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Can Green Power Save Us From Climate Change?

By

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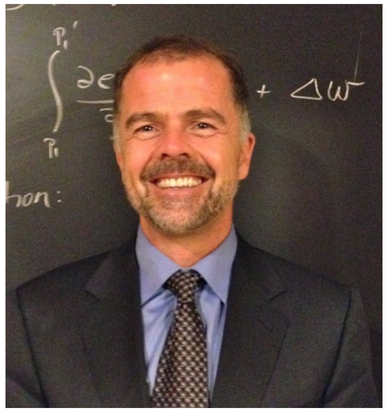

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Abstract

International efforts to lower emissions have largely failed, and many now believe we will fail to limit warming to less than 2 degrees Celsius by 2100. In this talk I discuss whether a wholesale movement to renewable energy or Green Power could limit carbon emissions to meet a 2 degree Celsius target while simultaneously meeting the world's growing demands for energy. Using a very simple growth model I calculate the burden Green Power must carry in order to keep emissions within the 2 degree target, and then discuss the speed, scope, and size of the energy transition this would imply. An energy transition of sufficient speed and magnitude to meet these targets is unlikely, leading me to believe that - no, Green Power cannot save us from climate change.

1. Introduction

International efforts to lower carbon emissions have largely failed, and many now believe we will fail to limit global warming to less than 2 degrees Celsius by 2100. In this lecture I discuss whether a wholesale movement to renewable energy or what I will refer to as “Green Power” could limit carbon emissions to meet a 2 degree Celsius target while simultaneously meeting the world’s growing demands for energy. I am interested in asking such a question because governments worldwide seem to be moving away from reliance on a multilateral treaty solution to climate change to domestically focused efforts encouraging renewable energy. While some of this change in emphasis is welcome, my concern is that there is a tendency to think of renewables as our silver bullet.

To work through an answer to my question I will use a very simple growth model to calculate the energy burden Green Power must carry in order to keep emissions within the 2-degree target, and then discuss the speed, scope, and size of the energy transition this would imply. I conclude that an energy transition of sufficient speed and magnitude to meet these targets is unlikely, leading me to believe that Green Power cannot save us from climate change. In fact, I will argue that the very same incentives that have limited our success so far will also undermine any large-scale government sponsored movements into renewables.

2. The Four Questions

In this lecture I put forward, and then try to answer, a somewhat provocative question – can a movement to renewable or green sources of power save us from climate change? While this question seems simple, answering it turns out to be far more difficult than it might first appear. In fact it requires me to answer four smaller questions and then weave these answers together into some sort of conclusion.

To proceed I first need to clarify what I mean by “saving us” from climate change. Although there are many potential answers to this question, I assume it requires a path for carbon emissions to 2100 that results in a less than 2 degree Celsius (3.6 degree Fahrenheit) increase in temperature. The 2-degree target is simple, and was adopted by all countries signing the Cancun agreement. It is my definition for what saving us requires.

Next we need to ask what the world would look like if something radical is not done to hasten the adoption of renewable power worldwide? That is, I need to construct a Business As Usual trajectory to develop an expected path for carbon. Although there are many forecasts for such a path, I will employ a very simple growth model to generate the forecast as this will allow me to amend it to incorporate a movement to Green Power in what follows.

Third, I need to ask how large and how fast a movement to Green power has to be to meet our overall carbon budget. In essence I ask how the business and usual path must be altered in terms of its carbon intensity so that the world can still grow, still demand energy, but still meet the 2-degree target.

And finally, by comparing the paths I construct in steps two and three I calculate what I call the burden of green power; that is, how much of the world's energy needs to be provided by green power and when. With this information in hand, I can ask the final question: whether the required shift in the energy mix seems feasible given our limited understanding of past energy transitions.

There are many pitfalls and problems with the method I have just proposed; its strength lies in the use of a consistent and simple economic model to create the BAU and counterfactual scenarios. Its weakness is that it relies on very long run forecasts for the impact of carbon on temperatures and the distribution of future economic growth worldwide. Since I would prefer not to forecast one hundred years out, I will cheat somewhat by relying on the forecasts of others. And since it seems reasonable to think that the scale and location and timing of energy demand should be best known by experts in the energy industry, I am going to rely very heavily on ExxonMobil's forecasts for these magnitudes. ExxonMobil is the world's largest energy company and it provides a yearly document discussing current trends and forecasting energy demand across countries and sectors for the next three or four decades. I will exploit their expertise in what follows. Similarly since many of the best and brightest climatologists and physical scientists are members of the US National Academy I will rely on them for recent work tying carbon emissions to temperature changes. The National Research Council (the publishing arm of the Academy) has recently provided a set of estimates and I will again rely heavily on this expert source. In this way I will leave the forecasting to the experts or at least to those who are comfortable doing it, and concentrate on using this information in a logical and hopefully consistent manner to answer the question I posed.

3. "Saving us" and the Role of Cumulative Emissions

To define what "saving us" means in term of carbon emissions, I will exploit the fact that recent scientific work is now placing more and more emphasis on the role played by the accumulated stock of emissions and less on the impact of current emission flows. This trend reflects an increased scientific understanding of the slow decay rates of carbon and the long lags in the warming process created by the storage of heat in the deep oceans. As a result, policymakers and politicians alike have now turned to the use of cumulative emissions as a guide to policy. For example, The National Research Council (the publishing arm of the US National Academy of Sciences) has recently developed a series of forecasts for climate change based entirely on cumulative emissions up to 2100, and it is these forecasts that I will use.

