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The effect of natural resources on a sustainable development policy: The approach of non-sustainable externalities

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ABSTRACT

The debate about the importance of non-renewable resources for economic development between optimists and pessimists shows that the extensive depletion of non-renewable resources, particularly oil, along with a higher level of consumption could have a significant impact on the economic development of future generations. Based on this debate, this paper proposes criteria under which the depletion of non-renewable resources would create excess costs for future generations. Therefore, this paper aims to answer the question "What will be the impact of the depletion of non-renewable resources on sustainable economic development?" Accordingly, a sustainable development policy appears feasible by minimizing non-sustainable externalities which derive from future externalities that weigh the benefits from a previous employment of natural resources. The research based on qualitative analysis clarifies the reasons for and the extents of taking sustainability into account as well as points to difficulties of implementing policies to time the transition towards a sustainable economic development. Finally, the research shows the implications of this approach for environmental degradation, the depletion of non-renewable resources and energy production.

1. Introduction

The fluctuations of the oil price in the past demonstrate the influence of non-renewable resources on global economic growth. Not only are consumers highly concerned about the price of oil, most companies consider any rise as a major threat to their profitability. Many scholars, such as Simmons (2005) and Watkins (2006), have discussed the impact of the depletion of natural resources on economic growth and their prognosis for the future falls into two basic camps. Pessimists, such as Meadows (1992), Deffeyes (2001) or Simmons (2005), argue that growth is limited by the finite nature of resources—the rising price of oil indicates a near term exhaustion of this resource, and as a consequence, the decline or impossibility of economic growth. On the other hand, Simon (1996), Radetzki (2002) and Watkins (2006) take an optimistic perspective and argue that growth is unlimited. They look at the price of oil from the viewpoint of price mechanisms for the aggregate supply of goods and their substitutes. Both perspectives, as will be subsequently explained, have merits as well as flaws in their argumentation. Yet they provide essential insights for a better understanding of the depletion of natural resources for sustainable development.

For the purpose of this paper it is worthwhile to look at the meaning of economic growth from a broader perspective. Although people have traditionally been more concerned about economic development during their life time, but as the example of global warming shows, people became more and more aware of the long-term impact of their economic life style during the last decades. In order to grasp the meaning of sustainability for development properly, it is necessary to set the time horizon further away. The approach of non-sustainable externalities proposes conditions, under which governments would have to choose between higher present consumption of non-renewable resources and future development. Currently, governments generally consider the immediate interests of their citizens and hence tend to disregard its impact on subsequent generations. The high public debts of many developed countries illustrate the choice governments have to make between redistributing resources to people and investing in their countries' long-term future economic competitiveness. When analyzing global sustainable development, this pattern is an obstacle in the shift from the depletion of non-renewable resources towards the employment of renewable substitutes. Bazhanov (2006) analyzes possible transition paths for a gradual substitution of non-renewable resources, but concludes that technical restrictions do not allow for a smooth transition to a sustainable resource employment. Past economic development has been characterized by the depletion of resources and resulted in the pollution of the environment, and most scholars agree that we cannot continue

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forever in this manner, because pollution and depletion will result in serious consequences for future development (Homer-Dixon, 2001).

This paper proposes to give an overview of the arguments of the two schools of thought regarding the use of natural resources for economic development and will further expand this discourse by applying the concept of sustainability in order to suggest the approach of non-sustainable externalities. This paper aims to answer the questions "What will be the impact of the depletion of non-renewable resources on sustainable economic development?" and "Under what conditions will current efforts of employing renewable resources create negative or positive externalities for future generations?" Furthermore, this paper points to the difficulties of implementing policies to time the transition towards a sustainable use of resources. Finally, the paper considers limitations of this approach for a policy for sustainable development.

In the following, Section 1 will clarify the meaning of sustainable development in terms of natural resources. Section 2 will review the arguments of both optimists and pessimists on future development. Section 3 will suggest a framework for the depletion of non-renewable resources under the condition of sustainability by applying the concept of externalities. Finally, Section 4 will point out the implications of policy approaches for a sustainable development policy.

2. Research background: natural resources and sustainability

This section defines the meaning of natural resources and sustainability and shows their interdependence. In general, the criteria of sustainability for both renewable and non-renewable resources emphasize that the stock of a resource remains the same over time. Therefore, sustainability requires that the rate of recovery at least equals the rate of destruction (Asafu-Adjaye, 2005). Examples of non-sustainable development can be found in environmental degradation, resource depletion, increasing income disparity, poverty and marginalization (Raskin, 2000).

