For better or for worse: capacity utilization and the “investment rebound effect” in climate-economy modeling

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The paper will analyze how the use of neoclassical equilibrium macroeconomics causes climate-economy models to ignore the potential for major macroeconomic effects of the transition away from carbon intensive energy sources. If the economy is not operating at full capacity, as is argued by many strands of heterodox economics, then decarbonization could cause a significant increase in economic activity, causing the standard climate-economy models to simultaneously overestimate the economic costs (in terms of GDP) and underestimate the environmental costs of decarbonization and the energy transition. This “investment rebound effect” could be accounted for and incorporated as a feedback within existing models in a similar way the energy efficiency rebound effect is treated.

1. Introduction

In 2015, the nations of the world collectively set a goal to limit global average temperature increases over pre-industrial levels to well below 2 degrees Celsius by the end of the century, and preferably to under 1.5 degrees. In order to achieve a stabilization of global temperatures, the world will eventually need to approach net-zero emissions of the greenhouse gases which drive man-made climate change, a fact stressed in the International Panel on Climate Change's 2018 report on warming of 1.5 Degrees (IPCC, 2018). In this context, countries, regions, cities, and even non-governmental bodies like corporations have begun to set net-zero targets, indicating the dates by which they plan to sequester at least as many emissions as they produce. These targets are not without their problems, as many lack the short term commitments needed to be in line with the indicated long term goals. And even if fully met, the long term commitments are not yet large enough to meet the goals set out in the 2015 Paris Agreement (United Nations Environment Programme, 2020). Still, these commitments are important because they do indicate that decarbonization policies, and the politics and economics which go along with them, are not a passing trend but will almost certainly be with us for decades to come.

While the science of climate change has achieved a high level of consensus about the process by which increasing greenhouse gas concentrations lead to average temperature increases, the economics of climate change are much less developed. Decades of research have produced dozens of integrated climate-economy models—also know as integrated assessment models, or IAMs—but this suite of models have yet to produce clear consensuses about the range of possibilities regarding key questions such as how either decarbonization activities or climate change itself will affect the macroeconomy.

Given the space to improvise, many politicians who are sympathetic to decarbonization have chosen to emphasize the possible up-side of decarbonization on the economy, with both progressives in the United States and the European Commission framing their climate activities in comparison to the expansive jobs and social welfare programs of the U.S.'s New Deal. In this rosy framing, decarbonization is not an economic deadweight to which resources must be diverted, but is rather an opportunity to boost economic activity and fix long standing economic issues of inequality and unemployment.

Economically speaking, the politicians' story is very plausible. As the world recovers from the economic contraction generated by the COVID–19 crisis, there is broad agreement that there is still slack in the global economy. If this is the case, government-financed decarbonization investments could indeed result directly in more growth and potentially more jobs. Longer term, it is possible that the energy transition from fossil fuels to renewables for energy generation could boost overall jobs levels, as renewable technologies tend to be more labor intensive and are more geographically disperse than their non-renewable counterparts. Decarbonization will also require many labor intensive activities which must be carried out on-site, from retrofitting old buildings to planting trees or preserving wetlands, which could provide a steady flow of non-outsourceable jobs for the foreseeable future.

The world of climate modeling however takes a less sympathetic position. In the large majority of the major climate-economy models used to project potential emissions pathways and the resulting climate effects, including all of the models used in the IPCC's 2014 5th Assessment Report, decarbonization has a strictly negative effect on economic activity, with each dollar of mitigation driving global GDP further and further down.

A small number of more recent models, particularly those by international organizations, show a more ambiguous picture, with possible small economic gains from investments in the first few decades, but a return to the status-quo equilibrium (or worse) over the course of the century. Few, if any, models allow for sustained decarbonization investments to have large and persistent positive effects on economic growth—the kind of beneficial effects currently being used to pitch decarbonization in most advanced economies. These large positive effects are not outside of the realm of economic possibility: indeed, they are exactly what would be expected in a number of Post-Keynesian economic frameworks in which the economy is not assumed to operate at full capacity in the long run. However, in the climate-economy modeling world, this 'Green New Deal led growth' is not only not predicted, in almost all cases it is explicitly excluded on theoretical grounds.

This situation is problematic not because the models prove the politicians are wrong, but because it means we are unprepared to understand what will happen if they are right and decarbonization generates a sustained economic boom. Economic growth is a complicated phenomenon, particularly in the context of decarbonization. On one hand, faster growth makes the needed investments in decarbonizing infrastructure appear less costly, as they will be paid for by a richer society and can be financed out of a larger overall economic pie. On the other hand, unless economic growth is fully decoupled from greenhouse gas emissions, faster growth will also increase the size of the problem which needs to be solved, as more economic activity drives more emissions and places other pressures on the earth's ecosystem. In this sense, some amount of each decarbonizing investment will be 'rebound' into new emissions somewhere else due to the investment's positive effect on growth.

In late February 2020, just days before Europe and the United States joined China and much of Asia in imposing severe mobility restrictions in response to the COVID-19 pandemic, McCollum et al. published a Nature Commentary piece calling on climate-economy modelers to "explore extremes" such as geopolitical realignment, structural economic changes, waves of social resistance to technological change, and things which are "not even on the radar". Their advice was well timed, although their specific examples of extremes failed to include the global pandemic which had just begun. A more foreseeable extreme is the possibility that the politicians, activists and non-economists who promote Green Deal policies are indeed correct about the economic consequences of their agenda, and global decarbonization will go hand in hand with rapid GDP growth.

Better understanding this potential future requires adaptations to current climate-economy modeling frameworks which are, for the most part, methodologically unable to capture and assess potential positive effects of investments in decarbonization on growth. This adaptation could be similar to the "rebound" framework used to understand the effects of increasing energy efficiency, in which some, or potentially all, of the expected energy saving from added efficiency are eroded by parallel increases in consumption driven by the efficiency improvement itself.

This conference paper will proceed by offering a short introduction to emissions pathway modeling (Section 2), followed by a summary of the treatment of economic growth in major types of models (Section 3), an overview of the relationship between growth and investment in post-Keynesian economic theory (Section 4), and finally a discussion of the possibility of a significant investment rebound effect and its implications (Section 5).

