The Global Economic Impact of Climate Change on Energy Expenditures

By Ken Gregory, P.Eng. **May 30, 2020**

A blog post here published May 2 shows that a 3 °C increase in the global mean surface temperature (GMST) would reduce USA energy consumption used for space heating and cooling by $_{2010}$US $10 billion, therefore would have a positive impact on economic wealth of +0.07% of gross domestic product (GDP), whereas the FUND[1] integrated assessment model (IAM) projects a wealth impact of -0.80% of GDP, with non-temperature drivers are held constant. In this post, I extend the analysis to global impacts.

The FUND IAM is the most complex economic model used to estimate the economic impacts of greenhouse gas emissions and global warming. The FUND models forecasts impacts for 7 impact sectors: storms, agriculture, water resources, sea level, health, energy and ecosystems. The negative overall impact of warming estimated by the model is mostly due to the energy consumption impact sector. The paper "Economic Impact of Energy Consumption Change Caused by Global Warming" by Peter Lang and me shows that for the USA, the FUND energy consumption impacts disagree with the empirical evidence. The US states span the latitudes where 82% of the world's GDP was produced in 2010. With energy impacts excluded, FUND projects the global wealth impacts to be +0.2% of GDP at 3 °C GMST increase from year 2000.

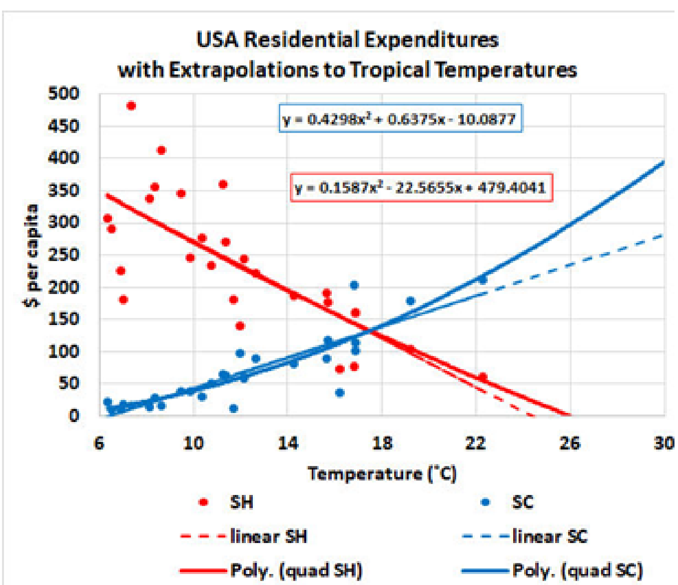

Figure 1.

I present a preliminary estimate of the global economic impact of energy consumption change due to a GMST change by extrapolating the effects of temperature change to latitudes beyond that of the USA states. A final estimate suitable for publication in a peer-reviewed journal would likely require detailed energy consumption and pricing data from some tropical countries.

To estimate global impacts, I slightly modify the space heating and space cooling relations of expenditures per capita versus temperature that was determined for USA states by using quadratic functions that allow for curvature across tropical temperatures. For space heating, I assume that heating expenditure decline to zero when the annual average temperatures reach 26 °C. I assume that space cooling expenditures increase faster than linearly such that the expenditures at 26 °C are adjusted from $234/capita to $297/capita as shown in figure 1. The space cooling curve is the best fit quadratic curve through the data.

[1] FUND means Climate Framework for Uncertainty, Negotiation and Distribution. It is developed by Dr. Richard Tol and Dr. David Anthoff.

The global energy consumption would decrease by 0.05% of Gross World Product (GWP) due to a 3 °C increase in the GMST thereby increasing wealth by +0.05%. This compares to the FUND estimated wealth impact of -1.59% of GWP. Both values assume that non-temperature drivers are held constant at 2010 values. Non-temperature drivers of energy consumption include changes in energy efficiency, population and GDP per capita. Non-temperature drivers are held constant to focus on the temperature impacts on energy expenditures.

Energy consumption per capita for space heating and cooling for non-USA regions are adjusted from USA values by applying ratios of the FUND's forecast changes in energy efficiency and GDP/capita of each region to that of the USA. In FUND, energy expenditures increase with GDP/capita to the power of 0.8. Energy consumption in each region is the population of each region, as forecast by FUND multiplied by the regional energy consumption per capita. Table 1 gives the results for USA, Canada and the World with non-temperature drivers at 2010 values.