The most recent NRC (2011) study contains two very useful pieces of information. First, when linking cumulative carbon emissions to temperature changes predicted for 2100, the NRC finds an almost linear relationship between cumulative carbon emissions and eventual warming by 2100. Different emission paths that add up to the same cumulative emissions exhibit only small differences in temperatures over short time periods, and over the span of a century it makes little difference whether emissions are primarily front loaded or back loaded - only cumulative emissions matter. This is an interesting scientific finding, but importantly for economists this change in focus provides several analytical advantages. For example it implies that the dynamics of temperature change are greatly simplified since they are now tied directly to cumulative emissions. For a broad range of different emission paths, temperature changes are simply linear in total emissions making analytical work simple. Moreover, since only cumulative emissions matter we can specify a simple carbon budget that the world must meet by 2100 to hit any temperature target. To see what these budgets might look like, in Figure 1 below I reproduce NRC (2011) figures linking the levels of cumulative emitted carbon (measured in 1000s of gigatons) by 2100 to their ultimate temperature impacts.[1] The error bars reflect uncertainties in our understanding of the climate system. As shown in the figure we have emitted a bit more than 500 gigatons currently, and to remain well within the uncertainty band for a 2 degree Celsius increase we have perhaps a carbon budget of 500 more gigatons to "spend" over the next 90 or so years.

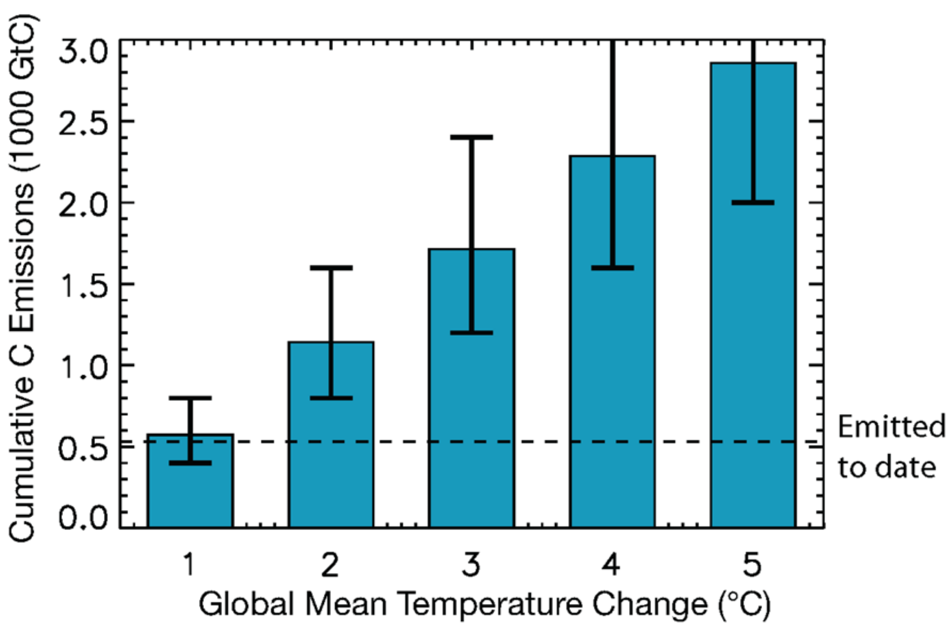

Figure 1

[1] This figure is drawn from data presented on page 110 of the NRC (2011) study.

Stabilization of any temperature change created by 2100 requires the stock of cumulative emissions be held constant thereafter. The implication of this result is fairly shocking: it implies that holding the world at any fixed temperature in 2100 will require an almost zero (net) flow of carbon emissions past 2100. That is, the entire world will need to be carbon neutral by 2100 if temperatures are to stabilize at a warming of 1, 1.5, 2, or even 3 degree C. Therefore, saving us from climate change means that we must meet twin challenges. We need to drive our current annual emissions of 10 gigatons carbon to zero over a period of 90 years, and we need to do so in a manner consistent with cumulative emissions not exceeding 500 gigatons.

4. Constructing the Business as Usual Path

To construct the business as usual path I need a forecast for emissions into the distant future. To do so I proceed in two steps. First, I note that ExxonMobil's *Outlook for Energy: A View to 2030* contains estimates for energy demand, population growth, economic growth, emissions growth, etc. but only until 2030. Although the authors are careful not to predict too far in the future, I will extend their forecasts to 2100 using a neoclassical growth model calibrated to the 2030 trajectory given. One noteworthy feature of ExxonMobil forecasts is that they come from a prediction model with very neoclassical features. For example, the forecasts provided for emission per capita show a strong tendency for convergence in emissions per capita over time. Emissions per capita in the United States and Europe are for example predicted to fall over the period, while those in India and China are predicted to rise. A second feature of their forecasts is decarbonization: that is, emissions per unit of GDP are expected to fall worldwide at roughly the same rate.

These two features – convergence and decarbonization – are tightly linked, and are in fact core features of the Green Solow model of Brock and Taylor (2010). This observation suggests a method to extend the ExxonMobil forecasts from 2030 up to 2100. It suggests that we calibrate a version of the Green Solow model so that its fits the ExxonMobil forecasts from 2010 to 2030; in this way it contains the best information possible about the near future. But then if we take these same calibrated parameters and run the model to 2100 we should be able to generate a reasonably informed business as usual forecast to 2100. It should be noted that this extended forecast is not that of ExxonMobil; I am just borrowing features of their forecasts until 2030, adding some additional assumptions of my own, and extending it to 2100.

To see how and why this method might work, we need to discuss some details of the underlying Green Solow model of Brock and Taylor (2010). The model itself is much like the Solow model: it features exogenous technological progress, fixed savings rates, and exogenous population growth rates. It is different from the Solow model in that the production of any output creates emissions, but emissions can be abated at some cost in terms of output. Just as goods production becomes more productive over time in the Solow model; both goods and abatement activities become more productive over time in the Green Solow model.