2. Integrated assessment modeling and scenario analysis

The economic aspects of climate change are widely analyzed using integrated assessment models (IAMs). These models are built by combining a number of separate 'modules' which model different aspects of the economy-climate-environment system. IAMs typically have both an economy module which projects economic activity and a climate module which projects emissions levels and their corresponding levels of warming. Other modules representing things like the energy system, land use and agriculture, and technological development are also common. Other physical and environmental factors such as biodiversity loss, materials use, or resource availability can also be included as modules, although molding these specific topics currently remains a largely unexplored field.

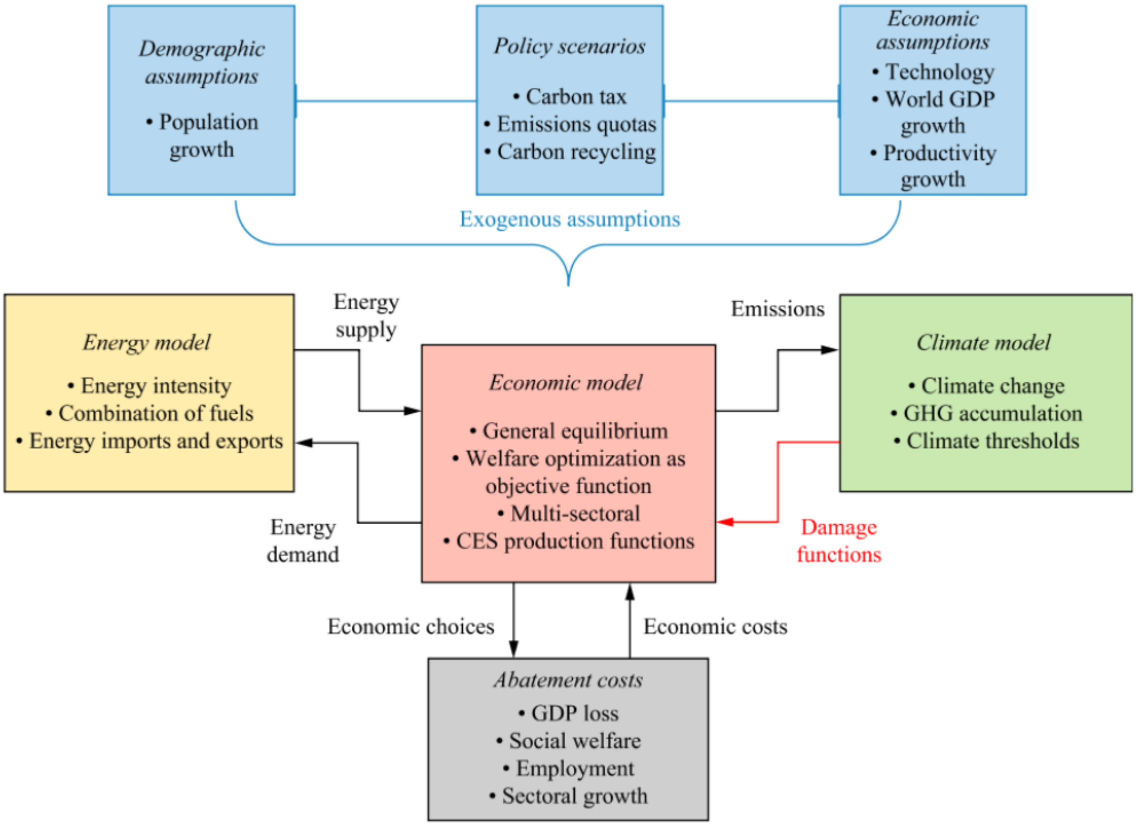
2.1 Types of IAMs

There are two main types of IAMs which are primarily used to analyze two distinct sets of questions. The first, *optimized growth models*, analyze the expected levels of economic damages that will be caused by climate change while the second, *emission pathway models*, attempt to show various potential scenarios for future economic, technological and environmental development.

Optimal Growth models attempt to estimate the damages which will be caused at various levels of climate change. These models are set up as cost-benefit analysis which simultaneously estimate the expected costs of climate change and the expected costs associated with mitigating climate change to produce an "optimal" level of global warming at which the avoided damages of climate change match the costs of further mitigation. A pioneering example of these types of models is the DICE model developed by William Nordhaus (Nordhaus, 1992). Following the typology developed by (Nikas,et al., 2019), these models can be described as "optimal growth" models, as they maximize economic growth over the long term, given the potential for climate damages. These models are typically relatively simple and include a very limited number of additional modules beyond the core climate-economy analysis. They are often global, but can also be done at a regional or national level. Optimal growth models have come under criticism recently both for some of their simplifying assumptions about how climate change will affect the economy, and for the limited size of their ultimate estimates of the economic damages of climate change (Keen 2020; Asefi-Najafabady, Villegas-Ortiz, and Morgan 2020; Woillez, Giraud, and Godin 2020).

Emission pathway models are a large range of modeling frameworks which generate plausible scenarios of possible emissions pathways given particular economic and technological developments. Instead of trying to optimize growth over a particular period, these models look to describe a coherent future by modeling the economic and technological possibilities for achieving various emissions levels. Emissions pathways models can either work backwards from a set target—for example, showing various paths which could achieve 2 degrees of warming by 2100—or can simulate from a starting point forward, analyzing how various policy choices or other developments affect the environmental and economic outcomes at the end of the simulation period. Policy choices and technological development can be modeled in significant detail in emissions pathway modeling, although a large majority of models rely on a universal carbon price as a stand-in representation of all other decarbonization policies. These models can also focus specifically on individual sectors, with a large number of models focusing in particular on the energy sector. Often the climate-economy components of the models can be combined with various other modules, resulting in extremely extensive and complex final modeling frameworks. There is an ongoing discussion about the complexity and transparency of these models, as their large scope and interconnectedness makes it difficult to isolate the causes of particular results or to explain how various assumptions or modeling decisions are reflected in results (Keppo *et al.*, 2021). Modeling can be done at virtually any level, with global and national models being common, but also models at the regional, city and even neighborhood level (Pfenninger and Pickering, 2018). Currently very few emissions pathways models, and none of the models used in the 2018 IPCC report, incorporate climate damages directly as feedbacks into their scenarios (IPCC, 2018 p. 109). A useful schematic representing the basic structure of most emissions pathway IAMs is provided in Figure 1 by Rafael Cattan and Florent McIsaac, 2021.