Furthermore, it is important to distinguish between renewable and non-renewable resources. Fossil fuels, for example oil, are non-renewable resources because they are consumed at a higher rate than their rate of reproduction (Conrad, 1999; Richards, 2006). However, there are reasons why a final depletion of oil is unlikely to occur—the rate of depletion might decrease dramatically, for example, due to the adoption of oils from vegetable sources (Harris, 2007:265f), an increased price of the good, decreased prices of substitutes, or a more efficient use. Furthermore, relatively costly resources create incentives for the exploration of new deposits. For example, the production of food has been controlled and increased to satisfy its demand.

One condition of sustainability for natural resources is fulfilled when the rate of consumption is equal to or less than the rate of recovery. Accordingly, the World Commission on Environment and Development defines sustainable development as "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED (World Commission on Environment and Development), (1987): 43). The goal to preserve the inter-generational capacity for development implicates barriers for the depletion of non-renewable resources. Without a change in the current input rate of non-renewable resources into economic processes, non-renewable resources will approach exhaustion sooner or later. Bartelmus (1994: 45–52) argued that two factors are important when taking the depletion of non-renewable resources into account: The life expectancy of the resource and the discount rate caused by its depletion. For instance, oil could be considered a renewable resource if it were produced artificially from renewable resources at a higher rate than current consumption. This would be feasible if the retail price in terms of sustainability would include the future costs of maintaining its stock. In addition, the substitution of fossil fuels by biofuels based on agricultural commodities is of questionable benefit as it causes rising prices on the agricultural market FAO (Food and Agriculture Organization of the United Nations) (2008). The conditions for a sustainable input of natural resources appear relatively clear-cut, but it remains uncertain whose transition path towards a sustainable development should be favoured.

The shift of paying now for long-term future costs of replacement will not be the only major challenge for the global economy. Still another will be the obstacle of providing enough energy at this increased cost for all economic processes. In this context, Barbier (2005) stressed that a "free deployability" of non-renewable resources by no means contributes to economic development, but may even hinder it. At present non-renewable resources are an important factor in many economic models, but they are likely to loose their importance in the long-run as their depletion progresses. Yet there are other ways of providing energy: for example, technological progress has made the employment of solar cells successively cheaper. Furthermore, as Simon (1996) pointed out, the pattern of invention and substitution is likely to be continued in the future. Hence, uncertainty about our future dependence on non-renewable resources in the long-run complicates the determination of an optimum transition towards sustainable development.

The above mentioned discussion of the underlying mechanisms points towards the next section. Having noted the importance of resource time-lines on depletion, the following part will review the arguments of both the pessimists and the optimists.

3. Literature review

The first debate: the British classical economists

In 1798, Malthus (1798) suggested that neither technological progress nor the human ingenuity would be sufficient to overcome obstacles of population growth. He criticized the prevailing idea that nature would never limit growth. This view had already been expressed by the French philosopher Nicolas de Condorcet in 1794 (Malthus, 1798). The British classical economists likewise argued that in principle nature could limit future growth, but such natural constraint would not be reached in any meaningful time frame. The most famous scholar who took this stance was John Stuart Mill (1862). In 1862 he argued that social institutions and increases in social welfare would slow down population growth. Therefore, the first debate was primarily concerned with the threat of an overpopulation in the future for economic growth.

The second debate: The US Conservation Movement (1890–1920) and the Studies by Hotelling, Barnett and Morse

Since the 1890s the debate increasingly considered the depletion of non-renewable resources as a major obstacle for future growth. In this context, the former US President Roosevelt (1908) promoted the conservation movement. Research was deepened by Hotelling in 1931 and Barnett and Morse in 1963, who took an optimistic view. Barnett and Morse (1963) assumed that technological development would produce substitutes for scare resources, reduce the relative prices of these goods and expand the total amount of economic reserves. Even so, they considered how the depletion of non-renewable resources could impede future economic growth and what the optimal rate of depletion would be. Although they allowed for the possibility of scarce natural resources, scarcity was an idea only considered validity in theory. In fact most companies chose a higher rate of depletion, because they simply sought short-term profit maximization. However, the situation was not that serious as Barnett and Morse (1963) showed because the price of most minerals as well as agricultural products had fallen, not risen.

3.1. The third debate: The Limits to Growth Report for the club of Rome

The debate that continued, there were scholars who argued a more pessimistic view. The most cited publication of this phase was *The Limits to Growth* (Meadows, 1972), published by scholars at the Massachusetts Institute of Technology (MIT). They argued that the economy would soon stagnate and finally collapse because many critical non-renewable resources would be exhausted in the near future. Although most of their predictions have not come to pass, it is worth looking at their arguments as they had a deep impact on the debate. According to them population grows exponentially, whereas resources and food supply grow linear at lower rates. Hence (1) an insufficient supply of food for an increasing world population will be one limiting factor on growth in the near future. Another limiting factor will be (2) the depletion of natural resources. As a result raw materials will become extremely expensive and the depletion of non-renewable resources will lead to a sudden collapse of economic development instead of a smooth transition. Pollution will further limit the availability of natural resources (Meadows, 1972).