Although emissions are a joint product of output, it is possible to rewrite the model so that pollution emissions and conventional factor inputs (capital, labor) produce output, and then by assuming one unit of emissions arises from one unit of dirty fossil energy use, the model can be transformed into one where energy and conventional inputs create output. By altering the relationship between energy, which now appears as an input, and emissions we can incorporate various assumptions about the carbon intensity of the energy supply; that is, by altering the size of energy demand met by green energy, we can alter the emission implications of this growth.

To calibrate a model such as this we need several pieces of information. For example, we need population growth rates, growth rates of technology, and the carbon intensity of energy used. All of these parameters are either provided directly by or implicitly by the forecasts in Exxon Mobil's *Outlook for Energy to 2030* when we interpret its predictions as those arising from the Green Solow model. To see how I connect these forecasts to primitives of the Green Solow model, we now briefly review its main features.

4.1 A Review of the Green Solow Model

The Green Solow model is an augmented Solow model where exogenous technological progress in both goods production and abatement leads to continual economic growth. In the simplest specification both savings and abatement choices are exogenously set. The fixed savings rate assumption is commonly used in the Solow model and is often innocuous. The assumption of a fixed abatement intensity helps us highlight the contrasting roles played by diminishing returns and technological progress.

Consider the standard one sector Solow model with a fixed savings rate *s*. Output is produced via a constant returns to scale and strictly concave production function taking effective labor and capital to produce output, *Y*. Capital accumulates via savings and depreciates at rate δ. The rate of labor augmenting technological progress is given by g_B.

$$Y = F(K, BL),\ \dot{K} = sY - \delta K \qquad (1)$$

$$\dot{L} = nL, \qquad \dot{B} = g_B B \qquad (2)$$

where *B* represents labor augmenting technological progress and *n* is population growth.

To model the impact of pollution follow Copeland and Taylor (1994) by assuming every unit of economic activity, *F*, generates Ω units of pollution as a joint product of output.[2] The amount of pollution released into the atmosphere will differ from the amount produced if there is abatement. We assume abatement is a constant returns to scale activity and write the amount of pollution abated as an increasing and strictly concave function of the total scale of economic activity, *F*, and the economy's efforts at abatement, F^A. If abatement at level *A*, removes the Ω*A* units of pollution from the total created, then we have pollution emitted equals pollution created minus pollution abated, or:

$$E = \Omega F - \Omega A(F, F^A) \qquad (3)$$

$$E = \Omega F[1 - A(1, F^A/F] \qquad (4)$$

$$E = \Omega F a(\theta) \qquad (5)$$

$$where\ a(\theta) \equiv [1 - A(1, F^A/F\ )] and\ \theta = F^A/F$$

where (4) follows from the linear homogeneity of A, and (5) by the definition of ϑ as the fraction of economic activity dedicated to abatement. I assume the intensive abatement function satisfies $a(0) = 1$ and note $a'(\theta) < 0$ and $a''(\theta) > 0$ by concavity. Abatement has a positive but diminishing marginal impact on pollution reduction. For simplicity, let $a(\theta) = (1 - \theta)^{\epsilon}$ where $\epsilon > 1$.

To combine our assumptions on pollution and abatement with the Solow model, we note that taking abatement into account, output available for consumption or investment Y, is simply given by Y=[1-θ]*F*. And to match the Solow model's exogenous technological progress in goods production raising effective labor at rate g_B, we assume exogenous technological progress in abatement lowering Ω at rate $g_A > 0$. Technological progress in abatement provides the slow but steady rate of decarbonization we see in the forecasts.

Now by transforming our measures of output, capital and pollution into intensive units, we obtain:

$$y = f(k)[1 - \theta] \qquad (6)$$

$$\dot{k} = sf(k)[1 - \theta] - [\delta + n + g_B]k \qquad (7)$$

$$e = f(k)\Omega a(\theta) \qquad (8)$$

$$where\ k = K/BL, y = y/BL, e = E/BL\ and\ f(k) = F(k, 1).$$

[2] This approach has been subsequently employed by many authors (Stokey (1998), Aghion and Howitt (1998), etc.). In these other papers, Ω is taken as constant over time and by choice of units set to one. Some authors (for eg; Stokey (1998)) who adopt this approach refer to the firm's or planner's problem as one of choosing across dirty or clean technologies rather than less or more abatement. These approaches are identical.

As with any Solow model, the Green Solow model provides predictions for both long run growth along a balanced growth path and predictions for transition dynamics. While it may be a reasonable assumption that developed countries are already approaching their balanced growth path this is clearly not true for India, China and the rest of the Non-OECD. As a result it is important to understand the model's properties both in and out of the balanced growth path.

To start, lets assume the Inada conditions hold for *F*, then with ϑ fixed it is immediate that starting from any $k(0) > 0$, the economy converges to a unique k^* as in the Solow model. As the economy approaches its balanced growth path, aggregate output, consumption and capital all grow at rate $g_B + n$ while their corresponding per capita magnitudes grow at rate g_B. Using standard notation for growth in per capita magnitudes, along the balanced growth path we must have $g_y = g_k = g_c = g_B > 0$. A potentially worsening environment however threatens this happy existence. Since *k* approaches the constant k^* we can infer from (5) that the growth rate of aggregate emissions along the balanced growth path, g_E, is given by:

$$g_E = g_B + n - g_A \qquad (9)$$

The first two terms in (9) represent the scale effect of growth on emissions since aggregate output grows at rate $g_B + n$ along the balanced growth path. The second term is a technique effect created by technological progress in abatement.