Figure 1: A schematic representation of integrated assessment models



(Rafael Cattan and Florent McIsaac, 2021)

There are a number of different economic modeling methodologies which are used to form the core economy modules within any given IAM, a topic which will be discussed in greater depth in Section 3. The remainder of this conference paper will refer primarily to emissions pathway models.

2.2 Using emission pathway models: scenario analysis

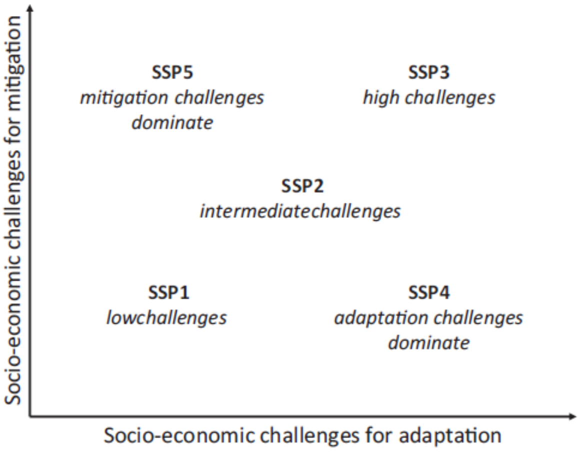
Emissions pathways models are highly influential in policy. They are the primary source for the socio-economic portions of the IPCC's reporting framework, and form the basis for international climate negotiations at the various Conference of Parties (COP) events. They are also used by governments, businesses and non-governmental organizations to plan for decarbonization and are the backbone of many national and regional reports on climate change mitigation. Energy-focused models in particular can be created at extremely high resolutions (down to the building level in some cases), allowing their use by cities and urban planners.

These models are not forecasts or predictions of what will happen, but rather are tools for understanding the various coherent ways in which target emissions outcomes can be achieved. They are intended to show a range of plausible futures and to provide insights into the most important components for achieving a desired emissions pathway. IAMs are regularly used to create ‘roadmaps’ which detail the path that a country, or the world, could take to achieve net-zero emissions by a certain date. These roadmaps can be very detailed and often provide specific numbers for topics like the rate of deployment of various key technologies or the number of jobs in various parts of the energy sector in a given year of the scenario. Energy-climate models can also be used to analyze more topical questions by changing key assumptions, inputs, or policy responses to see how the model responds. For example, many models now estimate the various ways decarbonization technology could develop going forward to see what the effect, for instance, of the average costs of things like renewable energy generation, nuclear energy, or carbon capture and sequestration being very high or very low (E. Larson, *et al.*, 2020). Similar scenarios have also been created for various levels of resource availability to analyze how the climate-economy system could develop with either very high or very low levels of fossil fuel availability (Capellán-Pérez, de Castro and Miguel González, 2019; Samsó *et al.*, 2020).

Two other key questions for climate-economy modelers are: 1) the choice of background input assumptions and 2) the emissions targets modeled. All IAMs need to provide background assumptions for key topics like demographic, economic and technological development, while only models which work backwards from a given level of emissions (as opposed to models which simulate forward) need to set emissions targets.

Standardized background assumptions and emissions targets are often combined to allow for easy comparison across models. Two important tools for these comparisons are the Shared Socioeconomic Pathways (SSPs) and the Representative Concentration Pathway (RCPs). The SSPs provide specific background assumptions for population, urbanization, education, and GDP growth for five different scenarios (Riahi *et al.*, 2017). The scenarios are categorized by their ease of mitigating climate change on one hand and their ease of adapting to climate damages on the other hand. This creates five numbered SSPs, with #1 representing a world with low adaptation and mitigation challenges, #3 representing a world with high adaptation and mitigation challenges, and the others falling somewhere in between. Separately, the RCPs provide a set of significantly different emissions concentration levels ranging from very low (RCP 1.9) to very high (RCP 8.5). Each RCP is labeled after the amount of radiative forcing (in W/m^2) generated by the given emissions level (van Vuuren *et al.*, 2011).

Figure 2: The Shared Socio-economic Pathways



(Dellink *et al.*, 2017)

A common framework then is to pair the SSPs with the RCPs to see the climate possibilities given various demographic backgrounds. In concrete terms, a modeler will pick a starting SPP, and use it to try to find paths to achieve a particular RCP. A key insight to come from this modeling is that some socio-economic pathways are incompatible with some RCPs, as the models are unable to find paths to the very high or very low emissions concentrations from the more extreme SSPs (Riahi *et al.*, 2017).

The importance of the SSPs for our discussion is that they set exogenously the status quo level of economic growth for the models which use them. This sets the starting point of what growth would be like in the absence of either climate change damages or mitigation activities, and deviations away from this level of growth generated by the model are a potential way to measure the total ‘costs’, or potential benefits of climate change mitigation. For a sense of scale, the baseline growth rate in SSP #2, the pathway labeled “middle of the road” which is often used as representation of current trends, shows global growth rates falling from roughly 3% a year to 1.7% a year by mid-century, where they stabilize until the end of the model in 2100 (Dellink et al., 2017). None of the SPPs represents negative economic growth at any point in the century.

3. Integrated assessment model design and economic growth

The core economics module of each IAM can be designed in a number of different ways. Each type of modeling puts restrictions on the possible relationship between the other outputs of the model (like technology adoption or decarbonization investments) on the overall level of economic activity generated by the model. There are two primary methods for treating the economics of IAMs: equilibrium modeling and macro-econometric modeling. There are also a small but growing number of IAMs based on systems dynamics models, as well as growing interest in creating agent based climate-economy models. While the results of each model will be determined to a large degree by the specific assumptions and calibrations which go into it, the choice of model structure places key limits on how growth can be affected by policy interventions.

