

The Role of Energy Intensity in Global Decarbonization Efforts: How Fast? Is it Possible?



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Avoiding extreme or dangerous climate change will likely require the nearly complete decarbonization of the global energy system during this century, with 50-90% reductions in global CO₂ emissions by 2050 (GEA, 2012; IPCC, 2014; Loftus et al., 2015). These deep cuts in emissions must be achieved against a backdrop of growing global population and significant projected increases in demand for energy and energy-related services.

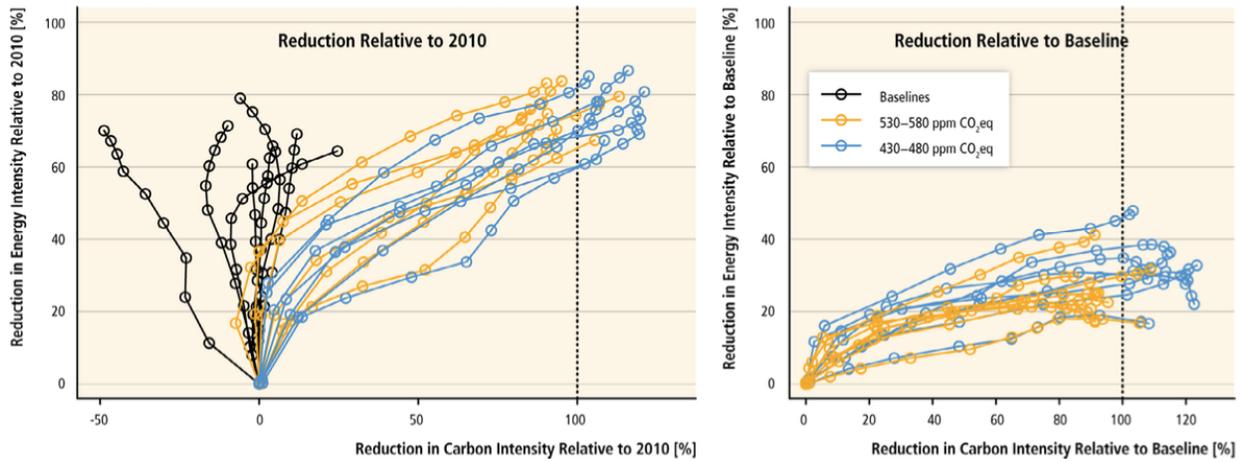
Driving global emissions down while economic prosperity expands and demand for energy services grows requires an unprecedented acceleration in the decarbonization of the global economy (Kaya, 1989). The quantity of CO₂ emitted per unit of economic activity, or the carbon intensity of the global economy, must decline at a rate of 4-10%/year, depending on assumptions about the pace of economic expansion and population growth (Loftus et al., 2015). By contrast, global carbon intensity declined at a rate of just 0.9%/year from 1990 to 2005, despite significant policy efforts in some countries (EIA, 2010).

Cutting CO₂ while keeping the economy growing will require improvements in the energy intensity of the economy — that is, declines in the amount of energy consumption per unit of economic output (i.e., GDP). It should come as no surprise, then, that energy intensity improvements feature prominently in almost all published scenarios proposing strategies to decarbonize the global economy and drive down emissions.

Energy intensity can be measured in one of two ways: (1) as the ratio of “primary” energy supplied, such as coal, oil, or renewable energy inputs, to GDP; or (2) as the ratio of the consumption of “final” energy, or usable forms of energy such as heat or electricity, to GDP. Regardless of which measure is used, published global decarbonization scenarios consistent with stabilizing atmospheric greenhouse gas concentrations at the equivalent of 430-480 parts per million of CO₂ all require dramatically accelerating the annual average rate of energy intensity improvement. Indeed, the rates envisioned in these scenarios stand in marked contrast with the historical rate of progress in energy intensity.

