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The Transition from the Neoclassical Growth Model to Ecology

Michael Schlauch, Gaia Palmisano*

Abstract

This paper examines the assumptions and conclusions of the neoclassical growth model put forth by Solow and many others. We investigate the origins of the paradigm of unlimited growth and technological progress and question their plausibility. In contrast, we develop a modified version of the neoclassical growth model where we consider non-human, environmental resources such as energy as an additional input factor and recognize their limited capacity to recover from human impact. Surprisingly, the same mathematical framework of the neoclassical growth model gets to the opposite conclusions - namely that long term growth cannot exceed a level in which nature begins to deplete. Growth further that level as we might experience today leads to natural and economic disaster. Technological progress understood as productivity increase can only delay but not prevent this crisis. We compare these conclusions to the opposite hypothesis of the Environmental Kuznets Curve. Also we show how this model can lead to a greater understanding of present or future observations that are connected to environmental deficiency, such as social divergence and stagnating life satisfaction in developed countries.

Keywords: growth, degrowth, limits of growth, ecological economics, resource efficiency, solow-swan model, sustainability, ecology, neoclassical growth model, EKC, environmental kuznets curve

Journal of Economic Literature Classification: O11, O30, Q01, Q26, Q43

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List of symbols

α	weight of capital input
β	weight of labor input
\dot{K}	dK/dt: capital over time, resp. net capital accumulation per year
ϕ	pollution, emission and other negative impacts per unit of economic output
R_{reg}	nature's ability to recover: energy added yearly, resp. environment's self adjustment power
Y_{max}	maximum size of economy beyond which depletion prevents growth
Y_{sus}	level of sustainability: any larger economy causes depletion
d	depreciation of capital
E	the total of all non-human inputs that contribute to welfare: e.g. energy availability, biodiversity
g	technological progress, growth rate of labor productivity
K	capital input
L	labor input
n	growth rate of population
s	saving's rate
T	technology, resp. labor productivity
Y	economic output, resp. economic value added

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1 Introduction

The search for the roots of the doctrine of unlimited growth leads to the traditional anthropocentric world view where human has to relate himself only to a given nature. This dualism between a human with unlimited technological power and a static nature is not able to explain such phenomena as stagnating happiness indexes, continuous food and resource insecurity, health problems and climate change.

In the first section of this paper we investigate how modern models of economic growth like the neoclassical Solow-Swan model have adopted this kind of world view. Notwithstanding the fact that there are many other models we chose the neoclassical growth model for its unquestionable impact and the dominant role it still plays in undergraduate and graduate economic courses. We outline the argumentation behind the notion that unlimited growth on a longer time scale is possible due to technological progress and analyse its plausibility with respect to the role of nature.

Taking these reflections into account this paper then introduces a new model of economic growth which extends the neoclassical model of growth in two important points. The first consideration is that the real value of economic output, not necessarily measured in terms of gdp, is very much influenced by the shape of the environment. The second consideration lies in the fact that nature has the ability to recover at a certain rate and that it also deteriorates depending on the negative impact and the size of that economy. A further analysis of this model leads to the conclusion that growth that exceeds the maximum level sustainable by nature causes instability, depletion and finally an environmental and economic crisis. At this point technological progress in terms of productivity growth can no more counterbalance the effect that depletion has on the economy.

There has already been research that denotes scepticism about strategies that involve the technological decoupling of economic growth and resource consumption leading to an international debate about the necessity of degrowth (Paech, 2009, p. 28). We will put our findings in relation to the scientific debate about the contrary hypothesis of the Environmental Kurznets Curve that predicts environmental betterment because of economic growth. In the final part we explain why it makes sense today to degrow in a controlled manner, avoiding a much more catastrophic depletion crisis. Long-term welfare cannot be achieved by increasing industrial productivity but by putting all efforts in maintainng a rich biosphere, promoting less intensive technologies and retaining an ecologically coherent economy. This means that our understanding of efficiency and growth has to be questioned constantly with respect to its ecological dimension.