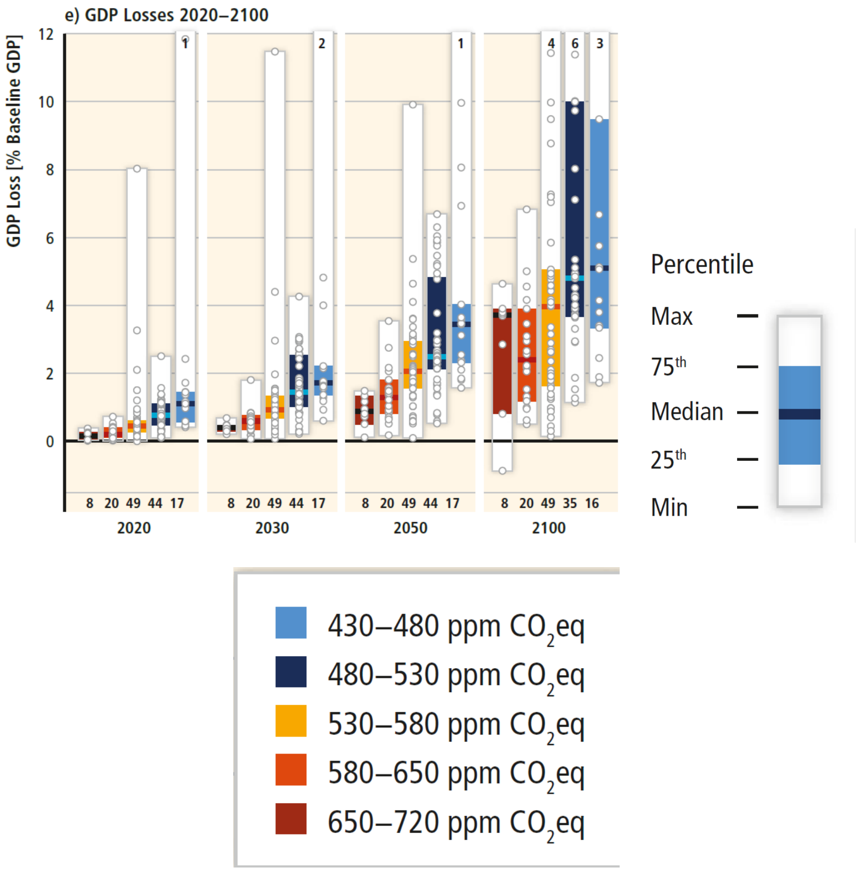
3.1 Equilibrium models

The majority of emissions pathway models, including all of the models used in the IPCC's 5th Assessment Report, use general equilibrium modeling to represent the economy. Most models are computable general equilibrium models (CGE) in which the path of the entire economy is optimized, typically at a sectoral level. A smaller number of models are partial equilibrium models in which only one sector—typically the energy system—is fully optimized while the rest of the economy is assumed to follow the status quo.

General equilibrium models work by assuming that the economy starts in a state of optimized equilibrium and constantly operates at full capacity. In the absence of policy interventions, the economy is assumed to reach its full potential, as defined by the inputs to the model, typically set by the Shared Socioeconomic Pathways. In order to achieve a certain climate target, new policy measures are introduced into the model. Typically, these policies are represented as a universal tax on emissions, which is gradually increased as time goes on to squeeze more and more emissions out of the scenario. In this framework, new investments in emissions mitigating technology are fully offset by reductions of investment and consumption elsewhere in the economy, meaning they can have no direct positive impact on short term growth. Energy transition investments are also assumed to decrease the long-term productivity of the economy, as they are not the optimized investment decisions that would have been made absent policy intervention. This leads to significant long-term reductions in growth, particularly when the carbon tax reaches extremely high levels in the second half of the century. This unbalanced growth effect, in which investments can have negative effects on the supply side of the economy but no corresponding positive effects on the demand side, means CGE models will by definition treat decarbonization as an overall economic cost in terms of GDP.

The results of scenarios generated by the leading IAMs regarding the GDP effects of decarbonization are represented in Figure 3 from the 2014 IPCC 5th Assessment Report (Clarke L. et al., 2014). The chart shows the total GDP losses in each scenario in four time periods, 2020, 2020, 2050, and 2100, and the emissions concentrations achieved in each scenario, with the highest in red and to the left within each time period, and the lowest emissions pathways in light blue and to the right. The bottom numbers show the number of scenarios represented in each box plot, while the numbers on top of the chart show the number of scenarios which had higher GDP loss values than the 12% maximum shown on the chart.

Figure #3: GDP losses in IPCC 5th Assessment Report emissions pathways



(Clarke L. et al., 2014 p. 450)

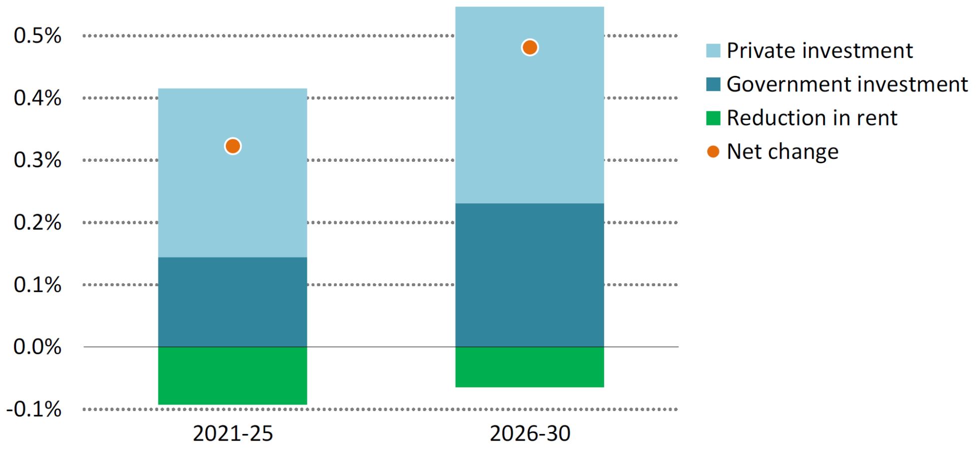
Strikingly, all but one of the scenarios has negative costs of decarbonization, with the only scenario with negative costs occurring in 2100 with a very high level of emissions. The scenarios with lower emissions concentrations have significantly higher GDP costs, reflecting the additional policy support and corresponding productivity losses from non-optimal investments needed to achieve decarbonization.