Table 1.

Wealth Impact of 3 °C GMST Change from 2000 of Energy Consumption per GDP (%)			
	USA	Canada	World
Empirical	+0.07%	+0.16%	+0.05%
FUND	-0.80%	-0.71%	-1.59%

Substituting the empirical estimate of energy consumption change for that estimated by FUND and using the FUND projected impacts of all other impact sectors, the total impact of a 3 °C increase of the GMST from 2000, occurring in 2097, would cause wealth impacts as shown in Table 2. These values are with all impact drivers included and assume an equilibrium climate sensitivity (ESC)[2] of 3.0 °C, which is the FUND default value.

Table 2.

Wealth Impacts of 3 °C GMST Change from 2000 of All Impact Sectors per GDP (%)			
ESC = 3.0 °C	USA	Canada	World
FUND with empirical energy impacts	-0.32%	+0.13%	+0.20%
FUND	-0.75%	-0.29%	-0.68%

The results show that substituting our empirical estimates of energy consumption change for the FUND values, the impact of 3 °C GMST change and other drivers would reduce the impacts for the USA from −0.75% to -0.32% of GDP. Canada's impact changes from -0.29% to +0.13%, and global impacts change from -0.68% to +0.20% of GWP. For Canada and the World, the empirical energy impact changes the harmful impacts to significantly positive impacts.

[2] ECS is defined as the change in the GMST due to a doubling of the CO_2 concentration in the air and after allowing the oceans to reach temperature equilibrium, which at ECS = 3 °C may take 1500 years.

The FUND space heating impact function assumes that the benefits of heating cost saving for each region quickly saturates with increasing GMST regardless of the actual temperature in each region. Figures 2 and 3 show the FUND space heating and space cooling impacts per GDP, respectively, from the year 2000 versus the regional temperatures. The regional temperatures are the FUND determined temperatures at the centre of each region, not at the centre of each population. FUND gives impacts for 16 regions of the world. The following graphs display 7 of those regions for simplicity.

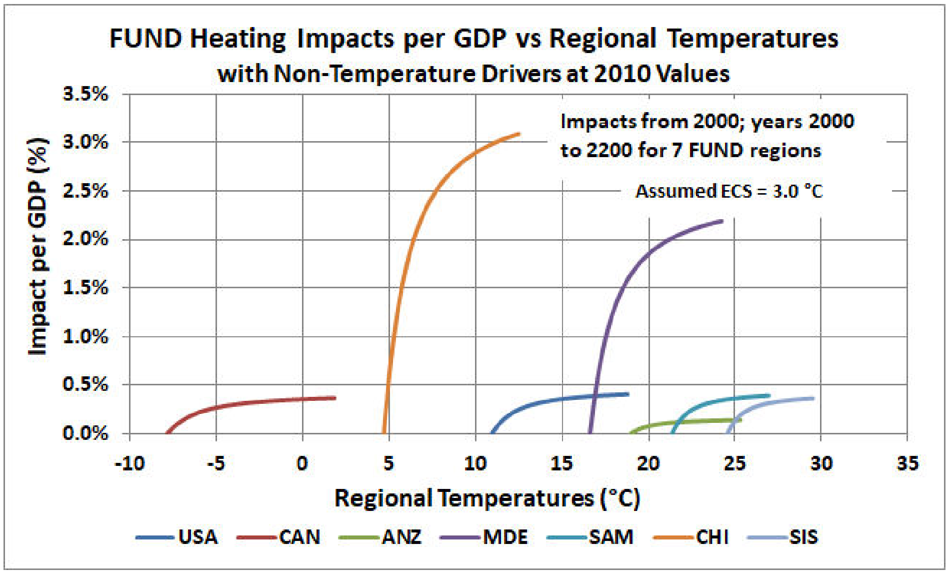

Figure 2.

The regions shown are; USA = United States, CAN = Canada, ANZ = Australia and New Zealand, MDE = Middle East, SAM = South America, CHI = China plus nearby countries, SIS = Small island states.