2 Neoclassical growth model

2.1 Production function

The starting point of this paper shall be the neoclassical Cobb-Douglas production function which is the basis for all variations of the Neoclassical growth model (Solow-Swan model). The output Y in conventional economic theory is determined by capital K and labor L with different weights according to the ratio between its exponents alpha and beta.

$$Y = K^\alpha L^\beta \quad (1)$$

The input factors have a diminishing marginal productivity which means that every added capital unit causes a lesser production increase with constant labor and vice versa. Due to condition 2 the Cobb-Douglas function has constant returns to scale, hence there are no scale effects ($Y(2K, 2L) = 2Y(K, L)$).

$$1 = \alpha + \beta \quad (2)$$

$$\dot{K} = sY - dK \quad (3)$$

Another important idea is that capital evolves depending on savings rate s and depreciation d . This leads to a so called Steady State which denotes an equilibrium of capital in relation to output ($\dot{K} = 0$, capital reaches a constant in an economy without technological progress and population growth).

2.2 Technology and population

An extended version of the Solow-Swan model considers also labor productivity T (technology) and defines the rate of technological progress g externally.

$$Y = K^\alpha (LT)^\beta \quad (4)$$

$$\frac{\dot{T}}{T} = g \quad (5)$$

As population growth n causes a growing workforce, the available labor L increases at the rate of n .

$$\frac{\dot{L}}{L} = n \quad (6)$$

2.3 Steady State in the long run

A central conclusion of the standard Solow model is that an economy tends to reach an equilibrium state of balanced growth after some time: if the initial capital stock is below the equilibrium ratio, capital and output will grow at a faster pace than the labor force until the equilibrium ratio is approached (Solow, 1956, p. 70). This means that the capital-output ratio converges to a constant value. Given a constant capital-output ratio both capital and output have to grow at the same pace which is expressed by:

$$\frac{\dot{K}}{K} = \frac{\dot{Y}}{Y} \quad (7)$$

The derivative of equation 4 divided by output leads to the growth rate.

$$\frac{\dot{Y}}{Y} = \frac{\beta \dot{T}}{T} + \frac{\beta \dot{L}}{L} + \frac{\alpha \dot{K}}{K} = \beta g + \beta n + \frac{\alpha \dot{K}}{K} \quad (8)$$

In the long run, under the Steady State condition 7, economic growth is only determined by technological progress and population growth.

$$\frac{\dot{Y}}{Y}(1 - \alpha) = \beta g + \beta n \quad (9)$$

$$\frac{\dot{Y}}{Y} = \frac{\beta}{1 - \alpha}(g + n) \quad (10)$$

It becomes evident that the neoclassical growth model leads to the assertion that growth and technological progress is unlimited as the growth rate in the balanced growth path does not change autonomously. The fact that we live on a finite planet with finite resources has cast doubt upon this notion. Soon we will find how simple changes to the basic conditions of the model lead to different conclusions.

3 Conditions of a model that considers natural resources

In this section we shall outline a model of growth that considers those environmental conditions which are partly influenced by human activity.

3.1 Energy dependency of output

To do so we introduce a new input factor E that reflects the availability of all natural (non-human) inputs that contribute to our wealth. E can resemble environmental inputs as well as energy. Condition 12 is responsible for constant returns of scale analog to the production function in section 2.

$$Y = K^\alpha (TL)^\beta E^\gamma \quad (11)$$

$$1 = \alpha + \beta + \gamma \quad (12)$$

3.2 E over time

The richness and health of the environment is influenced positively by its ability to recover itself R_{reg} and negatively by the size Y and intensity phi of our economy in terms of pollution and resource efficiency. For now R_{reg} is assigned as an exogenous constant. In the longest time prospect the interpretation of R_{reg} would be the constant radiation of the sun that reaches the surface of our planet each year. Respectively the external constant phi ϕ would denote energy usage per output and \dot{E} net savings or creation of fossil fuels. In another scenario \dot{E} ($-\dot{E}$) would resemble net increase (reduction) of biodiversity, soil fertility, ecc.

$$\dot{E} = R_{reg} - \phi Y \quad (13)$$

So E can be taken in a much more wider sense that comprises all natural elements that shape the quality of live and are exposed to human impact. Additionally the ability to recover R_{reg} suffers from depletion and is not always constant as assumed here rather optimistically. A not so simplified version of this model would consider all forms of human impact such as emission of greenhouse gases, waste and the reduction of biodiversity as aspects of ϕ . Thus for our logical analysis it is sufficient to take account of the constant nature of ϕ . Figure 1 shows that ϕ has not been correlated to technological progress in the past.¹

3.3 Output level of Sustainability

The interdependence of $\dot{E}(Y)$ and Y results in the existence of a highest output Y_{sus} that is still sustainable or does not lead to depletion. Every economy bigger than

¹ This does not mean that it is impossible to reduce the intensity ϕ . There are technologies such as the permacultural approach which aim to increase energy yields within living systems that are capable of sustaining themselves (Mollison, 2002, p. 18). In this way R_{reg} should benefit primarily and human consumption subsequently. Such an approach involves a different understanding of productivity which is not human-centered and accepts also short-term reductions in consumption.