In principle, these equilibrium models could be augmented by including various market imperfections and frictions which would prevent the model from achieving full capacity in the short or medium runs. These imperfections could also be such that decarbonizing policy interventions actually corrected the market, making it more efficient and thus having a positive effect on growth, at least in the short run. There has already been some work to develop equilibrium models with imperfections at the national level (*DREAM Denmark*, 2021), and it is possible that global models with imperfections could be included in the IPCC's Sixth assessment report, due for release at the end of 2021.

A similar method was employed by the International Energy Agency in their recent Net Zero by 2050 report in which they took the investment outputs from their climate-economy model and used them in the IMF’s Global Integrated Monetary and Fiscal (GIMF) dynamic stochastic general equilibrium model to see the short-term effects of decarbonization on growth (IEA, 2021). The results, depicted in Figure 4 show small but significant gains to annual global growth rates up until the year 2030, which the report describes as the “medium-term”. They do not provide estimates past 2030, but given the long run tendency towards full capacity embedded within general equilibrium modeling, it seems very likely that the reported gains fade out and reverse relatively shortly after 2030.

Figure 4: Annual growth rate of Global GDP in IEA Net Zero Case compared to baseline

Figure 4.3 ▷ Change in annual growth rate of global GDP in the NZE relative to the STEPS



IEA. All rights reserved.

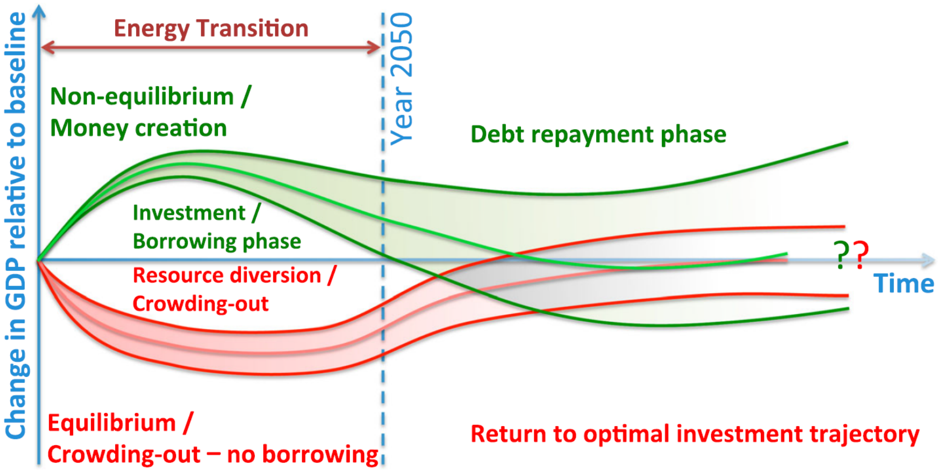
(IEA, 2021, p. 156)

3.2 Macroeconometric models

A second class of emissions pathway models are based on macroeconometric modeling. These models build a set of theoretical relationships within the economy and then use real world data to econometrically calibrate the coefficients of these relationships (Christian Lutz and Ulrike Lehr, 2019). The models then simulate forward to create scenarios based on both the structural relationships of the economy embedded within the model, and the inputs provided to the model to create a given scenario. Critically, unlike equilibrium models, macroeconometric models do not assume the economy operates at full capacity in the short or medium terms, but rather allow the level of economic activity to fluctuate based on the demand generated by previous periods in the model. This means that, at least in the medium run, changes in investment levels can directly increase economic growth, in line with econometrically estimated investment-growth trends found in historical data. Macroeconometric models generally rely on input output databases at the sectoral level.

Mercure et al. 2019 provide a useful stylized representation of the difference between macroeconometric and general equilibrium models in regard to economic growth, with macroeconometric models labeled as "non-equilibrium" in their figure. In their depiction, non-equilibrium models start with a boost of growth from new investment spending, facilitated by endogenous money creation and borrowing. This boom wears out by mid-century, at which point GDP slowly converges back to the long run trend. In Equilibrium models as previously discussed, decarbonization has purely negative effects on growth, which slowly wear off as the world reaches net-zero emissions and can return to making optimally productive investments.

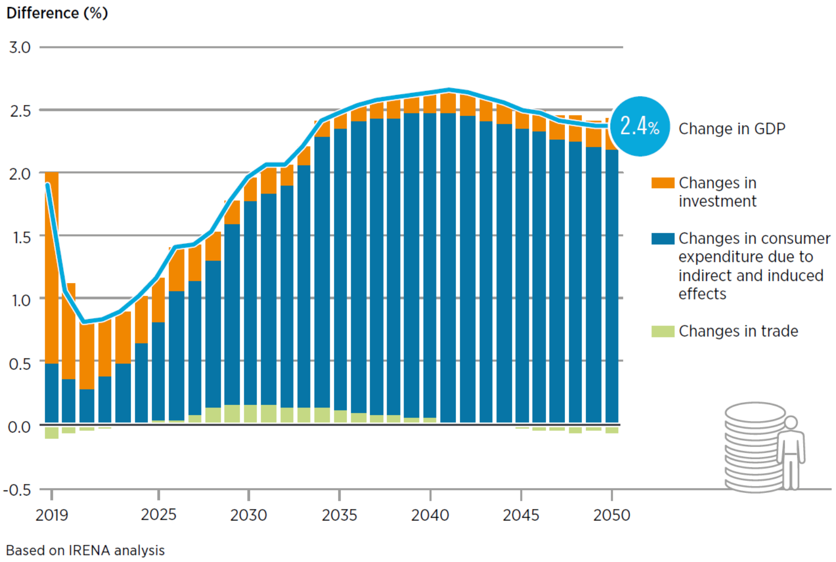
Figure 5: Economic Growth in Equilibrium and Non-Equilibrium models