Figure 2 shows for Canada, an initial increase in temperature from -7.9 °C at the year 2000 by 1 °C causes a positive impact due to reduced heating costs of 0.15% of GDP, but a 1 °C temperature increase from 0 °C causes only 0.007% increase of GDP. However, in China, a 1 °C temperature increase from 4.7 °C causes a huge 1.45% increase of GDP. The impact in FUND of a 1 °C increase is unrelated to the actual temperature in the region. The problem is two-fold.

1. The declining change of impact per degree of temperature change, that is, the saturation of impacts, is based on the GMST, not the temperature at the region.
2. The saturation rate is far too high. The USA data shows there is no saturation effect over the range of temperatures of the USA states from 6 to 22 °C.

As temperature increase toward tropical temperatures, the incremental benefit of heating cost savings declines because a smaller fraction of days and years requires space heating. As the impact per GDP isn't linear with temperature due to a saturation effect, the impacts must be based on actual regional temperatures, not global average temperatures.

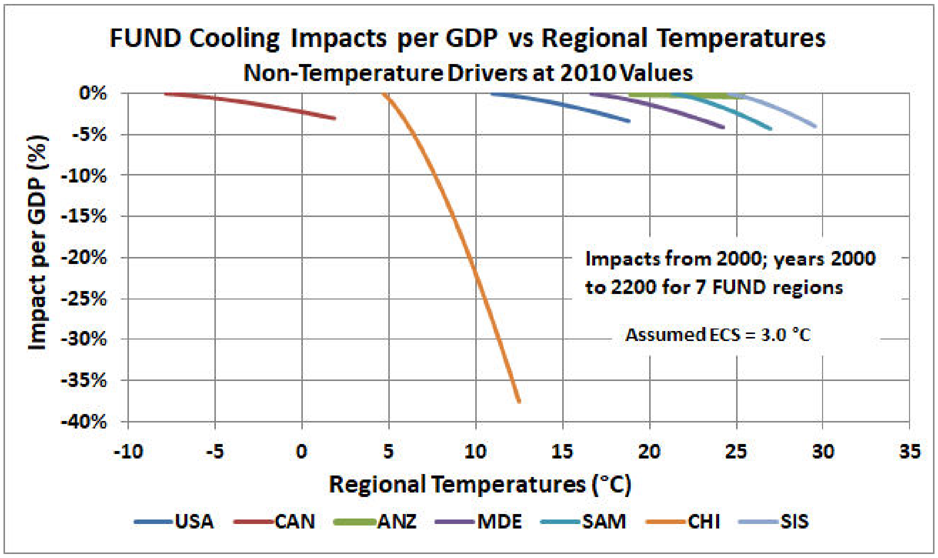

Figure 3.

Figure 3 shows that for Canada, a 1 °C temperature increase from -7.9 °C causes an impact of -0.16% with non-temperature drivers held fixed at 2010 values. The impact of a 1 °C temperature increase from 0 °C causes an impact of -0.29%. The impact per degree of warming increases with temperature because as temperatures increase air conditioning is required for more hours per year. However, this increase of incremental impacts is not forecast in FUND for warmer regions. In the ANZ region, a 1 °C temperature increase from 19.0 to 20.0 °C causes an impact of only -0.03% of GDP. China is forecast to suffer an enormous increase is space cooling costs. A 1 °C temperature increase from 10 °C causes an impact of -5.89% of GDP. FUND forecasts that when temperatures in China reach 12.5 °C, the cooling cost impact is -37.6% of GDP, which is ridiculous.

Figures 4 and 5 shows the corresponding graphs using our empirical space heating and space cooling functions. The regional temperatures in these graphs are at the population centers of each region. In the year 2000, the population centre temperature of Canada is 6.1 °C, whereas the area centre temperature used in figures 2 and 3 is -7.9°C. The energy impacts should be determined at the population centre as that is where the energy is consumed. Figure 4 shows that the slopes of the space heating impact curves for most countries are similar at a given temperature. A 1 °C temperature increase from 12 °C causes a 0.06% heating impact for Canada and a 0.05% heating impact for the USA. The slope of the curves of the MDE and CHI regions are due to steeper than those of the USA, CAN and ANZ regions due to lower energy efficiencies and GDP/capita, which increases energy use per GDP.