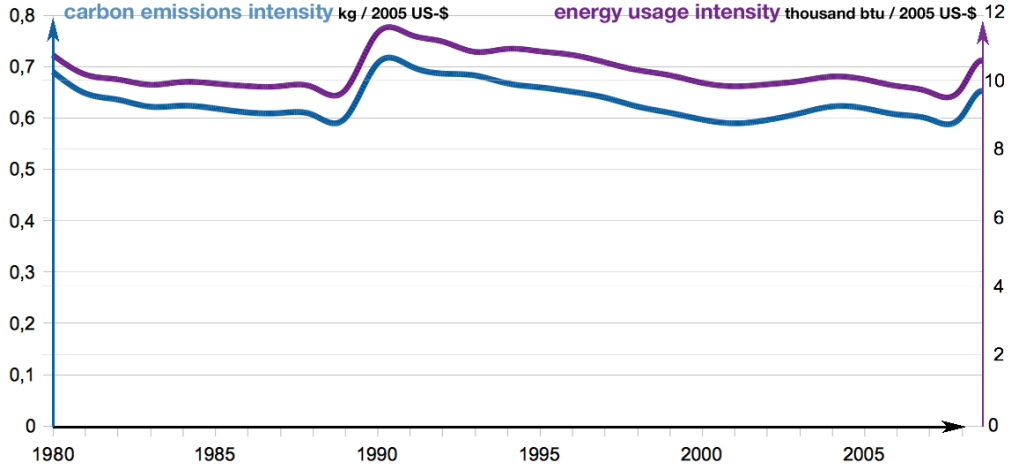


Figure 1: Resource intensity of world economy: the overall world energy and carbon intensity (inflation-adjusted) has not decreased in the last decades. This supports the assumption that environmental intensity ϕ remains high despite of technological advancement. Source: own representation based on data from U.S. Energy Information Administration

$\frac{R_{reg}}{\phi}$ leads to overconsumption of natural resources. This is characterized by the formation of a peak of resource availability on which has already been written in the past (Heinberg, 2007).

$$\dot{E} = 0 \quad (14)$$

$$Y_{sus} = \frac{R_{reg}}{\phi} \quad (15)$$

4 The long run

This section examines the initial behavior of our model-economy. We will find that until $Y < Y_{sus}$ or as long as the initial stock of E is available in abundance the economy doesn't differ very much from the one in the standard Neoclassical growth model.

4.1 Growth in the initial steady state

Like we did previously, we obtain the overall growth rate through differentiation of the output Y (equation 10). Then we take into account the Steady State condition (equation 7) that establishes itself early in relation to the longer timeframe we are examining.

$$\frac{\dot{Y}}{Y} = \frac{\beta \dot{T}}{T} + \frac{\beta \dot{L}}{L} + \frac{\alpha \dot{K}}{K} + \frac{\gamma(R_{reg} - \phi Y)}{E} \quad (16)$$

$$\frac{\dot{Y}}{Y}(1 - \alpha) = \beta g + \beta n + \frac{\gamma(R_{reg} - \phi Y)}{E} \quad (17)$$

$$\frac{\dot{Y}}{Y} = \frac{\beta}{1 - \alpha}(g + n) + \frac{\gamma}{(1 - \alpha)E}(R_{reg} - \phi Y) \quad (18)$$

When capital output ratio has converged to its equilibrium Steady state, i.e. constant capital-output ratio, the growth rate is determined by g (technological progress), n (population growth), net energy- or environmental savings \dot{E} and the environmental status E itself. The influence of net depletion ($-\dot{E}$) is relatively small as long as there is a large supply of energy and as long as Y is relatively small. This explains the observation that during industrialisation happiness index and nominal growth may not have been as disconnected as today. Figure 2 shows how economic growth which would have been expected by the conventional growth model persists even subsequent to the peak of E .