(Mercure *et al.*, 2019)

For a less stylized example of growth effects in macroeconometric models, we can turn to the recent Global Renewables Outlook 2020 of the International Renewable Energy Association (IRENA), which is based on the macroeconometric E3ME model developed by Cambridge Econometrics (IRENA, 2020). This scenario, which proposes decarbonization in line with 2 degrees warming and makes heavy use of renewable energy, includes extensive details about the effects of decarbonization on various economic factors, including jobs and growth. Their growth projections, shown in Figure 6, show large positive effects from new investments in the early years of the transition, with investment effects shrinking and stabilizing by 2030. From then, large consumption effects kick in, driven by a revenue-neutral carbon tax which is reimbursed back to households.

Figure 6: Growth over baseline in IRENA Transforming Energy scenario



(IRENA, 2020, p. 109)

3.3 System dynamic and agent-based modeling

Finally, there are two other types of modeling which are currently only used by a very small number of IAMs, but have the potential to become more popular in the future. The first, systems dynamics modeling has a long tradition in modeling energy and resource use and is currently used by at least one large scale global emissions pathway model. The second, agent-based modeling, has quickly become more popular within economics, particularly for analyzing the financial sector, and is a promising tool for creating larger emissions pathway models.

As their name suggests, systems dynamic models are designed to capture the complex and dynamic interactions between the various components represented within the model. They do so by integrating a large number of algebraic equations which are then simulated by computer. The models are path dependent, and can be combined with sectoral input-output databases to calibrate them to the real world. They generally work forward through simulation rather than backcasting from an emissions target.

These models gained popularity after the 1972 publication of *The Limits to Growth* by the Club of Rome, which featured the World3 systems dynamics model (Donella H. Meadows *et al.*, 1972). World3 was designed to analyze the interactions between demographic changes, economic growth, and resource availability and found the possibility of large and sudden crashes in economic activity due to gradually declining energy resource availability. The World3 model is often noted as an inspiration for a series of system dynamics models of the energy system developed in the following decades.

There is currently one prominent large-scale global emissions pathway model based on systems dynamics. The “MEDEAS” model, is a newly developed IAM which attempts to achieve a higher level of realism by introducing both bio-physical constraints and an open demand-led economic framework in which the decarbonization policies analyzed by the model can have both positive and negative growth effects (Capellán-Pérez *et al.*, 2020). MEDEAS is an open source project with packages available for both the global and European levels, and is being further developed in the ongoing LOCOMOTION project (*LOCOMOTION*, 2021).

One early finding from the MEDEAS framework is that, much like in the original World3 model, limits on energy resource availability can lead to sharp declines in economic activity. Figure 7 shows the results for three scenario runs in MEDEAS: A business as usual (BAU) scenario showing a continuation of current trends, a Green Growth (GG) scenario designed to represent a global turn to pro-growth decarbonization policies and a Post-Growth (PG) scenario in which global GDP growth rates are intentionally decreased, with active ‘degrowth’ targeted in richer countries. Figure 7 shows the GDP growth levels of the three scenarios through 2050 both with and energy resource limits (the lighter lines) and without (the darker lines). In both the business as usual and green growth scenarios, including energy limits causes sharp crashes in growth compared to the model without such limits. For business as usual, these limits are reached quickly, with limits in oil and other fuels driving low, and eventually negative growth rates, while the green growth scenario runs into solid fuel limits in the medium term which significantly limits growth. As a qualitative explanation of the Green Grown scenario, the primary issue in the model is that the growth generated by the model increases energy demand faster than the corresponding increase in renewable energy provided by the energy module of the overall model.

This forces the scenario to rely on solid fuels which drive up emissions well past the range needed to keep warming to the 2 degree goal, and result in limited fuel availability when energy limits are accounted for (Nieto *et al.*, 2020).

Figure 7: Growth projections in MEDEAS scenarios

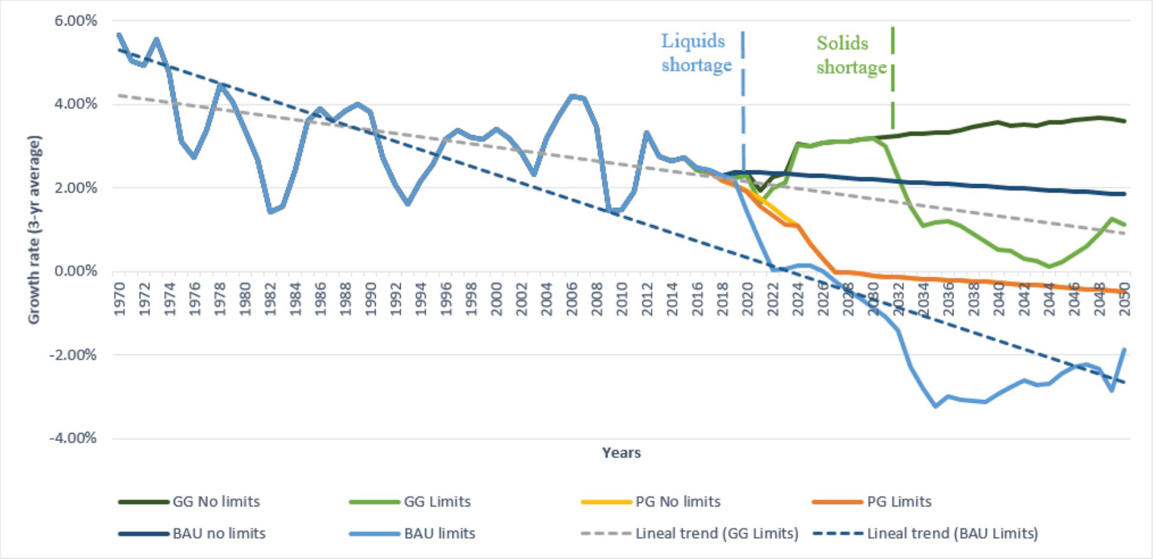


Fig. 8. GDP growth scenarios (3-yr mobile average). Source: own elaboration on the basis of MEDEAS World results.