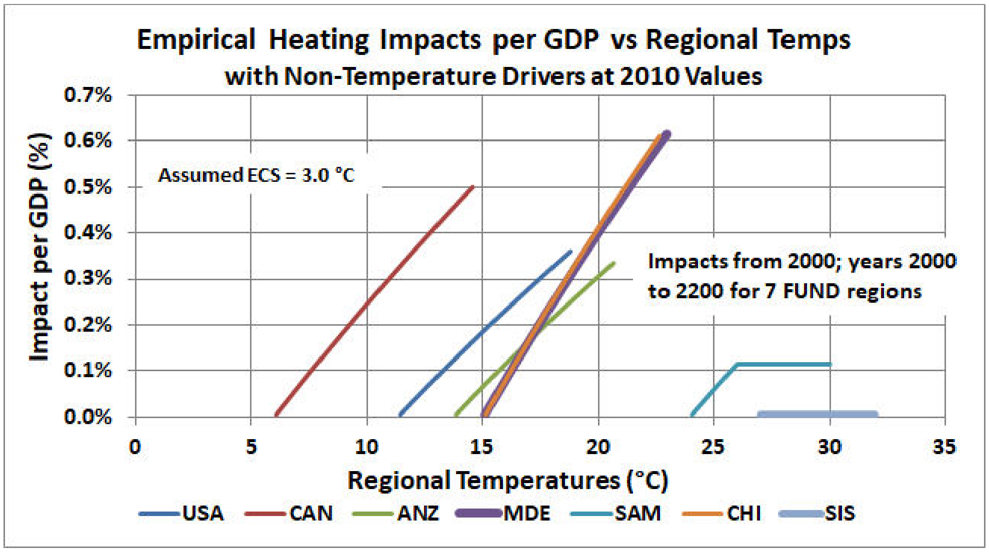

Figure 4.

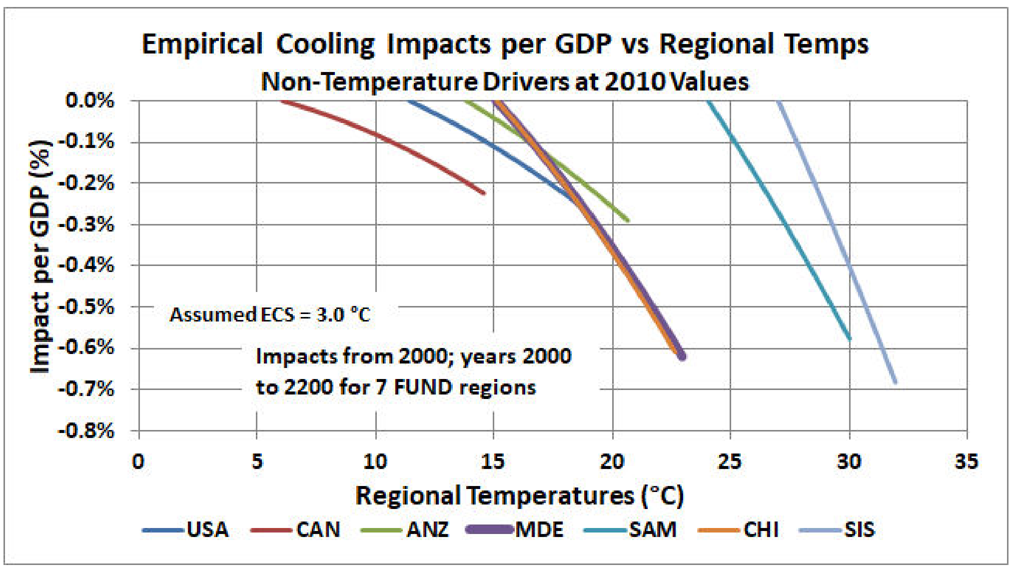

Figure 5.

Figure 5 shows that regions with similar GDP/capital and energy efficiencies (USA, CAN and ANZ) have similar incremental impacts per GDP at a given temperature. The other regions have lower GDP/capita and so have larger incremental cooling impacts.

Figure 6 shows the empirical energy impacts per GDP versus reginal temperature for 7 regions with non-temperature drives held at their 2010 values. Cold regions benefit and warm regions are harmed by the energy expenditure changes due to warming. Canada benefits the most from a reduction of energy costs of any region.