5 The very long run

Figure 2 views the simulation of this model with a considerable initial stock of E . Like the equations suggested, the peak of Y occurs subsequent the peak of E . This section analyses the economy during stagnation and on its downfall.

5.1 Immanent instability and its consequences

Logically the maximum of Y eventuates when growth rate is zero. Due to the interdependence of the growth rate and Y we can figure out the highest possible size of the economy Y_{max} .

$$\frac{\dot{Y}}{Y} = 0 \quad (19)$$

$$Y_{max}(E) = \frac{R_{reg}}{\phi} + \frac{\beta}{(1 - \gamma)} \frac{E(n + g)}{\phi} \quad (20)$$

As Y_{max} is conditional on the endogenous (non-constant) variable E we can identify an inherent instability of the long run output function. The economy that reaches Y_{max} is per definition bigger than Y_{sus} . This implies a persisting depletion (decrease of E) which again conditions Y_{max} . With every period depletion alters the circumstances and hence the ceiling limit of economic growth decreases even further. In consequence the economy is characterized by an unprecedented disruption and decline.

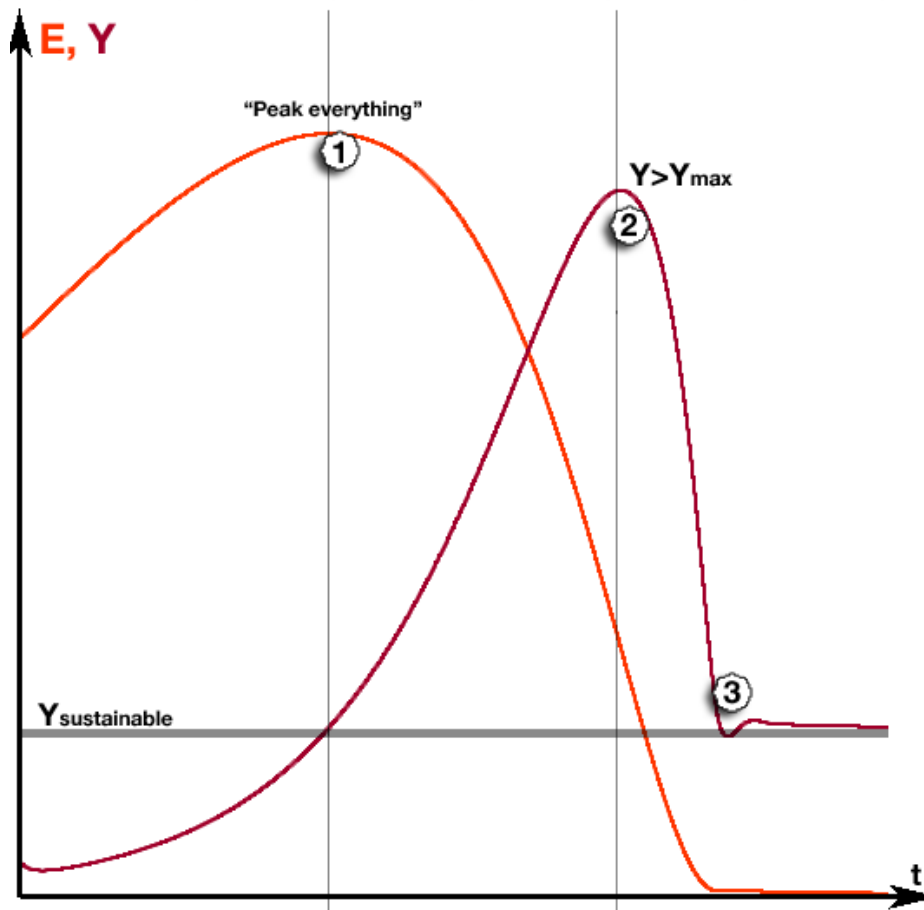


Figure 2: Simulation: environment and output in a longer timeframe. A simulation of E and output Y shows how they interact. Before and even some time after the peak of resource availability (timepoint 1) growth behaves as predicted by conventional models. But soon after, depletion affects the economic value added (Y) substantially. After timepoint 2 output exceeds the maximum limit Y_{max} which itself shrinks due to depletion. A natural and economic crisis continues until sustainability Y_{sus} is reached despite persisting technological progress.