Define sustainable growth as a balanced growth path generating both rising consumption per capita and an improving environment. Sustainable growth is guaranteed then whenever:

$$g_B > 0 \; and \; g_A > g_B + n \qquad (10)$$

Technological progress in goods production is necessary to generate per capita income growth. Technological progress in abatement must exceed growth in aggregate output in order for pollution to fall and the environment to improve. In terms of our exercise here, we will be assuming that the OECD is close to its current balanced growth path. Then with very little population growth, whether emissions fall or rise will then depend only on whether the decarbonization rate is greater or less than the rate of technological progress in goods production.

Next let's consider transition dynamics as they are surely the most important feature in the next 100 years for Non-OECD countries such as India, China and Brazil. Although the Green Solow model is very simple it provides a very interesting set of predictions for transition dynamics; in fact, it provides very suggestive evidence for much of the empirical evidence relating income levels to environmental quality. Despite the fact that the intensity of abatement is fixed, there are no composition effects in our one good framework, and no political economy or intergenerational conflicts to resolve, the Green Solow model produces a path for income per capita and environmental quality that traces out an Environmental Kuznets Curve.[3]

To demonstrate we use the two panels in Figure 2. The top panel plots the growth rate of emissions and capital against capital per effective labor and is very similar to graphical representations of the Solow model. The second follows from the first and plots the level of emissions as a function of capital per effective worker and is very similar to representations of the EKC. To understand the path for emissions we need to develop a differential equation for emissions.

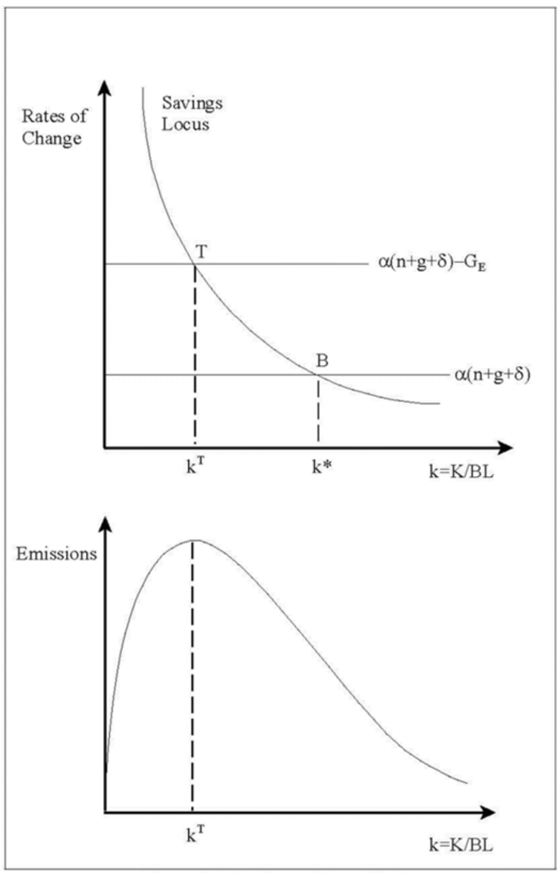

Figure 2

[3] For example, although we take ϑ as exogenous and independent of other model features, it is likely that tighter regulation spurs technological progress in abatement and hence is related to our primitive g_A. For empirical evidence along these lines see the recent survey by Popp et al. (2009). Xepapadeas (2005) also notes that technological progress in abatement can generate an EKC pattern. His discussion is brief and appears in a review article as does our first discussion of Green Solow in Brock and Taylor (2004).

To generate closed form solutions, we adopt a Cobb-Douglas formulation with a constant capital share α, with 0 < α < 1 as this allows us to write emissions at any time t as[4]:

$$E = B(0)L(0)\Omega(0)a(\theta)\exp[g_E t]\,k^{\alpha} \qquad (11)$$

where *B*(0), *L*(0), and Ω(0) are constants given by initial conditions, and use has been made of (5), (1) and the linear homogeneity of *F*. For example in our exercise we choose B(0) to match initial differences in income per capita across regions; we choose L(0) to reflect different population levels; and we choose Ω(0) to match existing data on the carbon intensity of GDP. Differentiate with respect to time to obtain the growth rate of emissions:

$$\frac{\dot{E}}{E} = g_E + \alpha\frac{\dot{k}}{k} \qquad (12)$$

where we note the rate of change of capital per effective worker is simply

$$\frac{\dot{k}}{k} = sk^{\alpha-1}(1-\theta) - (\delta + n + g_B) \qquad (13)$$

Using (12) and (13) we can now link the dynamics of capital accumulation to the evolution of pollution levels using the two panels of Figure 2.

In the top panel of the figure we plot on the vertical axis the rates of change of (α times) capital per effective worker $\alpha\dot{k}/k$ and aggregate emissions $\dot{E}/E$, and on the horizontal axis capital per effective worker *k*. In drawing the figure we have implicitly assumed growth is sustainable: i.e., $g_E < 0$. I will refer to the negatively sloped line given by $\alpha sk^{\alpha-1}[1-\theta]$ as the savings locus. The savings locus starts at plus infinity and approaches zero as *k* grows large; therefore, it must intersect the two horizontal lines as shown by points T and B. From (13) it is clear that the vertical distance between $\alpha sk^{\alpha-1}[1-\theta]$ and the horizontal line with height $\alpha[\delta + n + g_B]$ is just α times the growth rate of capital per effective worker or $\alpha\dot{k}/k$ Capital per effective worker is therefore rising at all points to the left of B and falling at all points to the right. As is well known, the intersection at point B gives us the steady state capital per effective worker k^*. Growth is most rapid for small *k* and falls as *k* approaches k^*. When the economy enters its balanced growth path, $\dot{k}$ is zero and the economy's aggregate output and capital grow at rate $g_B + n$.