Loftus, et al. (2015) critically review 17 global decarbonization scenarios, finding sustained *primary* energy intensity improvements rates between 1.6% and 3.6%/year. Likewise, Working Group III of the Intergovernmental Panel on Climate Change (IPCC, 2014) presents a range of potential decarbonization strategies which rely on different combinations of energy intensity improvements and decarbonization of energy supplies (see Figure 1). These scenarios depend on improvements in *final* energy intensity at sustained rates between 1.0% and 3.6%/year over the next 50 years.

FIGURE 1. REDUCTIONS IN ENERGY INTENSITY AND CARBON INTENSITY OF ENERGY SUPPLY IN IPCC WORKING GROUP III CLIMATE STABILIZATION SCENARIOS



Development of carbon-intensity of energy supply (CO₂/energy) vs. final energy-intensity (final energy/GDP) reduction relative to 2010 in selected baseline and mitigation scenarios reaching 530-580 ppm and 430-480 ppm CO₂-eq concentrations in 2100 (left panel) and relative to baseline in the same scenarios (right panel). Consecutive dots represent 10-year time steps starting in 2010 at the origin and going out to 2100. Graphic source: IPCC (2014, WG III, Chpt. 6, p. 39).

Figures 2 and 3 compare the sustained rates in primary and final energy intensity improvements called for in these representative decarbonization scenarios with historical changes in energy intensity (presented as five-year rolling averages). Consistent with Loftus, et al. (2015), we group decarbonization scenarios into four groups, based on the stringency of energy intensity improvement rates required. Figures 2 and 3 show the range of energy intensity rates consistent with both “Group 1” scenarios, which all foresee sustained growth in global energy demand, and “Group 4” scenarios, which envision absolute declines in global energy use due to efficiency improvements. In general, Group 4 scenarios depend to a greater degree on demand reductions and include a more limited range of primary energy sources (i.e., primarily renewables) while excluding other technologies from consideration (Loftus et al., 2015), while Group 1 scenarios achieve more rapid decarbonization of energy supplies (IPCC, 2014) and include a greater diversity of low-carbon primary energy sources (i.e., nuclear and fossil energy with carbon capture and sequestration) (Loftus et al., 2015).

As these figures illustrate, primary energy intensity historically improved at an average rate of 1.3%/year from 1980-2000, but progress has slowed in recent years. The rate of improvement averaged just 0.3%/year from 2000-2012 and even began to reverse progress after 2008. Likewise, final energy intensity improved at 1.6%/year from 1980-2000 but at a rate of just 0.6%/year after 2000.

Compared to these historical rates, even the decarbonization scenarios envisioning the least aggressive cuts in energy usage (“Group 1” in the Figures 2 and 3) depend on sustaining energy intensity declines at rates matching the most rapid declines seen over the last 40 years and much faster than the average energy intensity improvement rate over the last decade.