In contrast, the optimists emphasized the short-term occurrence of over-consumption. Simon (1996) pointed out that in the short-run, it is indeed possible that supply will fall short; but in the long-run, increased price levels will boost production. For instance, rising food prices will make the application of new technologies profitable and agricultural output will be amplified (Kahn, 1976: 4–11). In fact, the price of resources indicates the underlying mechanism of scarcity rather than depletion. For oil the situation is likewise: a distinct pattern of fluctuating oil prices and new discoveries in the past demonstrate a strong correlation between oil demand and supply, because increased oil prices encourage oil companies to invest in exploring for oil, at deeper and less accessible layers. Although an unexpected demand shock cannot be covered in the short-run, market mechanisms will balance supply and demand in the long-run, albeit at eventually higher prices (Simon, 1996).

In addition, the optimists argued that non-renewable resources as input in economic activities will loose their importance in the long-run. This pattern of adaptation can, for example, be illustrated by the unexpected diminishing importance of coal in developed countries. Simon (1996) stressed that the depletion of natural resources need not conflict with future economic growth, because (1) a rising price will stimulate the search for new deposits and (2) increase the profitability of currently more expensive renewable resources.

3.2. The fourth debate: Long-run Growth Models, 1974 until the mid 1980s

During the next phase Dasgupta and Heal (1974) discussed whether it is possible to maintain sustained economic growth in light of diminishing non-renewable resources. Similarly Solow (1974) and Stiglitz (1974) showed that market economies may not lead to sustainable outcomes, i.e. market forces could lead to over-consumption of non-renewable resources and hence limit future growth. Anderson (1987) argued that even technological change could not impede this outcome. Only if capital accumulation can be substituted for non-renewable resources, can consumption levels be maintained in the long-run (Hartwick, 1977). A more optimistic perspective is the idea that investments into new technologies could decrease the costs of renewable energy and hence make the substitution of non-renewable resources feasible (Dasgupta and Stiglitz, 1981).

3.3. The fifth debate: New Economic Growth Models

During the last decades New Economic Growth Models showed the effects of technological change and substitution on sustainable development. Though non-renewable resources are by definition finite, either in terms of supply or by relative pricing, there is no reason to argue that economic growth will be limited in the long-run. Barro and Sala-I-Martin (1995) showed how sustained growth is possible even in the long-run. For example, as Schmalensee et al. (1998) has shown, pollution measured by per capita emissions has peaked in some OECD countries. Likewise there are scenarios that predict a falling demand for oil after the year 2030 (IEA (International Energy Agency), 2003) partly due to the substitution by cheaper renewable energy sources. Salo and Tahvonen (2001) emphasized that an unexpected demand shock cannot be covered in the short run, but supply will adjust to its demand in the long-run.

Still there are scholars who argued that development in the long-run will reach a steady state. Daly (1991) assumed that sooner or later only renewable resources could be consumed, but a comparison with reality shows that the short-term occurrence of his predicted ‘cycle-stage’ seems unlikely. The experience with oil proved the pessimistic assumptions to be misleading; instead of decreasing oil reserves due to its depletion, oil reserves have actually increased during the last decades (BP statistical review of world energy report, 2008; Radler, 2006). A more efficient employment of oil due to new technologies as well as the input of substitutes have compensated for overall increases in consumption. The pessimists acknowledged that technological progress and substitution could possibly compensate for increased demand and usage rates of non-renewable resources; however, these effects were not been taken sufficiently into account (Tahvonen, 2000).

3.4. Lessons from the debate

Because of the above mentioned diverging opinions of scholars (Table 1), there is uncertainty about the future supply of non-renewable resources. The broad debate whether we are soon reaching the main peak of oil depletion shows this dilemma. As Daly (1991) explained, even if we cannot measure the total amount of oil, oil is still a finite resource. However, oil would only be infinite, as Simon (1996) suggested, under the condition that oil could be reproduced artificially at a rate faster than consumption. World oil supply could fall short of satisfying demand in the coming decades. Unless there is a collapse in oil demand, Lahn (2009) and Stevenson (2008) expect a rise of the oil price to $200 per barrel or more and a resulting oil crunch around the year 2013 due to inadequate investment by oil companies. For the purpose of this paper it is not necessary to deepen the analysis of the actual time-path of oil depletion and determine the peak of oil depletion. Nevertheless, the debate between the pessimists and the optimists provides significant insights which are relevant for the subsequent argumentation:

(1) First, the intrinsic characteristic of a non-renewable resource is its finiteness because the current rate of consumption exceeds the time that it takes to restore its initial stock. Therefore, the consumption of oil at the current rate states an example of non-sustainable development.
(2) Second, it is unlikely that the world economy is close to a total collapse due to a near depletion of the non-renewable resources. The world economy will rather face the burden of increasing costs, for example, due to a rise of the oil price. In the

Table 1
Main arguments of pessimists and optimists by debate.
Source: organized by authors.