Since g_E is *a* constant, we conclude from (12) that the growth rate of aggregate emissions inherits most of the properties of the growth rate of capital per worker. Using the same methods we employed to determine the

[4] The constant capital share assumption lets us solve for the evolution of *k(t)* explicitly, but has no impact on the results in general.

growth rate in k, we note that the vertical distance between the savings locus $\alpha sk^{\alpha-1}[1-\theta]$ and the horizontal line with height $\alpha[\delta+n+g_B]-g_E$ equals the percentage rate of change of emissions in $\dot{E}/E$. This implies, the growth rate of emissions is zero at T, positive to the left of T and negative to the right of T. Transforming this information into a prediction for emission levels, it is apparent that point T must represent a turning point in emission levels as shown in the bottom panel. Emission levels are rising to the left of T and falling to the right of T. Under the assumptions that growth is sustainable, $g_E<0$ and point T lies to the left of B, the model generates the EKC profile shown in the lower panel.

The figure illustrates several features of the model. It shows that if growth is sustainable then T lies to the left of B and the time profile for emission levels depends on the location of $k(0)$ relative to point T. If an economy starts with a small initial capital stock then emissions at first rise and then fall as development proceeds: i.e. we obtain a hump-shaped EKC profile for emissions. Note that while this replicates the well-known EKC for conventional pollutants it would also hold for carbon emissions if the carbonization rate were sufficiently high and the country involved a long way away from its balanced growth path. If initial capital is larger it is possible that the level of emissions falls monotonically as the economy moves towards its sustainable growth path. When emissions peak depends on the relationship between points T and B. For example, if - g_E is small, then T and B differ very little and emissions will only peak as the economy approaches its balanced growth path that may of course take a very long time.

When growth is not sustainable T lies to the right of B and emissions will grow forever even as the economy approaches its balanced growth path. In all cases, the economy's intensity of abatement is constant, and its emissions to output ratio falls - both in and out of steady state - at the constant rate - g_A.

It is important to note while the model allows for the possibility that emissions may at first rise and then fall, or they may fall continuously or rise continuously, the growth rate of emissions is monotonically declining in k. This is true because the growth rate of emissions is very rapid for countries a long way from point B, and slower for those near B. Even in the unsustainable case, the growth rate of emissions falls along the transition path until it approaches its balanced growth path rate from above.

4.2 Calibration

ExxonMobil's *The Outlook for Energy: A View to 2030*, contains forecasts for economic growth in the developed and developing world, for population growth, and for emission trajectories based on an assumed price per ton of carbon of \$30 ton/CO2 in 2020 rising to \$60/ton in 2030. While I do not have access to the ExxonMobil model, as I mentioned earlier it exhibits convergence across the two major world regions, and long run growth in the model is tied directly to rates of technological progress. The major assumptions reflected in the report and used here to calibrate the amended Green Solow model are as follows: the world consists of the OECD and the Non-OECD; world population grows by 1 billion by 2030 with almost all this growth in the Non-OECD; OECD GDP grows at 2% per year; Non-OECD grows on average 5% per year; Non-OECD emissions exceed OECD emissions by 40% in 2010; and the carbon emissions to GDP ratio decreases at 2.5 to 3% per year.

I use these assumptions to calibrate the amended Green Solow model to match the 2030 forecasts of ExxonMobil. To see how this is done consider the following. If I assume that the OECD is along its balanced growth path with zero population growth, then its predicted GDP growth of 2% per year translates into an assumption that technological progress in goods production is 2% per year. Assuming this is the same across regions gives us the Non-OECD rate of technological progress in goods production as well. Moreover, since world population is expected to grow 1 billion by 2030, but none of this occurs in the OECD, this can be used to determine the predicted rate of population growth in the Non-OECD. To match the fact that the OECD has a much lower emissions per unit of GDP we adjust initial conditions; and to fix the rate of decarbonization rates I follow ExxonMobil by assuming the OECD rate is 2.5% while that of the Non-OECD is slightly higher at 3%. These figures become the rate of technological progress in abatement. Finally, since the Non-OECD grows on average 5% per year, but should only grow at 2% in its balanced growth path I choose the Non-OECD's initial capital per worker so as to generate transitional growth that averages to 5% over the period in question.

The Green Solow simulation in Figure 3 shows the impact of these assumptions using the parameters I calibrated. In the figure, I plot annual emissions for the OECD, Non-OECD, and World on the left hand side axis; the world's cumulative emissions are plotted using the right hand side axis. For the moment, focus on the period to 2030 which covers the same period as the ExxonMobil forecast. Over this time period the amended Green Solow model is able to reproduce the forecast quite well. As shown, the model predicts that OECD emissions fall 15% by 2030. The reason is simply that the decarbonization rate in the OECD (2.5%) exceeds its balanced growth rate change in GDP (2%). In the Non-OECD, emissions however double by 2030, since their transitional growth rate is far above their decarbonization rate. As a result, we find world emissions approach 12 gigatons by 2030 which implies an annual growth rate of about 1% per year in emissions.