FIGURE 2. GLOBAL TRENDS IN PRIMARY ENERGY INTENSITY: HISTORICAL RATES AND PROPOSED RATES IN DECARBONIZATION SCENARIOS

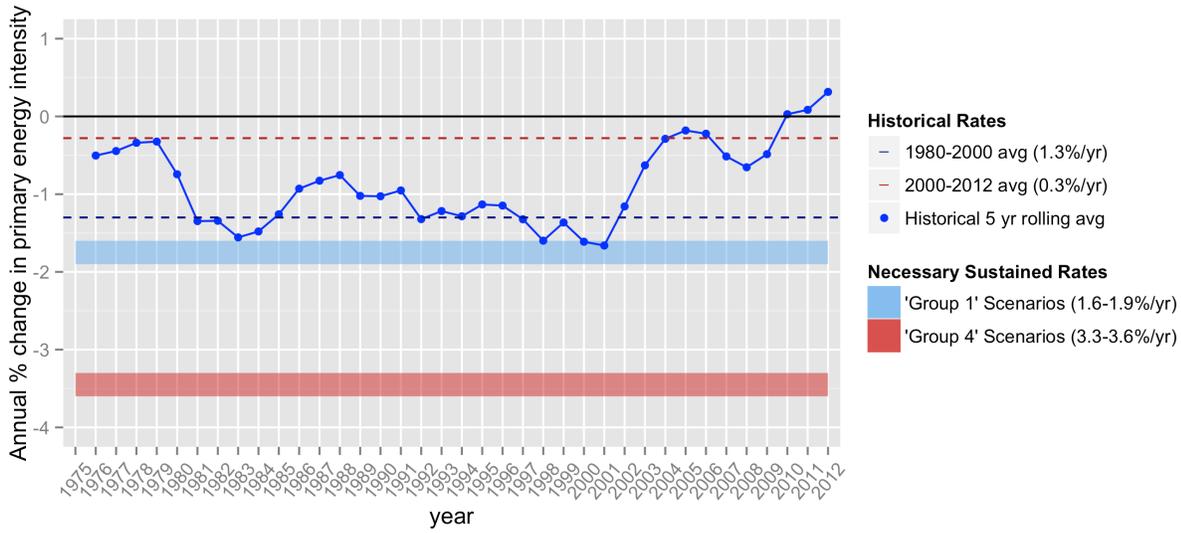
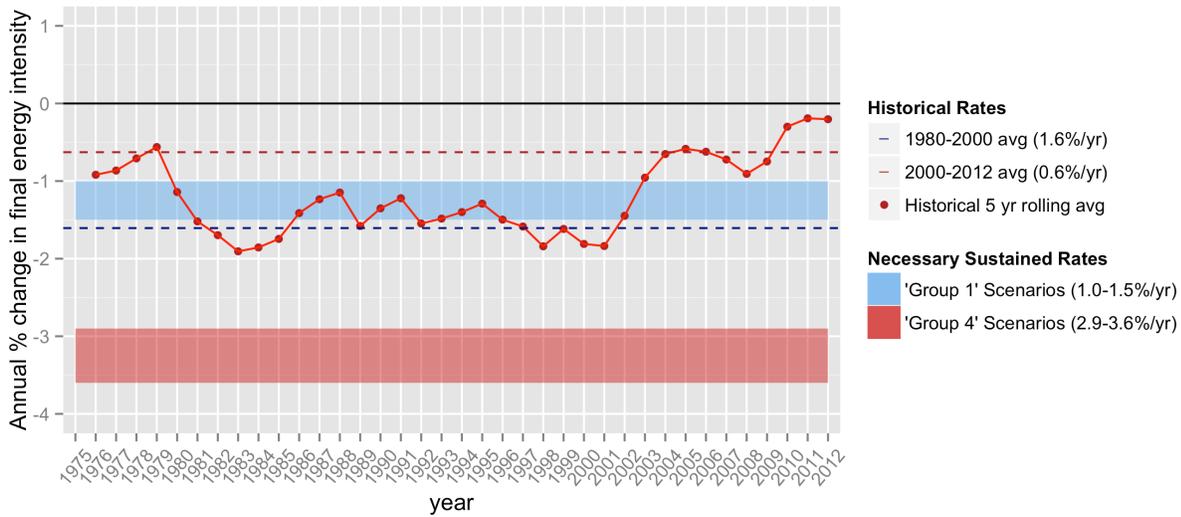