(Nieto *et al.*, 2020)

While the above analysis of the MEDEAS scenarios does not focus directly on the growth effects of decarbonization policies, they note that the input growth rate for the Green Growth scenario was 2.55, meaning this was the initial targeted growth rate from which the model endogenously produced the final growth numbers. In the Green Growth without limits scenario, the final annual growth rate gradually increases from approximately 3% to 4% until 2050, implying large, significant and persistent growth effects from the policies analyzed by the model. This additional growth also appears to be quite important when energy limits are introduced into the model, causing both higher emissions and resource availability problems which ultimately undermine the stability of the scenario.

Finally, apart from system dynamics modeling, there has also been interest in using agent-based techniques which can represent heterogeneous actors to create integrated assessment climate-economy models (Hoekstra, Steinbuch and Verbong, 2017; Lamperti *et al.*, 2019). There has been at least one attempt to apply agent-based modeling to the question of the economic cost of climate change —the question currently addressed primarily by optimal growth models referenced above—but there are currently no large-scale global emissions pathway models using agent based modeling (Czupryna *et al.*, 2020).

4. Post-Keynesian economics suggests large and persistent growth effects are possible

4.1 Aggregate demand in Post-Keynesian economics

The equilibrium climate-economy models referenced above are based on neoclassical economic theory in which the economy is imagined to tend towards full employment of both labor and capital as competition between firms will continuously drive excess capacity out of the system. The total level of economic activity in this framework is determined then exclusively by the economy's productive capacity, as it is assumed that over time this capacity will be ultimately realized. This is important for climate economy-models, because it explains how decarbonization policies—typically represented simply as carbon taxes—manage to have such strong negative effects on long term economic growth. By introducing a large and far reaching tax into the economic model, a large number of investments which would have otherwise been seen as the most productive option are rejected due to the price distortions introduced by the tax. Over time, the model will select progressively less and less productive investments than it would have in an optimized equilibrium growth path, leading to a lower and lower long term productive capacity for the economy. As productive capacity is assumed to equal economic activity in the long run, this 'supply side' effect directly drives down growth without the potential for corresponding demand effects to counteract the productivity losses.

While the assumption of long run full employment is part of the core of neoclassical economics, it is not universal within economic theory. In particular, Post-Keynesian economic theories typically start from the exact opposite assumption and envision the economy as generally operating underneath its full potential capacity. In this framework, economic activity is determined not just by the overall level of productive capacity (the supply side), but also by the amount of the capacity which is able to actually be realized by the level of aggregate demand in the economy. Aggregate demand is conceived of as the total level of investments, consumption, government expenditure and net-exports in the economy. Each of these factors is free to fluctuate within the Post-Keynesian model within the overall limit set by the productive capacity of the economy, with increases in any factor directly resulting in higher levels of economic activity. This is in comparison to the neoclassical model in which the four factors can also fluctuate, but with a fixed total level such that an increase in one factor, say government spending, will necessarily be offset by corresponding decreases of the same size to the other factors in the long run.

The implications for decarbonization and the energy transition are apparent: in the neoclassical framework the transition can only create growth if it can increase the productive capacity of the economy faster than the status quo, while in the Post-Keynesian economics, the act of transition itself can have direct growth effects if it manages to increase total levels of either private investment, government spending, consumption, or, in the national context, net-exports.

For a sense of scale, the recent IEA Net Zero scenario referenced above projected that decarbonizing the energy sector will require more than doubling the annual levels of investment in energy from roughly $2 trillion now to $5 trillion by 2030 (from 2.5% of global GDP to 4.5%) (IEA, 2021, p. 81). This scenario assumes there are effectively no new investments in fossil fuel infrastructure, meaning the real amount of needed investment projected by the model is larger than the $3 trillion gap between current and future spending. These estimates are also only for the energy sector, which accounts for roughly three quarters of global emissions (Our World in Data 2020). Should these investments be made in a way which does not crowd out other forms of demand, the demand effect would be significant in a Post-Keynesian framework. Demand could also be affected by changes in consumption driven by changes in income distribution, either directly from policies related to decarbonization—for instance a carbon tax with revenues directly rebated as shown above in Figure 6—or by structural changes in the labor market stemming from the labor intensive nature of the activities needed for decarbonization, especially in the deployment and maintenance of dispersed renewable energy generation and in retrofitting buildings for electrification and energy efficiency improvements.

4.2 Path dependency and long term growth

Finally, Post-Keynesian economics typically emphasizes that the economy is path dependent, such that activities in one period will fundamentally change the starting place for future periods. Instead of conceptualizing the economy as varying around a certain fixed trend over a number of decades, this framework allows for short term fluctuations to change the long-term trend, making new futures possible and closing off others in the process. In terms of the economics of decarbonization, this means that a large growth boom driven by investment in the early years of decarbonization would not imply a future shrinkage to return to the original growth trend, but would simply result in the economy growing from a larger base in future periods. This concept of path dependency can also be applied to improvements in productivity, with the idea that long periods of high growth and low unemployment can improve long term productivity and shift the economy to an even faster growth trend for the future (Fontanari, Palumbo and Salvatori, 2020).

Within this framework, changes in demand can have very large, compounding effects over long time periods. For a sense of scale, a useful simulation is provided by Fontanari, Palumbo and Salvatori, 2020 who model the potential growth path of the United States economy if it had maintained near full employment (defined as 3.4%) since the end of the 1950s. The chart below shows the results, with the bottom dotted line showing the actual observed level of GDP, the green middle line showing the estimated potential GDP in any given year and the top red line showing the potential GDP path had full employment been achieved in all previous years, given assumptions that persistent low levels of unemployment would positively affect productivity growth. Over the course of 50 to 60 years, the estimated gap between realized and potential cumulative GDP is massive, with an economy of roughly double the size projected had unemployment remained low over the entire period. While there are certainly limits to projecting historical estimations like this into the future, they can provide a promise, or indeed a warning, that, with the very long time periods involved and large investment amounts required, decarbonization could have significant effects on the size of the economy over the life of the energy transition.