Debates	Main ideas		Authors/years	
	Optimists	Pessimists	Optimists	Pessimists
The 1st debate	Technological progress and human mind will overcome obstacles for future development	Exponential population growth will limit economic prospects	Mill (1862)	Malthus (1798)
The 2nd debate	1. Market forces extract resources at socially optimal rate 2. Most resources are not diminished, because technological progress creates relatively cheaper substitutes	Due to competition and monopoly resources are excessively depleted	Hotelling (1931), Barnett and Morse (1963)	Roosevelt (1908)
The 3rd debate	Energy extraction and substitution is dynamic; obstacles will be overcome in the long-run	Economic development will collapse worldwide due to final depletion of resources, limited agricultural production and pollution	Simon (1996)	Meadows (1972)
The 4th debate	The input of non-renewable resources will switch to the use of relatively cheaper renewables due to technological progress	Substitution possibilities are limited and so is future consumption. Technological change is insufficient to change the pessimistic outcome	Dasgupta and Stiglitz (1981)	Anderson (1987)
The 5th Debate	Sustainable development is feasible through technological progress and substitution by a broad range of substitutes, including investments into human capital	Economic development will stagnate and reach a steady state when non-renewable resources are exhausted	Barro and Sala-I-Martin (1995)	Daly (1991)

end a crises caused by escalating price levels could be overcome by the employment of substitutes which provide, for example, comparatively cheaper energy.

Obviously the current economic development stands in contrast to the concept of sustainability. Yet there remains uncertainty about the effects of the depletion of non-renewable resources for future development. To answer this question the following section will propose the approach of non-sustainable externalities.

3.5. *The approach of non-sustainable externalities*

The approach of non-sustainable externalities proposes criteria under which the depletion of non-renewable resources could cause negative effects on future development. Though previous approaches addressed this issue, shortcomings result in limitations of their significance. One of the most prevalent concepts in the field of measuring sustainable development is the concept of genuine savings which will be discussed subsequently.

According to Hamilton and Clemens (1999) genuine savings is measured as GNP minus consumption, minus the loss of natural capital including resource depletion and pollution damages, minus depreciation of produced capital, plus the increase in human capital. Therefore, zero genuine savings state development where future utility equals current utility, i.e. sustained development. Contrariwise, negative saving rates indicate unsustainable development and call for a policy change sooner or later. Genuine savings appear to be a useful indicator to measure environmental sustainability. Particularly, developing countries could apply this concept to impede reductions in wealth, when the rents of non-renewable resources are not invested into other forms of capital and hence cause lower saving rates (The World Bank, 2005). Yet this approach implies complete substitutability between non-renewable and renewable resources which is critical for two reasons.

First, it overlooks the possibility of ecological limits by assuming that all types of capital are substitutable (Everett and Wilks, 1999). Hence the indicator appears to indicate weak sustainability rather than strong sustainability. Hecht (2005) argues that if a single measure is unsustainable, the whole system is unsustainable. He further stresses that all sustainability indicators merely show unsustainable development. Similarly Pearce et al. (1996) acknowledge that strong sustainability indicators are more suitable to address the conservation of critical natural assets. Finally, Everett and Wilks (1999: 5) question how useful an overall estimate of national sustainability is, instead of analyzing, for example, resource depletion alone. For example, resource importing countries with strong positive GDP hardly show negative saving rates, but a possible future supply shortage of non-renewable resources involves lasting effects for global development which are not captured by genuine savings.

Second, the approach inherits the risk of underestimating negative effects caused by resource depletion on a global level, because non-renewable resources could be substituted by other assets within a country; though on a global level substitution is limited. Although the consumption of non-renewable resources has almost no effect on the genuine saving rates in advanced countries, on a global level, particularly for critical natural resources, strong sustainability should be applied (Pillarisetti, 2005). Pillarisetti (2005) argues that the genuine savings measure is a misleading indicator in a sense that many developing countries are on an unsustainable path while all advanced countries achieve sustainable development. Likewise Martinez-Alier (1995) shows that the positive genuine saving rates of the US and Japan are actually unsustainable when global trade of natural resources is taken into account.