6 Relation to the Environmental Kuznets Curve

A reviewer criticized the assumption that every economical activity decreases ecological quality. One argument which has been cited is the hypothesis of the Environmental Kuznets Curve (EKC). The EKC suggests that "[...] at higher levels of development, structural change towards information-based industries and services, more efficient technologies, and increased demand for environmental quality result in leveling-off and a steady decline of environmental degradation" (Panayotou, 2000, p. 2). Assuming that the hypothesis holds, there is no reason to modify the model as defined here. The reduction of environmental degradation cannot be an equivalent to increasing environmental quality. Whereas the first is a flow variable (\dot{E} , the deviation of E over time, in our model), the second is a stock variable, represented by the variable E. As long as the reduction of environmental degradation does not stop degradation itself, the EKC predicts only a deceleration of degradation and no decoupling of the underlying relationship. In our model this corresponds to a decreasing pollution per output ϕ over time. As shown before this does not remove the need to degrow when the sustainable output level Y_{sus} has already been surpassed.

Nonetheless the empirical relevance of the EKC is still subject of ongoing scientific debate (Stagl, 1999) (Perman and Stern, 2003). The main problem is that it is very difficult to verify a causal connection between reduced pollution and rising GDP per capita with many other factors involved. Studies often analyse only isolated pollution variables such as carbon emissions or sulfur oxides within one country or within a restrained group of countries (Selden and Daqing, 1994) (Cole et al., 1997). This puts them in a weak position for verifying a generalized EKC assumption that involves all ecological variables. Also it leaves room to other explanations. It is not clear how the import of energy intensive, material goods (thus an export of emissions to poorer countries) contributes to a reduction of energy intensity in western service based economies (Stagl, 1999, p. 7). Figure 1 suggests that these effects annihilate local improvements on a global scale. Another explanation for a seemingly verified EKC hypothesis is the substitution of one pollutant with another. For example, in a recent study which examined carbon emissions in different countries Japan was the only one for which the EKC hypothesis has not been rejected (Mota and Dias, 2009, p. 25). But there has also been the unprecedented expansion of the nuclear power sector between 1970 and 1990 in Japan (Tanaka, 2006, p. 25). So in this case the EKC hypothesis competes with the much simpler suspicion that nuclear waste replaced much of the carbon emissions during the time period in question.

7 Conclusions

7.1 Logical deductions

Out of the preceding mathematical and conceptional reflections we can deduce following findings.

1. **Certain Crisis:** No matter how small γ or how big the initial supply of E, Y_{max} exists and will be reached. This means that also if nature's influence corresponds to $\gamma = 0,001$ an energy crisis will occur sooner or later if not avoided by self-restriction to the level of sustainability. On the very long run, humanity has no other choice than producing at the level of Y_{sus} .
2. **Non-Compensation:** Depletion cannot be compensated by technological progress g . When the economy reaches point 2 (figure 2) even an exponential increase of labor productivity cannot prevent the downturn back to the level of sustainability.
3. **Perceived Inflation:** Although we accounted for environmental inputs in our model, the GDP will still measure only human output. This means that growth indicators still keep rising when depletion already affects the economy substantially. As a consequence nominal growth and perceived satisfaction detach from each other until the consequences of depletion become obvious and the biosphere suffers. Still conventional indicators would not be aware of this.
4. **Social Distress:** Capital and output evolve proportionally due to the Steady-State condition. But depletion limits the possible amount of "active" capital that can be used to process resources, e.g. diminishing oil wells make functioning refineries useless. Still working population L continues to grow at rate n . This means a diminishing marginal product per worker while the marginal product per capital unit remains constant because of the constant capital output ratio. The typical adding-up theorem from the textbook predicts diminishing wages as a consequence (Cezanne, 2005, p. 123). Hence inequality between capital owners that have access to resources and working population rises.

7.2 The opportunities of degrowth

All these consequences can be resolved avoiding growth and by limiting production to the level of sustainability. Like demonstrated in this paper degrowth² can

² more precisely: a paradigm shift that alters the understanding of progress

preserve environment, favor a less intensive production and eventually increase the possible level of sustainability by reducing pollution per output. Figure 3 demonstrates this scenario.

The conventional growth model has been transformed with the simple and reasonable assumption that our environment conditions the value of our yearly output and that this environment has a limited capacity of regeneration. The conventional conception of progress has shown to be inadequate.