FIGURE 3. GLOBAL TRENDS IN FINAL ENERGY INTENSITY: HISTORICAL RATES AND PROPOSED RATES IN DECARBONIZATION SCENARIOS

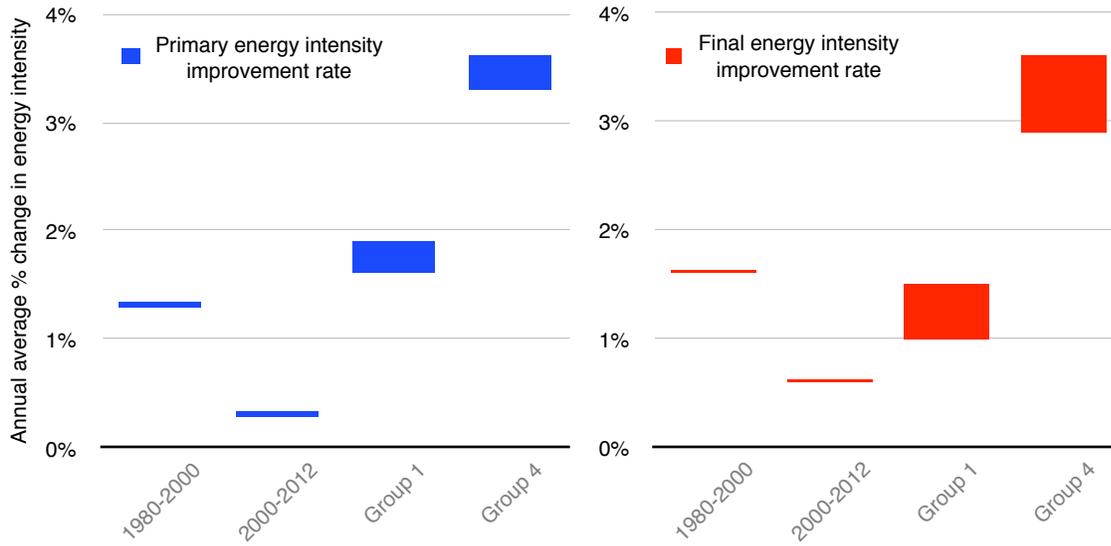


Historical primary and final energy data from IEA (2015). Historical GDP data from World Bank (2015). Prospective primary energy intensity rates from scenarios in Loftus et al. (2015) and final energy intensity rates from IPCC (2014, WG III, Chpt. 6, p. 39).

By contrast, scenarios which depend heavily on energy intensity improvements to hold global energy demand in check despite growing populations and affluence (“Group 4” scenarios) require roughly doubling the historical final energy intensity rate achieved from 1980-2000 and nearly tripling the primary energy intensity rate experienced over that period.

Furthermore, final energy intensity improvement would need to progress at up to six times the average rate experienced from 2000-2012 while primary energy intensity gains would need to see a twelve-fold acceleration (see Figure 4).

FIGURE 4. HISTORICAL AND PROPOSED AVERAGE ANNUAL PRIMARY (LEFT) AND FINAL (RIGHT) ENERGY INTENSITY IMPROVEMENT RATES



Historical primary and final energy data from IEA (2015). Historical GDP data from World Bank (2015). Prospective primary energy intensity rates from scenarios in Loftus et al. (2015) and final energy intensity rates from IPCC (2014, WG III, Chpt. 6, p. 39).

Is a dramatic acceleration of energy intensity improvement possible? To answer this question, we must consider that a number of different mechanisms drive the rate of change in global energy intensity, including:

1. *Sectoral shifts* in the composition of the global economy, such as the increasing importance of services as a share of global GDP, which tend to consume much less energy per unit of economic activity than heavy industry or agriculture;
2. *Substitution* of other economic inputs for energy, such as an increased reliance on capital or labor in productive processes in lieu of energy inputs; and
3. Improvements in *primary to final energy conversion efficiency*, or the efficiency at which “primary” energy supplies, such as coal, oil, or renewable energy inputs, are converted to usable, “final” forms of energy such as heat or electricity;
4. Improvements in *end-use energy efficiency*, or the amount of final energy inputs needed to deliver a given energy service, such as heating, cooling, transportation, or industrial process energy inputs.