Finally, the concept of genuine savings appears to be a reliable indicator of unsustainable development on a national level unless there is insufficient substitutability between natural resources and produced assets (Ness et al., 2007). Even so, there remains uncertainty about whether the current depletion of non-renewable resources could cause harmful global effects on future growth. In addressing this issue, the approach of non-sustainable externalities focuses on the dynamics of resource depletion and substitution. Thus, the approach aims to overcome the aforementioned differences between importing and exporting countries and suggests an approach which could be applied to analyze the transition from resource input based on weak sustainability towards strong sustainability. The approach will be shown via a brief introduction of the concept of non-sustainable externalities and by setting the criteria as well as the time horizon. Subsequently the applicability of the approach will be illustrated in its application to the problems of environmental degradation, the depletion of non-renewable resources and energy extraction.

3.6. Externalities

In Economics there are four main causes of market failures: public goods, monopoly, externalities and information asymmetry. Among those externalities is one of the most recognized form of market failure. In Environmental Economics, externalities are defined as costs or benefits caused by economic activity which affect uninvolved market actors (Pigou, 1920). Many economic activities cause secondary effects that are not recognized in market transactions and impose costs or benefits on the society or individuals. Examples for negative external effects are air pollution created by automobiles and factories, unwanted noise pollution or the inflow of warmer water from a power plant into a river where fishing industry is located. They derive mainly from transaction costs, for example, when large numbers of third parties are involved. Otherwise contractual agreements aiming to internalize externalities become too costly. If parties could bargain without cost over the allocation of resources, then the market would always solve the problem of externalities. In the absence of voluntary exchange institutions enable the enforcement of agreements at low costs, for example, by eliminating poorly defined property rights (Dahlman, 1979).

Yet there are measures that governments can implement to remedy some of those externalities, for example, regulations, ecotaxes or emission certificates. An appropriate policy takes both the emerging costs and the benefits of all involved actors into account. In other words the goal is not simply to avoid negative externalities, but to determine the optimal output where the total economic benefit is at its maximum (Hanley et al., 1997).

Referring to this concept the authors argue that externalities not only exist in the present, but also between different generations. In this sense, current economic activity creates both benefits and costs for present as well as future generations. Accordingly, non-sustainable externalities are defined by the net costs as the difference between benefits and costs of both present and future societies that were not taken into account by the causing actor. A comparison of the total costs and benefits between different generations allows for a better understanding of the total effect of non-sustainable development. The following figure visualizes the concept, though the actual effect of an excessive depletion of resources on GDP will probably be much less dramatic than the graph suggests (Fig. 1).

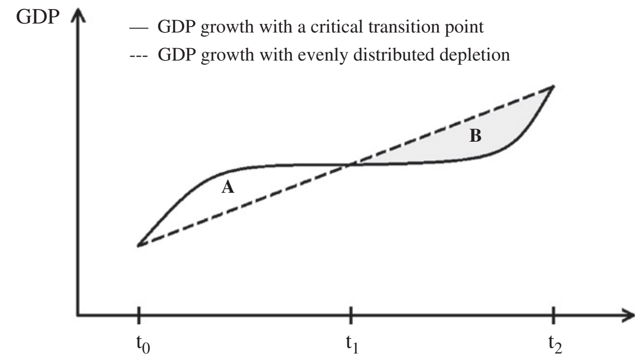

Fig. 1. Growth with and without non-sustainable externalities.
Source: by authors.

Assuming that there is a critical transition point in time t_1 when relatively costly non-renewable resources are continuously used despite the availability of relatively cheaper renewables because renewable substitutes are not yet available in sufficient amounts at the right place, costs B will emerge from excess production costs until a broad substitution by renewables is accomplished at the point in time t_2. Benefits A derive from the excessive input of non-renewable resources from the present t_0 up to the critical transition point t_1. Non-sustainable externalities show the net costs when the costs B exceed the benefits A. Otherwise the benefits outweigh the costs and sustained growth is feasible, for example, if the benefits are invested properly. The straight dashed line indicates linear growth where depletion is evenly distributed from the present t_0 until a substitution is accomplished at t_2 without causing harmful effects on the growth rate. The costs and benefits can be measured by the area between the GDP graphs with a critical transition point and evenly distributed depletion.