Now if we were to stop in 2030 and simply extrapolate these results to our own distant future in 2100, we would predict that annual emissions would hit 25 gigatonnes and cumulative emissions would put us in uncharted waters with a prospective temperature rise of 4-5 Celsius. An extrapolation like this would be a huge error since the Non-OECD cannot grow forever at 5% per annun; instead convergence in growth rates and convergence in carbon emissions will help keep emissions in check. To see what the world might look like by 2100, I need to extend our assumptions to cover periods beyond 2030. In doing so, I assume world population growth slows to .5% per year (recall this is all in the Non-OECD) and assume the Non-OECD has the same rate of technological progress in goods production as does the OECD (2%). This implies that in the very long run all regions of the world would exhibit per capita income growth of 2% per year. The results from these assumptions are reflected in the continuation of the simulation past 2030 to 2100 as shown in Figure 3.

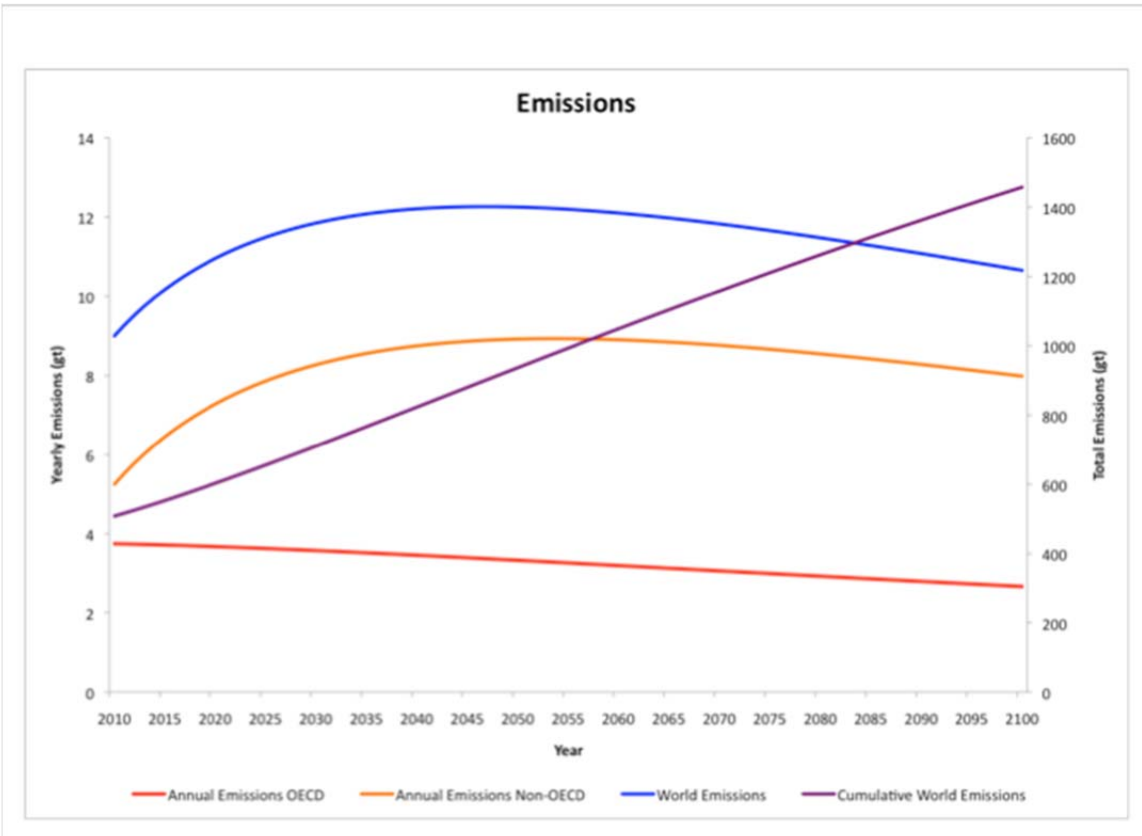

Figure 3: The Business as Usual Trajectory

As shown in Figure 3, OECD emissions after 2030 continue to decline throughout the century much as they did up to 2030. Not surprisingly their balanced growth path predictions for emissions remain unchanged. In contrast we now see that Non-OECD emissions peak in 2050. Since world emissions are the sum of these two groups it peaks a little earlier than 2050 and then falls continuously and would eventually fall at the same rate as the OECD.

Despite the welcome peak in Non-OECD emissions, annual world emissions are still over 10 gigatons C in 2100 and cumulative emissions reach 1450 gigatons C. Therefore, the temperature implications of these implied cumulative emissions (using the NRC study) is perhaps a 3 degrees Celsius increase, with error bands running from 1.75 to 4 Celsius. In addition, the world enters 2100 emitting over 10 gigatons of carbon a year which is not too far off where we are at present. Consequently we know that in the years after 2100 there will be even greater temperature changes.

5. The Counterfactual and Calculating the Burden of Green Power

I now construct a counterfactual scenario that uses a very rapid introduction of clean and Green power to satisfy two conditions. First cumulative emissions to 2100 cannot exceed 500 gigatons. Second, annual emissions in the last years of the period have to be very close to zero since this is what stabilization of the temperature change requires. Therefore, the path by construction will "save us" from climate change.

To create such a path several additional assumptions are needed. I need to make an assumption on the carbon intensity of Green Power and this I set to be 1/6 as carbon intensive per unit energy delivered as are typical fossil fuels or what we could call Brown sources. In addition I have to decide when to allow Green Power sources to rapidly come online. Since the ExxonMobil forecast runs to 2030, and already contains some movement to renewables, I adjust the fraction of energy delivered by Green sources only past 2030. Finally, I assume the rate of economic growth is unaffected by what would be a major energy transition. These are clearly heroic, but necessary assumptions. The results of them are shown in Figure 4 below.