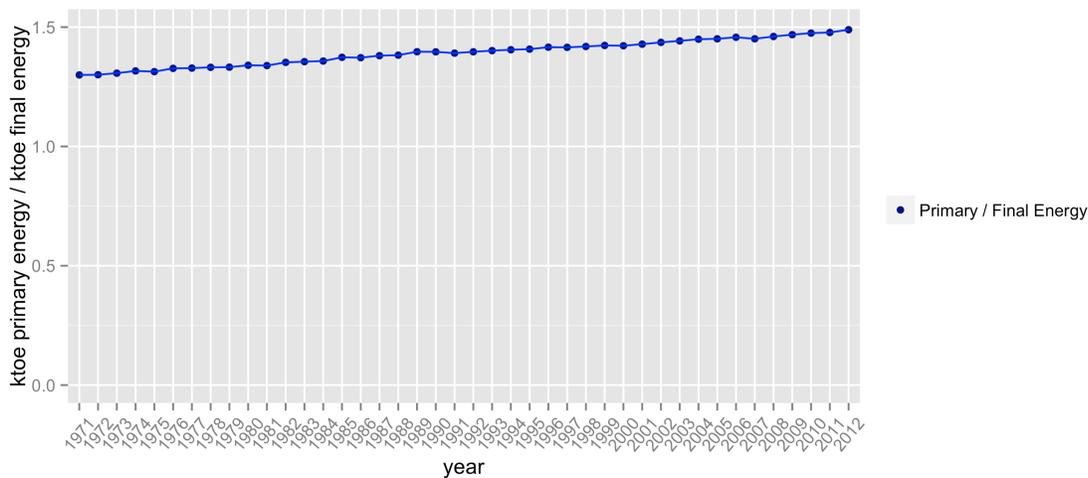
All of these processes contribute to reductions in the amount of energy necessary to support a given amount of economic activity. Yet only a few of these mechanisms can be affected by energy and climate policy levers. We will consider each mechanism in turn.

Sectoral changes in the makeup of the global economy have little to do with climate or energy policy, yet are an important driver of energy intensity trends (see Baksi & Green, 2007; Ma & Stern,

2008; Mulder & de Groot, 2013; Voigt et al., 2014; Wing, 2008). Energy taxes or carbon pricing may induce substitution of capital, labor, or other inputs in lieu of energy, but the efficacy of these policies is complicated by the many other factors driving the relative price and productivity of goods and services in the global economy and the complementary nature of energy and many other factors of production (see Kim & Heo, 2013; Vega-Carvera & Medina, 2000). In general, both of these mechanisms are affected by complex economic trends influenced by a wide range of factors far outside the scope of decarbonization policy

As Figure 5 illustrates, primary to final conversion intensity has been gradually worsening over the past four decades, with more and more primary energy required to produce a given quantity of useful final energy. If this trend continues, it will make it even more difficult to achieve the rates of primary energy intensity declines necessary to confront climate change.

FIGURE 5. GLOBAL HISTORICAL TRENDS IN PRIMARY TO FINAL ENERGY CONVERSION INTENSITY



Historical primary and final energy data from IEA (2015).

Going forward, a substantial transition from fossil-fueled power stations to nuclear and renewable electricity or an increase in the use of combined heat and power plants could help reverse this trend. On the other hand, electrification of heating, cooling, or cooking could reduce primary to final energy intensity, as using fuels to produce heat directly is typically more efficient than converting primary energy first to electricity and then to heat. Likewise, installation of carbon capture and storage at fossil-fueled power stations would reduce the efficiency of these plants, increasing the primary to final energy intensity of electricity generation. In short, the impact of decarbonization policies on primary to final energy conversion could be mixed, and in any case, has more to do with supply-side energy policies than the end-use efficiency policies typically associated with improvements in energy intensity.

Finally, end-use energy efficiency is the frequent focus of climate and energy policy making. Yet even here, the policy lever at our disposal may be smaller than it first seems. Indeed, actors in the global economy are constantly pursuing efforts to improve the productivity of inputs to production,