The merit of this approach is that it shows the global effects of resource depletion caused by an over-consumption of critical resources. It can be applied to show if the application of prevalent approaches, for example genuine savings, will yield explanatory power in terms of a sustainable use of resources. The application of prevailing approaches appears adequate when there are no non-sustainable externalities or when the transition towards the substitution by renewables is accomplished without a continued use of relatively expensive non-renewable resources. However, in the event of emerging non-sustainable externalities, combined action of governments will be necessary to impede the harmful effects on the prospects for future growth which stands in contrast to the conditions of sustainable development. The following discussion shows the application of this concept in the areas of environmental degradation, the depletion of natural resources and energy supply.

3.7. Environmental degradation

In order to determine the impact of environmental degradation more accurately, it is important to distinguish between non-renewable and renewable resources. The excessive employment of non-renewable resources means that nature is diminished at a higher rate than it takes for its recovery. Benefits include a higher growth rate in the present as well as positive effects for future growth deriving from a stronger previous development. Costs include negative external effects, for example pollution, for both contemporary and future generations. Depending on how future generations will value nature and future requirements for economic development, the lasting diminishment of nature could cause negative externalities for future societies. Though current environmental policies can compensate for the negative effects in the present, there might still remain unwanted costs for future generations if the aggregate costs exceed the aggregate benefits in the long-run.

For instance, farming under normal conditions has no negative consequences for subsequent generations. However, the use of some chemicals could cause serious damage by making farming impossible for many years while increasing productivity in the short-run. Hence future agricultural productivity might decrease and the resulting loss of output cause costs which eventually exceed the initial benefits. In this sense, the restoration of the soil due to the previous use of chemicals is considered a cost for subsequent generations and this could be considered an example of a non-sustainable externality. Similarly, the badly damaged ecosystem in China is estimated to incorporate annual costs from air and water pollution of at least 5.8% of China's gross domestic product. But these costs underestimate the total impact on future development by focusing on the acute effects (The World Bank, The State Environmental Protection Administration, 2007). A more comprehensive evaluation of the negative effects affecting prospects for development would further compare the benefits with the lasting costs of pollution.

3.8. Depletion of non-renewable resources

Due to the intrinsic characteristic of non-renewable resources, costs for future generations only emerge from the depletion of non-renewable resources—not from the employment of renewable resources. The authors argue that current economic development is approaching two possible points in time: first, the final depletion of non-renewable resources in the far future and second, the point in time when renewable substitutes are available at relatively cheaper prices compared to the input of non-renewable resources. Because the latter case is likely to occur long before the final depletion of any resource, the transition towards a sustainable employment of natural resources is feasible when renewable substitutes are available in terms of scale and price levels that allow for a total substitution of their non-renewable counterparts. Before the transition is accomplished the long-term price level of non-renewable resources may exceed the price level of respective renewable substitutes. Despite relatively cheaper renewable substitutes, a shift of the economy towards the input of renewables might not be feasible if those resources are not available in sufficient amounts at the right place. In such a situation, costs for future generations emerge from excess input costs in economic activity due to the continued employment of relatively costly non-renewable resources, a reduction of total economic output or a combination of both. In the former case, a sustained employment of non-renewables indicates the price inelasticity of demand. The latter case shows the difference between the actual output and the potential output as costs. Either way, costs emerge from a previous excessive employment of non-renewable resources because the transition towards the substitution of non-renewables could not be accomplished in time.

Hence, in the long-run the depletion of non-renewable resources will result in excess costs in terms of increased input costs and/or an undersupply resulting from diminishing reserves or increased costs for resource extraction. Examples are found in the extraction of oil from less accessible deeper layers or the less efficient extraction of oil from tar sand. In this context, the time factor is crucial for the determination of the effects. Any short-term shortage of supply would be overcome in the long-run by the exploration of new deposits and not affect the price level in the long-run.

Finally, it is necessary to calculate the benefits that arise from excessive previous depletion. The total benefits of the depletion could be calculated as the difference between the input amount multiplied by the corresponding price of both the actual rate of depletion and the rate of depletion that would have been necessary in order to avoid above described costs. The difference between those benefits and the resulting costs are considered non-sustainable externalities. Therefore, a continued employment of non-renewable resources could impose non-sustainable externalities on future generations until the transition of substitution is accomplished. In the event that a transition is accomplished without the price levels of non-renewable resources surpassing the price levels of renewable substitutes, there will be no non-sustainable externalities and the transition will be completely smooth.

