnell (2011) is $328/m2. (This is half the present cost.) Therefore to provide 9.42 EJ/month in winter we would need 174 billion square metres of collector, costing $57 trillion, or

$2.3 trillion p.a. over a 25 year plant lifetime...to provide 27% of energy demand.

3) Let us assume this time that the final target is again 420 EJ/y, that biomass provides 100 EJ/y of ethanol, 42 EJ/y is low temperature heat, and plus hydro plus the minor renewable add to 25 EJ/y, leaving 257 EJ/y to find. If this is to come equally from wind, PV and solar thermal sources (ignoring integration limits or storage problems) each must supply 7.13 EJ/per month.

   Wind: Assume a 1.5 MW turbine at .38 capacity in winter, costing $3 million, generating a net 1.49 TJ/month. To generate 3.58 EJ/month we would need 2.4 million turbines, and they would cost $7.2 trillion.

   PV: Assume 1 square metre at .15 solar-to-electricity efficiency, in 7 kWh/m2 global radiation in winter in Central Australia, generating 115 MJ/m2/month, but delivering only 88 MJ/m2/month at distance net of losses for transmission, embodied energy cost and $3/W for future installed overall plant cost, ($7/W now, Lenzen, 2009), i.e., $450/m2. We would need 33 billion square metres, costing $14.9 trillion.

   Solar thermal: Assume central receivers at Central Australia where DNI in winter is 5.7 kWh/m2/day, operating at .15 solar-to electrical efficiency, at a future cost of $328/m2 and therefore generating 71 MJ/m2/month, but delivering only 51 MJ/m2/month net of transmission losses, embodied energy costs and dry cooling cost. We would need 74.5 billion square metres of collection space, costing $24.4 trillion.

   The total cost would be $46.5 trillion, or $1.86 trillion p.a., or 2.7 times the IPCC figure. Note that this would be for the plant needed to meet half world energy demand.

However there are several significant cost factors not included in the these three exercises which would multiply the investment cost figures they arrive at several times. Among these are the cost of the hundreds of long distance transmission lines from deserts (where plant would have to be located to enable winter supply), and the operations and management costs. The derivation does not take into account the need for extra plant to meet peak demand, nor the fact that for a whole winter month solar energy can average 40% below the norm for that month. Nor does the exercise deal with the need for extra capacity to store huge amounts of energy to deal with several days in a row without wind or solar radiation. Whatever cost all this comes to, the interest cost on borrowing the capital to build the plant would probably multiply that sum by 1.75.

The above exercises are crude but they sketch the kind of quantified approach that is needed to clarify the limits to renewable energy making assumptions and reasoning transparent. Trainer 2010 offers an initial and imperfect attempt to apply this approach to world energy supply, and it is also used in the examination of the limits to solar thermal energy in Trainer, 2011. It is the kind of approach which Chapter 10 of the IPCC report should have included. Unless the assumptions and reasoning in these exercises can be shown to be seriously mistaken it seems that a global renewable energy supply system would be either impossible to achieve or to afford.

EVEN IF THE TARGET WAS ACHIEVED THIS WOULD NOT SOLVE THE PROBLEMS.

The Report says the review indicates that global CO2 emissions could be reduced by 14% to 37% (from the cumulative 1,531 Gt CO2 which business-as-usual would release by 2050.) But again this is not an IPCC finding, as it is stated that these conclusions come from the four studies selected for special consideration in Chapter 10. (SPM, p.20.)

Even if this conclusion is accepted it would still leave us with a catastrophic greenhouse situation, because emissions would still be far in excess of tolerable limits. The 2007 IPCC Fourth Assessment Report estimated that emissions should be cut by 50 – 80% by 2050, i.e., to c. 5.7 to 13 Gt/y of CO2(e) p.a. We are heading towards a 2050 'business as usual" emission level that could be 65 Gt/y. (IPCC, 2011, Ch.1, p. 10), so even a 37% reduction on that would probably leave us emitting around 44 Gt/y, somewhat more than at present.

However those 2007 estimates are probably quite invalid. Firstly emission rates have accelerated and all indices of warming seem to be tracking higher than the highest points anticipated by the models. The 2007 4R was not able to take into account the many feedback mechanisms increasing CO2 in the atmosphere, such as warming drying out tundra and releasing methane, and acidification of the oceans reducing their capacity to absorb carbon, because of insufficient scientific agreement on effects and magnitudes. It is very likely therefore that when these factors are taken into account, it will be generally agreed that <u>all</u> emissions must be eliminated by 2050. (Hansen, 2008, Meinshausen, et al., 2009.)

Meinshausen, et al. reinforce current thinking in terms of a "budget" of emissions we can "spend". At present we are on track to have exhausted that budget before 2050. (The IPCC Report actually notes in passing that emissions must go down to near zero. Chapter 10, p. 25.)