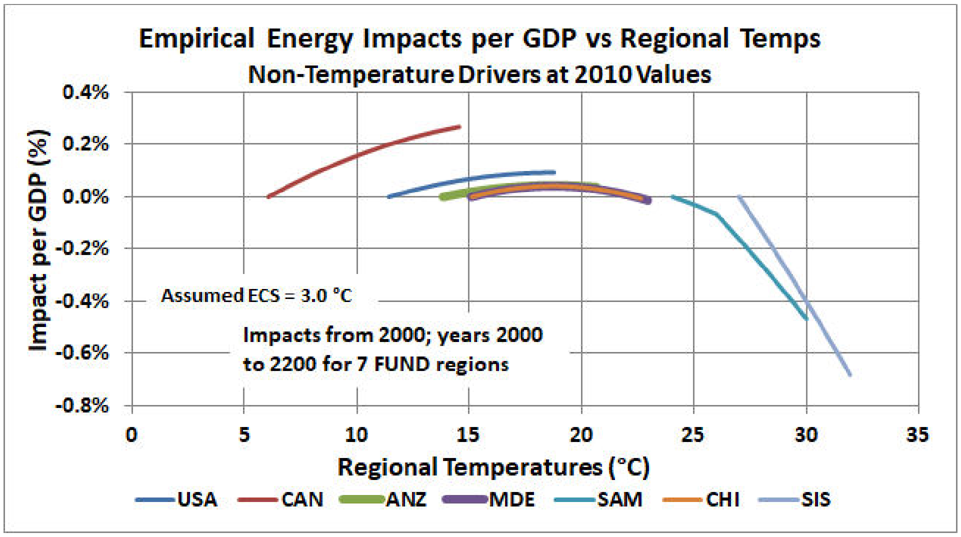

Figure 6.

Figure 7 shows the global energy impacts per GDP versus global temperature anomalies as per FUND and empirical data. Global energy impacts are the sum of the global heating and cooling impacts. Non-temperature drivers are at 2010 values.

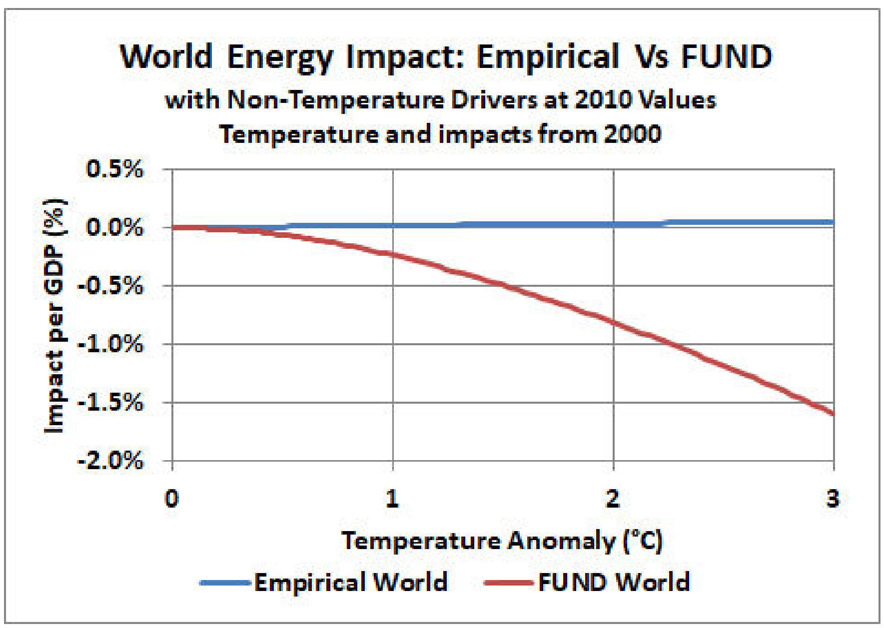

Figure 7.

Empirical data shows that the energy impacts of warming are positive, rather than strongly negative as forecast by FUND. A 3 °C temperature rise from year 2000 would increase GWP by 0.05% using empirical data. This is in stark contrast to the FUND projections which forecast a -1.59% per GWP impact.

Figure 8 shows the world energy impact per GDP according to empirical data and FUND with all drivers of energy expenditure change included, at two values of ECS. The red line shows the impacts of energy expenditures versus GMST anomalies from 2000 assuming an ECS of 3.0 °C. The purple line shows the energy impacts per GDP assuming an ECS of 1.0 °C. The temperature change is limited to 2 °C change from 2000 because at ECS = 1.0 °C, the time to reach 2 °C change is almost 150 years.