7.3 Final considerations

But not only our conception of progress has to be doubted. The neoclassical growth model's blind eye lies in a mainly anthropocentric world view which assumes that nature can be substituted and hence be ignored. Although this paper has shown the opposite, it is not liberated from a certain anthropocentric way of thinking. We have presumed on nature as an object to be exploited by man, although in a sustainable manner. We have not taken into account nonrenewable resources nor intrinsic values such as the non-extinction of a species. Solow himself was aware of the need of social and environmental accounting. But he suggested that an innovation in social accounting practices would make it possible for us to take decisions precisely and rationally, leading to optimal trade-offs between environmental preservation and consumption (Solow, 1992, p. last). This view can be questioned as it presumes the possibility of complete information. It is almost certain that from a human perspective some natural impacts remain always undiscovered or underestimated. With this model the authors did not intend to predict the optimum long-term output, but rather disclose the hidden assumptions behind the notion of unlimited growth. Ironically we used pure logic, being aware of its potential to be instrumentalized as it has been in our long history as "zoon logicon", supposedly, the only rational animal on earth (Aristotle, 1934, book 1, chapter 13).

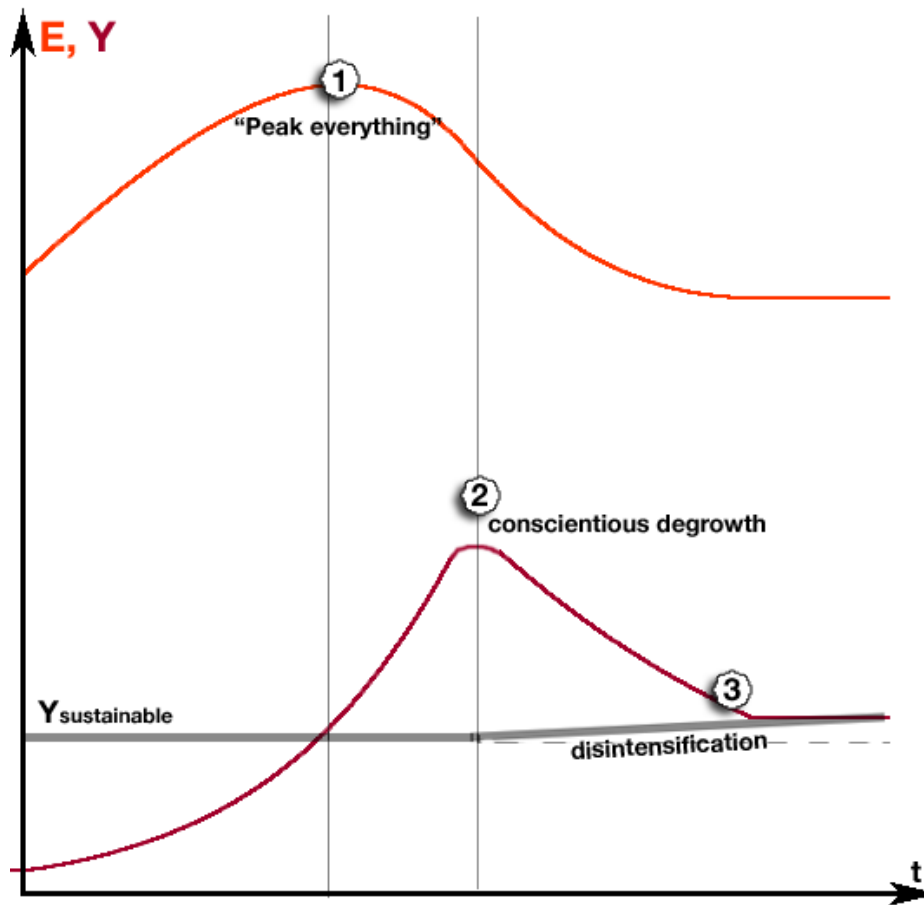


Figure 3: Degrowth: an alternative growth path. In many regions and regarding many resources, we might already have surpassed the level of sustainability (Murray and King, 2012). A different outcome is yet possible. Intentional degrowth can retain nature as basis for a healthy economy. A less technology intensive but more ecological economy (smaller ϕ) means greater welfare in the long run. It also prevents a hypothetical downturn, i.e. it increases social and economic stability.

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