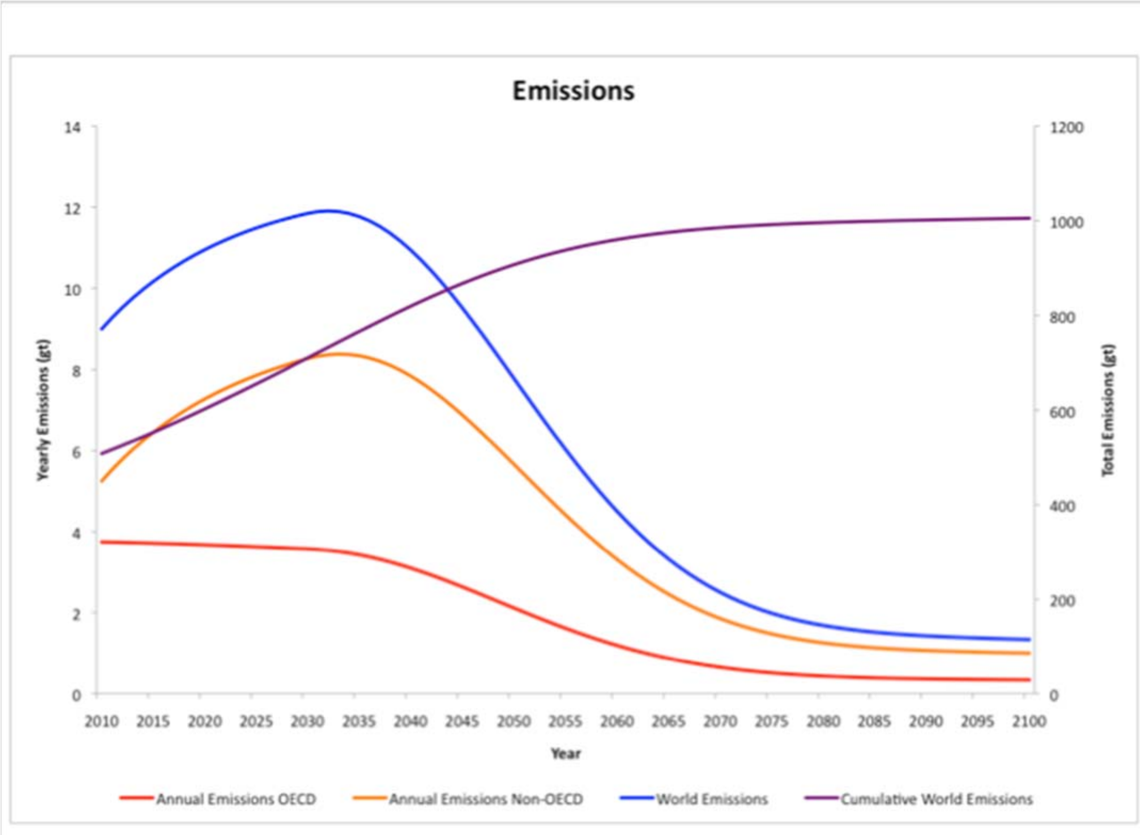

Figure 4: The World with Green Power

As shown OECD emissions decline at a faster rate as Green and less carbon intensive power is introduced much more quickly than in the BAU scenario. Since the flow of emissions must be very close to zero by 2100, the introduction of Green Power has to accelerate the decarbonization process already at play in the mature OECD economies. In addition, we now find that Non-OECD emissions peak in 2035, and then decline quite rapidly. This rapid fall in emission intensity ensures that cumulative emissions reach approximately 1000 gigatons C by 2100. While world emissions are not quite zero in 2100, they are relatively close to zero giving us some room to reduce emissions further in the coming years.

Apart from the usual caveats we would have to such an analysis, we need to ask whether this movement to Green Power is in any sense possible since it requires a huge and very rapid transition towards less carbon intensive energy. To understand the scale of the challenge we can compare the BAU path to our newly constructed Green Power counterfactual to determine what it entails for energy supplies. For example, an implication of the trajectory shown above is that Green Power has to deliver the equivalent of 650 quadrillion BTUs of energy by 2055. This is a large number especially when in 2010 Green Power delivered 65 quadrillion BTU worldwide, and of this biomass provided 47, hydro 11, and solar, wind, and other renewables only 7.

Clearly there is a large challenge facing Green Power if it is to be the sole means of meeting our carbon budget.

6. Can it be done? What does history tell us?

Engineering a very rapid energy transition from fossil fuels to Green energy sources is not likely to be easy, although it is difficult to say much more with certainty since there is very little empirical evidence we can bring to bear on this question. What we do know comes from our understanding and documentation of past energy transitions. To this information we can add what we know about the incentives economic agents, both pubic and private, may have to adopt green power rapidly.

There is a large literature documenting energy transitions, and I cannot begin to do justice to this material here (See Foquet (2010) and Smil (2010) for some examples and references). Therefore I will try to stick to the stylized facts with little interpretation. The stylized facts regarding energy transitions are as follows: 1) there were only two transitions before: from biomass to coal and from coal to liquid fossil fuels; 2) past transitions were very slow; 3) the transitions were of relatively small magnitude because energy use was relatively small in previous years; 4) the energy sources we transitioned from do not disappear, instead new sources arrive and the shares of energy from each source change; 5) new energy sources lead to the introduction of new energy converters and new ways to transform energy into useful work; and 6) all previous energy transitions have been to from fuels with lower energy density to fuels with higher energy density.