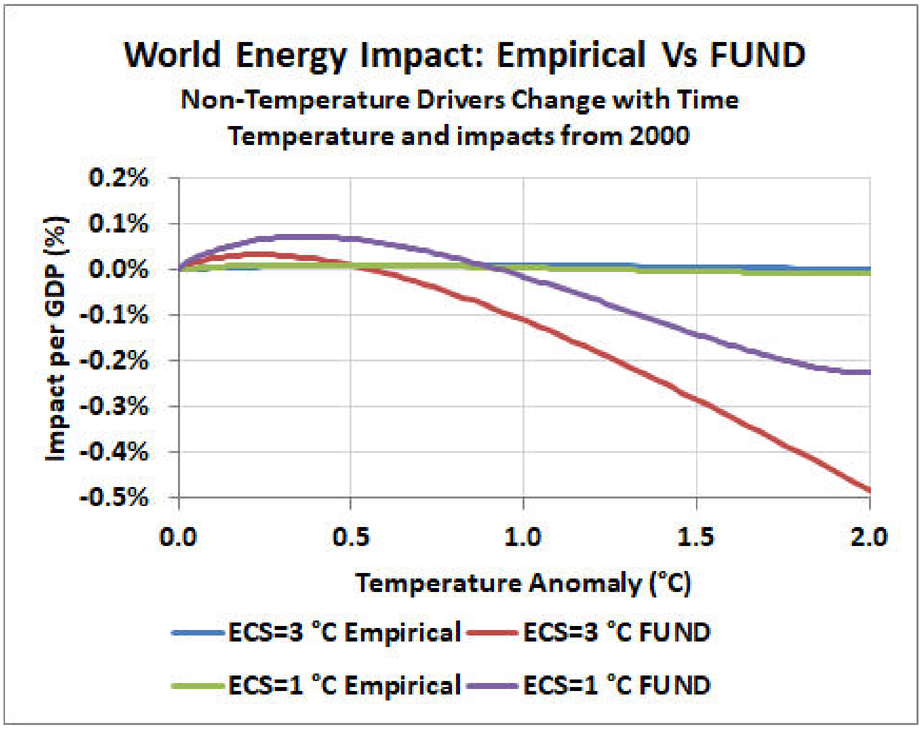

Figure 8.

A 2 °C temperature rise from year 2000 with all energy drivers included and assuming an ECS of 3.0 °C would cause no energy expenditure impact (0.00% of GWP). This is in stark contrast to the FUND projections which forecast a -0.48% GWP impact at a 2 °C above the 2000 temperature in the year 2074. The FUND forecast impact of energy costs, including the energy efficiency and GDP/capita impacts, is much less (smaller negative) than when considering only temperature impacts because those non-temperature impacts reduce energy use per GDP.

The FUND default ECS is 3.0 °C based on climate models. However considering empirical estimates of ECS and that the historical temperature record includes warming from both natural causes and by the urban heat island effect, the actual ECS is likely near 1.0 °C as shown in this study. Assuming an ECS of 1.0 °C, a 2.0 °C increase in GMST occurs in 2147, or 73 year after that temperature is reached with an ECS of 3.0 °C. A 2 °C temperature rise from year 2000 in this case causes a -0.22% of GWP energy impact from 2000 according to FUND, but only a -0.01% using our empirical data.

The total impact of a 2 °C temperature rise with ECS of 1 °C when considering all impact sectors is +0.86% of GWP according to FUND, but is +1.07% of GWP with the empirical energy impacts.

A new paper by Dayaratna, McKtrick & Michaels recommends that the CO_2 fertilization effect in FUND be increased by 30% due to recent studies of the effect. This would substantially increase the social benefits of CO_2 emissions. Figure 9 shows the impact of greenhouse gas emissions versus time from 2000 to 2200 using an ECS of 1.0 °C with the empirical energy impacts and all the other FUND impact sectors as the blue line. The red line also includes the 30% increase in the FUND CO_2 fertilization effect. The graph shows that the maximum benefit of emissions, with the empirical energy impacts, is +1.08% of GWP in 2164. Including the recommended increase in the CO_2 fertilization effect increases the maximum benefit to +1.45% of GWP in 2160.