Again the significance of one of the Report's "findings" is not brought out at all appropriately. What is being revealed here is that even if the most optimistic 2050 scenario for the deployment of renewable energy which the Report refers to could be achieved it would leave us far short of solving the greenhouse problem. Yet the report conveys an air of optimism regarding the capacity of renewables to solve our problems.

It should also be kept clearly in mind that the appropriate focus for a discussion of world energy supply is the amount all the world's people could use. Australians are heading towards a 2050 per capita use of 500-600 GJ/y given current growth rates. If 10 billion people were to live as we would then be living, global energy production would have to be maybe 6,000 EJ/y, <u>twelve times as great as it is now</u>. If the IPCC wants us to feel confident that renewables can provide for us they need to explain how they can provide not the 27% or 50% of 500 EJ/y the report is being taken to claim, but 25-50 times as much.

CONCLUSIONS

- Again as a summary of studies and evidence the report is of considerable value, but even this is jeopardised by the fact that its core is only a report on 164 selected studies. We do not know whether there are other studies which contradict the impression we are forming when reading about the findings the selected studies state on a topic. Again, there have been studies critical of the potential of renewable energy but these do not seem to be referred to anywhere in the Report. This issue of selectivity alone is quite disturbing; what is the value of a large and expensive Report which will be consulted by people wanting to understand what renewable can do when it is only based on selected studies? Normal meta-study practice is obviously to engage experts familiar with the field in reviewing as much of the literature in the field as possible in order to summarise what all accumulated knowledge tells us about the situation, including the diversity of views on it. Chapters 2 – 9 do this re evidence on the specific renewables, but it is not done in the crucial Chapters 8 and 10 which are supposed to deal with what the extent to which renewables can provide for us.

- Then there is the lack of critical assessment. A valuable report would have attempted to assess claims made, especially in a field where exaggerated and poorly supported claims abound. The 1000 pages contain almost no critical or evaluative commentary, or attempt to judge between claims.

- Most disturbing is the attention given to the Greenpeace Report. It is puzzling that it was treated as a valuable document, let along as so important and persuasive as to provide the core claim the IPCC Report is seen to be making.

- Above all the Report does not set out <u>to work out</u> what proportion of 2050 demand renewables can meet. It actually gives very little space to this putting-it all-together question (which should have been dealt clearly and convincingly within Chapters 8 and 10), but just restates the Greenpeace claims.

It follows that although the Report is a large and valuable compendium of information, it simply does not throw much or reliable light on the crucial question of the extent to which we are likely to be able to rely on renewables in 2050. It is being regarded as providing strong reassurance but this is not justified.

The greenhouse and energy supply problems are of immense importance and it is crucial that the situation and the options available be clearly sorted out. This Report is seriously misleading, reinforcing optimism regarding the potential of renewables to enable continuation of energy-intensive societies, and in reassuring people that there is no need to think about vast and radical structural and cultural change.

Finally, if the above criticisms are valid the Report raises concerns about the conduct of science. It is difficult to understand why such an unsatisfactory report has emerged. What we want to know, and what this Report is supposed to clarify (or at least will be taken to have settled), is the extent to which we can run on renewables. But the hundred or so authors have not worked on that question; they have only reported on, and apparently endorsed, what a selection of others have said. They have not critically examined what those others have said in a process intended to determine who's right. Above all they have been content to allow their Report's take-home message to come from the transparently problematic Greenpeace Report, without giving it any critical attention. These are not satisfactory scientific ways of proceeding.

This critique is not intended to have any implications regarding climate science. It is not to do with the claim (which I accept) that human activity is a significant cause of dangerous global warming. However it does raise concerns regarding the IPCC and its processes. It is greatly to be hoped that the IPCCs conclusions on climate change do not derive from analyses such as those evident in this report. It would be disturbing in the extreme if its climate claims were based on the selection of "scenarios", relied heavily on one, and carried out no critical examination of their worth. This report on renewables damages the IPCC's credibility and could be used by agencies with an interest contradicting its climate messages.

It is also important to stress that this has not been a rejection of renewable energy. The Simpler Way (Trainer 2010b, 2011) stands for a shift to full reliance on it as soon as possible, and for the claim that we can live well on it...but not in energy-intensive societies.

So what's the solution? The point is that there isn't one. The argument in Trainer, 2010 and the core theme in The Simpler Way (2011) analyses is that global problems are basically due to the commitment to grossly unsustainable levels of consumption and to limitless economic growth. The problems cannot be solved on the supply side, i.e., by trying to provide the quantities of energy that a consumer-capitalist society for 10 billion would require. That kind of society is generating other major problems in addition to energy and climate, including the poverty of billions, the destruction of the ecosystems of the planet, resource conflicts, and deteriorating social cohesion. These problems cannot be solved unless there is vast and radical transition a Simpler Way of some kind. This IPCC WG3 Report reinforces the dominant faith that there is no need to think about this perspective on our global situation.

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