Oil is currently broadly employed in industry, residential, commercial and transport, but substitutes such as solar energy are already employed and will reduce the importance of oil in the long-run. The price advantages of renewable resources will be triggered as the extraction costs of non-renewable resources increases and the production costs of renewables decreases. While technological advances opened access to oil from more remote reservoirs, total costs have increased sharply in recent years. Oil production costs, including finding and lifting costs, rose from $ 12 per Barrel in 2001 up to $ 27 in 2007 (U.S. Energy Information Administration, 2009). At the same time the costs of substitutes decreased continuously: according to the IEA (International Energy Agency) (2010) Photovoltaic (PV) systems could provide 11% of global electricity production by 2050. While installed PV capacity grew from 800 MW in 2000 to 13,500 MW in 2008, PV matured into a mainstream technology and costs of PV systems fell at annual rates of 15–22%. As a result renewable resources have the potential to substitute non-renewable resources at lower costs in the near future. The development of hybrid or electro cars, better insulation of houses or wind sails for cargo ships are further examples where there is a reduction or substitution for energy resource.

An estimation of whether the transition can be accomplished without causing negative externalities for future generations would include the following steps:

(1) The first challenge is to determine all possible substitutes for any resource for different sectors and regions. For example, whereas electricity from geothermal power installations could substitute the input of oil in the transportation sector in California, this kind of substitute would not be suitable in Greenland where geothermal heat is not accessible.
(2) The second task is to compare the current price levels of both oil and its renewable substitutes with future projections. So far most substitutes are both relatively costly and only available in limited amounts. A comprehensive valuation of the real price level would further take public subsidies for the employment of renewables into account that were not captured by the market. For example, public subsidies for the installation of solar panels are considered costs for contemporary societies, because public subsidies are burdened by the tax payer.
(3) In order to estimate the point of time when resources could be substituted as well as whether there will be non-sustainable externalities emerging from its depletion, it is necessary to compare the future supply and demand of both the resource and all possible substitutes. Similarly, a lasting rise in the price of oil over the price level of its substitutes before a broad substitution is feasible would result in higher costs for future generations until that shift is accomplished.
(4) In a last step, the benefits as mentioned above need to be taken into account. Benefits would emerge from increased growth rates in comparison to growth rates without a previous excess depletion. Further benefits emerge from a stronger economic growth in the future which itself is a result of a stronger previous growth. Finally, if the total costs exceed the total benefits there would be non-sustainable externalities.

Obviously, it is not an easy task to accurately predict future externalities. A combined approach of including all kinds of renewable substitutes would probably be most suitable to capture the diverse mutual effects of resource substitution and future price development because this way the correlations between the price and substitution of non-renewable resources could be taken into account. On the other hand, analyzing the depletion of resources separately would simplify the measurement. Further obstacles arise from difficulties in predicting the future demand and supply of each resource as well as the development of new technologies that allow for additional substitution of it and which are unknown so far.

3.9. Energy supply

Energy is of greatest relevance in discussing economic growth. In 2001, green energy extracted from renewables accounted for an estimated 13.5% of total primary energy supply worldwide (IEA, 2003). Even so, the vast majority of energy was produced from non-renewables. It will take very long until energy will be predominantly produced from renewable resources due to economic reasons. Before this point is reached it is possible that energy will continue to be produced from non-renewable resources, despite the availability of renewable substitutes at lower costs. This could be the case if renewables are not available in sufficient amounts or in certain regions. Similarly, the externalities for future generations that emerge during this time span need to be compared with the benefits resulting from the excessive input of non-renewable resources for energy production. In addition, the investments in making renewable substitutes accessible for energy production at lower prices need to be taken into account and be subtracted from the externalities. The remaining net costs show the amount of non-sustainable externalities.

A growing world population in combination with high economic growth rates in several developing countries will cause a constantly increasing energy demand and puts pressure on the price of resources that are employed for energy extraction. In the very long-run renewables are likely to compensate for the diminishing supply of non-renewable resources, but before this condition is reached, the price levels of non-renewable resources may surpass those of renewable substitutes. During this time there could emerge externalities if the supply in terms of price or quantity does not satisfy energy demand. An insufficient energy supply could cause a decline in economic growth and/or excessive energy costs. Most contemporary societies put considerable effort into the development of renewable resources in order to avoid harmful consequences on subsequent generations. In 2008, investments in sustainable energy projects reached $155 billion and surpassed fossil fuel investment (UNEP Sustainable Energy Finance Initiative (SEFI) and New Energy Finance (NEF), 2008). Since many of these expenses are borne by the tax payer, they need to be subtracted from potential externalities in order to determine the actual amount of non-sustainable externalities. A suitable example is the development of fusion power: the ITER project is the first step on the road to fusion power. It will be followed by DEMO power plants which could be connected to the electricity grid by the year 2030. The merits of fusion power include, among others, inexhaustible resources, emission-free energy production, as well as inherent safety. Therefore, fusion power could substitute a broad range of non-renewable resources in the long-run, but the cost of fusion electricity depends upon future advances on fusion physics, technologies, materials and the optimization of fusion power plant concepts (Gnansounou and Bedniaguine, 2005).