Figure 8: USA compounding potential output

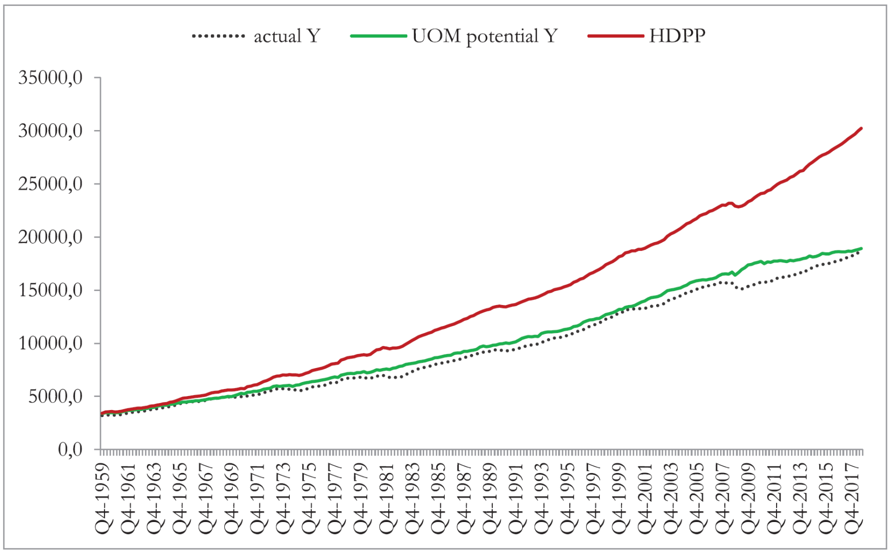


Figure 6. A comparison between actual output, UOM potential output and the high-demand potential path ($u^*=3.4$).

(Fontanari, Palumbo and Salvatori, 2020)

5. Investment, growth, and emission: Unpacking the investment rebound effect

5.1 The investment rebound

Within energy economics, there's a fairly well-established phenomenon by which increases in energy efficiency can enable a corresponding increase in energy use, leaving the total energy savings from the efficiency gains lower than would otherwise be expected. This "rebound effect" can occur through a number of different specific transmission mechanisms, but most simply, when people need to use less of something to achieve a desired outcome, they're freer to use more of it to achieve more of the desired outcome (Lange, et al. 2019). A common example is increasing fuel standards in personal vehicles: when cars get more efficient people can afford to drive more, meaning there's less than a one to one reduction between the expected fuel savings due to better technology and what is actually experienced.

A similar effect could be present in relation to decarbonizing investments. Decarbonization does not occur in an economic vacuum, and any efforts to decarbonize the economy will be associated with their own environmental and emissions costs. Clearly, these emissions costs should be lower than the overall emissions savings, or else no decarbonization would take place! Still, it is important to understand these emitting effects of decarbonization activities in order to understand the level of decarbonization that will be ultimately needed.

There is already a broad conversation about the direct environmental costs and 'rebounds' involved in many of the activities needed to reach net-zero emissions (Galbraith, 2020)—the staggering mineral needs projected for scaling renewable energy generation are a prime example—but there so far has been much less attention to how these activities could indirectly drive emissions through economic growth.

If the economy is not operating at full capacity, then additional spending, both by governments or the private sector, on climate change mitigation will have a positive effect on growth which is not captured in equilibrium climate-economy models. Assuming economic growth has not yet been absolutely decoupled from emissions, this additional growth will be associated with some level of increased emissions elsewhere in the economy. These new emissions will undercut the expected reductions from the original investment, meaning only a certain percentage of the expected decarbonization will ultimately be realized.

5.2 Implications

This notion of an “investment rebound effect” is not a particularly radical invention for those familiar with heterodox economics, and is indeed implicit in much of the modeling work on climate change within Post-Keynesian and Ecological Economics in which the economy is already assumed to be demand-led and not tied to long run full employment. Still, there is value in developing the point explicitly, first to identify a potential shortcoming of existing climate-economy models and second to better understand the complicated relationship between climate mitigation investments, economic growth, and the ecological transition.

Modeling for Green Growth

In terms of modeling, the primary takeaway is that we should build models in which Green Growth is possible and can feed back on the other components of the model. This will ensure that dramatic shifts in the adoption and deployment of various technologies projected within the model are not treated in an economic vacuum, but are able to then recursively affect the total demand the model is attempting to fulfil. It seems unlikely that core computable general equilibrium models will be able to adapt to fully account for these effects, but ad hoc treatments could be included to show the effect on the model results of various levels of investment rebounds. In parallel, new climate-economy models should be developed using methods which do not require the assumption of long run full employment.

Planning for better and for worse

The implications of investment rebound for the overall project of the energy transition, or the larger socio-economic transition of which it is a part, are oddly mixed. On one hand, mitigating climate change will be economically much easier to finance than our models have suggested, as rather than depressing growth, decarbonizing investments could permanently boost it, leaving a progressively richer and richer global economy from which to fund new investments. On the other hand, the investment rebound means that the task of mitigating climate change will be larger than we currently expect, as more mitigating investments will need to be deployed to cover for the currently unaccounted for increases in emissions which will be caused by decarbonization itself.

A key takeaway from this analysis could be the need for growth management, or “post-growth” policies which could actively redirect economic activity away from more emissions intensive activities and towards activities with limited ecological footprints and high social value. Another is the economic desirability of frontloading mitigating activities in the early years of the transition where they can have the biggest growth effects, rather than postponing them until late in the century when technology costs are expected to be lower. Finally, the investment rebound implies the need for increased attention to the ecological pressures other than climate change, such as biodiversity loss, which will receive the growth-related damages implied by the investment rebound but without the corresponding mitigating investments.

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