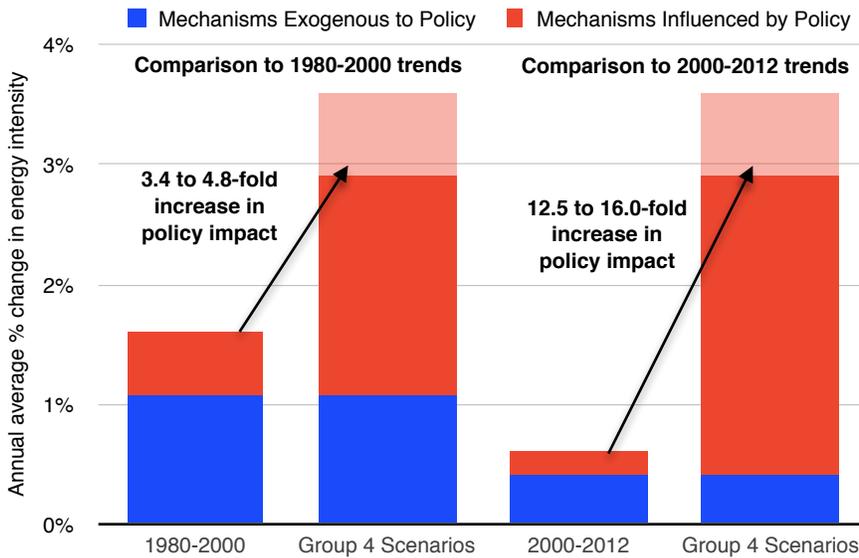
energy included. In short, we have a basic economic incentive to progressively squeeze more and more GDP out of a unit of energy, all else equal. As such, there is a long-term trend of improvement in the energy intensity of end-use economic activities, irrespective of energy policies (IPCC, 2014). From a policy-making perspective, this background rate of energy efficiency improvement is “autonomous” or “exogenous” to policy efforts.

From a climate policy perspective, this reality cuts both ways. On the one hand, decarbonization efforts can safely count on continued help from these autonomous efficiency improvements. Some portion of historical final energy intensity improvement rates are likely to continue into the future, irrespective of climate policy. On the other hand, the ability of policies to affect the rate of energy efficiency improvement is correspondingly diminished to the extent that much improvement is already “baked in” to business-as-usual trends and cannot be counted twice (Pielke, Wigley & Green, 2008).

In sum, after factoring in all of the mechanisms behind historical energy intensity improvement rates, it is difficult to find the policy “signal” in these “noisy” trends. Only a fraction of the overall final energy intensity improvement rates seen historically have anything to do with the wide range of end-use energy efficiency or climate policies pursued by a variety of nations over the past four decades. How large a lever then do policy makers hold as they seek to accelerate energy intensity improvements? The answer to this question is speculative, but of critical importance. Indeed, further research to decompose the mechanisms behind global energy intensity trends and identify those factors over which policy measures have influence could be of critical importance to designing effective decarbonization strategies.

After an initial examination of Figures 4 above, for example, one might easily conclude that accelerating final energy intensity to the rates envisioned by Group 1 decarbonization scenarios is trivial and the much faster rates envisioned by Group 4 scenarios could be accomplished with “only” a doubling or tripling of historical rates. Yet consider a speculative case where energy and climate policy efforts have influence over factors accounting for just one third of the historical energy intensity improvement rates experienced over recent decades. In that case, accelerating to the rates envisioned in the most aggressive (Group 4) scenarios would entail a 3.4 to 4.8-fold increase in the efficacy of policy efforts relative to 1980-2000 historical averages and a 12.5 to 16-fold increase in policy impact compared to 2000-2012 rates (see Figure 6). The relative importance of mechanisms over which policy has influence thus dramatically changes the outlook on the feasibility of scenarios envisioning rapid energy intensity improvements.

FIGURE 6. RELATIVE INCREASE IN POLICY EFFICACY REQUIRED TO ACCELERATE ENERGY INTENSITY TRENDS: A SPECULATIVE EXAMPLE



Historical primary and final energy data from IEA (2015). Historical GDP data from World Bank (2015). Prospective final energy intensity rates from IPCC (2014, WG III, Chpt. 6, p. 39). Share of historical and future trends due to mechanisms exogenous to or influenced by policy speculative and depicted for illustrative example only.

In conclusion, energy intensity improvements must play a critical role in efforts to decarbonize the global economy. Global decarbonization scenarios depend on a wide range of energy intensity improvement rates, some of which entail a dramatic acceleration compared to historical rates of improvement. As policy making has only limited influence over the mechanisms behind changes in energy intensity, critical attention should be paid to the ability of policy to accelerate energy intensity improvements. Further research should carefully unpack the mechanisms behind historical rates of change in energy intensity to further benchmark and calibrate global decarbonization strategies. Until then, scenarios calling for a step-change acceleration in energy intensity rates should be treated with caution.

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