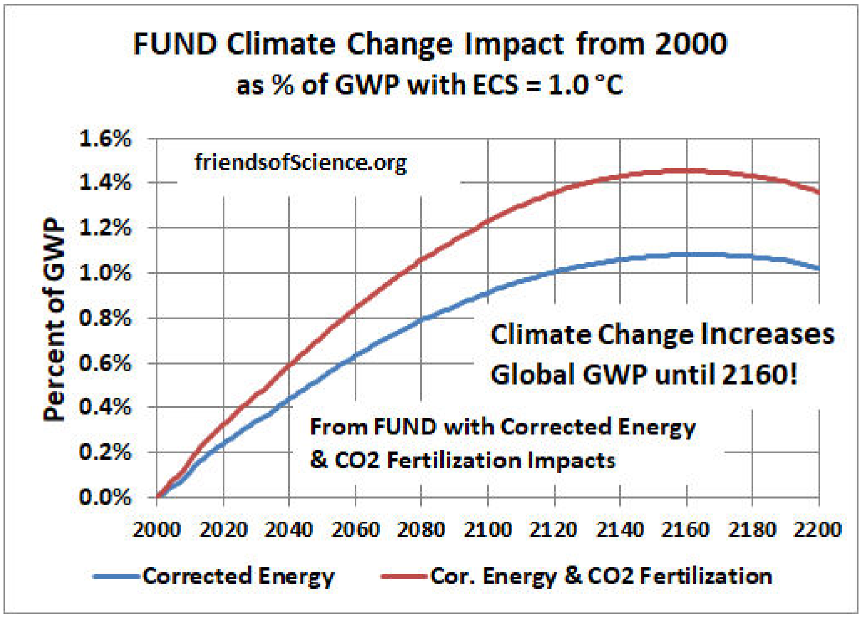

Figure 9.

In summary, the FUND energy impact sector is badly calibrated. The temperature impact on energy expenditures of a 3 °C temperature rise from 2000, with non-temperature drivers at 2010 values, is forecast in FUND to cause a wealth impact of −1.59% of GWP, whereas using our empirical results, the wealth impact is +0.05%, a difference of +1.64% of world wealth. FUNDS energy sector incorrectly assumes a very rapid saturation effect of heating cost savings with temperature increases which does not appear in the empirical data. FUND also calculates the energy impacts with respect to the GMST anomaly rather than the actual temperatures at the centre of populations in each region. This causes the energy impact profiles versus regional temperatures of the regions to be inconsistent. Including non-temperature drivers and using the realistic ECS of 1.0 °C, FUND forecasts a 2 °C temperature rise from 2000 would cause the impact of energy cost to by -0.22% of GWP, but a negligible impact using empirical data.

When including all impact sectors, a 3 °C temperature rise from 2000, with an ECS of 3 °C, is forecast in FUND to cause a loss of 0.68% of world wealth, but when the empirical energy expenditures are used, the loss becomes a benefit of 0.20% of world wealth. Using a realistic ECS of 1.0 °C, FUND forecasts a 2 °C temperature rise would cause a gain of +0.86% of GWP. This gain increased to 1.07% of GWP with empirical energy impacts, and increases further to 1.45% when including updated CO_2 fertilization effects.

Table 3 shows the impacts of a 2 °C temperature rise from 2000, occurring in 2147, assuming an ECS of 1.0 °C with empirical energy impacts and with both empirical energy impact and a 30% increase in the FUND CO2 fertilization effect.

Table 3.

Wealth Impact of 2 °C GMST Change from 2000 of All Impact Sectors per GDP (%)			
ECS = 1.0 °C	USA	Canada	World
FUND with emp. energy	+0.12%	+0.61%	+1.07%
FUND with emp. energy and +30% CO_2 fertilization	+0.19%	+0.65%	+1.45%

This study shows that CO_2 emissions have a large social benefit, so policies to restrict CO_2 emissions are harmful and misguided. The FUND model, with updated energy and CO2 fertilization impacts, shows that a 2 °C global mean temperature rise from 2000 would cause an increase of world wealth of 1.45%, equivalent to $_{2019}$US$1.26 trillion. I also note that FUND has estimated the private benefits of fossil fuel use expresses as a benefit per tonne of CO_2 emitted is $_{2010}$US$411/t$CO_2$. The private benefit of CO_2 emissions is often forgotten by those who want to restrict fossil fuel use. Both the private and social net benefits of CO_2 must be considered when formulating energy and environment policies.