To make these stylized facts concrete consider the U.S. case. Using US data, we find that in 1885, coal surpassed wood as the dominant fuel source but total energy usage was only 6 Quads (Quadrillion BTUs) per year. In 1945, coal was surpassed by petroleum and natural gas as the dominant fuel source with total annual energy usage now equal to perhaps 30 Quads. In 2010, total US consumption had grown to approximately 92 Quads/year and this figure is of course many times more than the energy use at previous transition points. Unfortunately, the Green power counterfactual I constructed indicates that the scale of the change towards Green Power is on the order of six times current US energy consumption (approximately 650 quads inn 2055). In this sense the scale of the needed transition is unprecedented.

Next consider the timing involved. If we again use US figures and dates we know that from coal's first introduction in 1850 to its complete dominance of energy supply by 1920, coal took 70 years. Similarly, from the first U.S. oil well in 1880 until their point of maximum dominance in 1970, liquid and gaseous fossil fuels took 90 years. Unfortunately, the counterfactual I constructed shows Green Power must move from a very small energy share today to almost complete dominance in 50 years time. This is of course less than the 70 and 90 years mentioned previously. Finally consider the economic incentives that typically drive energy transitions. Coal's first use was to generate heat; coal was cheaper than wood but only after a period of time did it overtake wood in heating. But coal also brought us a new way to harness power–the steam engine. It gave us a power source not tied to rivers, wind or animate power. Later still mobile applications arrived powering trains, ships, and even cars. Finally, the energy density of coal facilitated its use in transportation. Similarly, petroleum was first a lowly lubricant, until the internal combustion engine was invented in the 1880s. Eventually this innovation and the even higher energy density of liquid fossil fuels brought us further mobility and the development of diesel, gasoline, and jet engines.

Unfortunately, Green Power does not provide any new benefits in terms of energy density for transport applications, nor has it lead to any new innovative means to harness power. Bio-fuels are less dense energy sources than liquid fossil fuels; and solar, wind, and tidal sources of electricity produce just that – electricity. Green Power has yet to provide any new products that may well spur the introduction of new innovations or accelerate adoption. Therefore, the market incentives that drove the earlier energy transitions appear to be weak or absent in the case of Green Power.

With only a relatively few exceptions worldwide, direct government subsidies or regulations are required for green power to be commercially viable; and this creates another incentive problem. The real benefit to green power is not that it offers us advantages in mobility, density, or application that fossil fuels do not have; its advantage is that it is far cleaner in terms of carbon. While this is certainly a huge benefit, this benefit is a public benefit and not a private benefit; moreover, the good in question – the climate - is a global public good. And therein lies the rub: the massive introduction of Green Power will require active government involvement, and it will not be the cheapest energy solution absent a worldwide price on carbon. The incentives needed for the massive introduction of Green Power will only be in place if we already have an international climate change treaty limiting emissions. If we put all of this evidence and argument together it suggests we need to look further than Green Power to solve our climate problems. While a massive introduction of Green power may in theory be able to keep us within the 2-degree C target set in Cancun, the needed policies will be costly. Moreover since the impact of these policies is a better climate and reduced emissions, we are asking governments to undertake costly and unilateral policies for the global environment. Since we have already seen how well this works in practice - Green Power cannot save us from climate change.

7. Conclusion

Unless our current scientific understanding of climate change is radically in error the world's ongoing love affair with carbon based energy sources will imply large temperature changes in the next 100 years. By constructing a business as usual trajectory for the world economy, I showed that while the convergence in growth rates across regions helps, as does ongoing decarbonization of GDP, the business as usual trajectory implies a much warmer world in 2100. I then asked whether a movement to power sources with lower carbon contents – so called Green Power – could save us from breaching the carbon budget associated with a 2 degree C warming by 2100. Unfortunately, unless the world economy grows much slower, converges faster, and has a smaller population, the challenge for Green Power is daunting. The needed scale, speed and direction of change in energy sources would be unprecedented in human history. Green Power cannot save us from climate change.

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The Timlin Lecture

This is the twenty-seventh in a series of lectures established in 1983 in honour of Mabel Frances Timlin (1891-1976). Mabel Timlin's association with the University of Saskatchewan began in 1912 when she took employment as a secretary in one of its departments. In 1929 she was made director of the University's program of correspondence courses, a position she held until 1942. She began her graduate training in economics in 1932, when she registered as a doctoral candidate at the University of Washington. Taking summer courses and one six-month leave, she fulfilled the residence requirements by 1935. That year she was given her first regular academic appointment: instructor of economics at the University of Saskatchewan.

Her dissertation on Keynes's General Theory was completed in 1940 and published by the University of Toronto Press in 1942 under the title *Keynesian Economics*. From Keynesian theory, Mabel Timlin turned to welfare economics, which she studied while on a Guggenheim Fellowship in 1945. She next took up a study of immigration policy which was to occupy her attention for many years; on that topic she published a brief monograph entitled *Does Canada Need More People?* (Oxford University Press, 1951). Her scholarly papers, a dozen in number, on general economic theory, welfare economics, monetary policy, and immigration policy were published in *the Canadian Journal of Economics and Political Science,* the *American Economic Review*, and edited volumes of essays. After retiring from her university appointment, she completed a commissioned study of the funding and organization of social science research, which was published in Mabel F. Timlin and Albert Faucher, *The Social Sciences in Canada: Two Studies* (Social Science Research Council of Canada, 1968). In all, hers was a prodigious output for one whose first work saw print when its author was fifty years of age.

She held office in the Canadian Political Science Association (member of executive 1941-43, vice-president 1953-55, and president 1959-60); and she was elected, by ballot of the membership, a member of the executive of the American Economic Association (term 1958-60). She was elected to the Royal Society of Canada in 1951 and awarded a Canada Council Senior Fellowship in 1959. In 1975 she was named a Member of the Order of Canada.

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