As shown, the approach of non-renewable externalities could be applied to determine the net costs of unsustainable resource depletion. In this context, it is worthwhile to look at the role of governments. This question leads to the final part which will point at implications of governmental policies for sustainable development.

3.10. Implications for a policy of sustainable development

The approach of non-sustainable externalities has the potential to facilitate fair governance for sustainable development by taking a steady supply of resources in the long-run into account. Hence the main policy goal is to minimize non-sustainable externalities in order to support a smooth transition towards a sustainable economic development and stable energy prices. Therefore, the development policy of importing countries tends to facilitate substitution through such actions as subsidies and laws promoting sustainable energy production. Similarly, exporting countries seek to maintain national income by substituting the inflow from exports of non-renewable resources. Until the transition is accomplished exporting countries will deplete their non-renewable resources because the resource revenues can be invested more profitably compared to expected increases of the price. Accordingly, resources will be depleted at their optimal rate in terms of short-term profitability, but this does not attest a smooth transition towards the input of renewables.

In order to avoid any disruptions in the long-run, importers could apply the approach of non-sustainable externalities as a tool to facilitate a smooth transition. The biggest challenge, as empirical experience with oil shows, would be to determine the point of transition where renewable resources will be available at lower prices. This is for several reasons: (1) the rate of depletion will change over time due to the development of new technologies, (2) there will be new discoveries of reserves, (3) consumer behavior will change over time and (4) the structural framework of the global economy will change due to such things as the implementation of various environmental regulations. Furthermore, it is an ethical question, how far contemporary interests can be pursued at the expense of the interests of future generations. In other words, it is difficult to transfer future interests into money terms and take the interests of following generations into account which would essentially have to include changes in societal values.

During the transition process governments have to choose among to consumption, to public investment, or paying off public debt (Stevens and Mitchell, 2008). Uncertainty about the actual amount of resource reserves, future prospects for oil and natural gas prices, costs of production and the government's future share of rent or profit – not to mention the risks of investment – further complicates this decision. Case studies show that while real GDP has risen in many countries, indicators of weak sustainability show that sustainable economic welfare declined over the last 20 years (Hackett, 2001). This suggests that despite existing policy approaches, for example Green GDP or genuine saving rates, governments have often failed to pursue a sustainable development policy and tend to over-emphasize short-term goals. The application of a sound development policy is often limited by several, possibly incompatible, objectives: economic growth, increasing wealth, avoiding balance-of-trade deficits and maintaining the ruling party in power. For instance, the US government took measures to guard against resource shortage by accumulating stockpiles, subsidizing the domestic petroleum industry and protecting domestic mineral production by tariffs. Contrarily, Least Developed Countries (LDCs) often depend on foreign investment which could cause a poverty trap and hence hinder the implementation of sound environmental policy measures (Kahn, 2005). LDC mineral producers also used export tariffs as a revenue-raising measure by promoting the domestic processing industry, but their policy options have been limited by international agreements and high competition. As Russet (1984) showed, they hold no significant resource power. In addition, Hufschmidt and Hyman (1979) discussed special limitations on developing countries in formulating or applying a sustainable depletion policy, including inadequacies in monitoring and enforcement of laws and regulations.

Further constraints on implementation of policies for development derive from the global system because national measures often lack far reaching effectiveness. International cooperation remains voluntarily until an effective global authority is established that can enforce a sustainable use of resources (Xepapadeas, 1996). Yet agreements often cannot be reached because countries stand on different developmental stages and over-emphasize national interests. In this context Conrad (1999: 78) suggested that economies first need to grow until they achieve advanced developmental stages before governments, as well as the public in those countries, will be more concerned with the effects of depletion and environmental problems. Without a consistent international depletion policy, there will be incentives to defect, and decision makers will tend to be selective by emphasizing those factors that include relatively high gains for their own country. Yet sustainable development requires good governance within each country and at the international level which includes sound environmental, social and economic policies (Nieuwenhuys, 2006:203).

Finally, whereas both exporting and importing countries seek to maintain the prospects for development in the long-run, the approach of non-sustainable externalities is a concept which could particularly be applied on a global level to measure the transition effects towards the input of renewable substitutes.

4. Conclusion

The debate between the optimists and the pessimists shows that the depletion of non-renewable resources will have a significant impact on the economic development of future generations. A continued depletion is unlikely to lead to a collapse of economic development and the use of resources will due to relatively cheaper renewables more or less smoothly shift towards a sustainable economic development. Based on this discussion, this paper proposes to answer the questions "What is the impact of the depletion of non-renewable resources on sustainable economic development?" and "Under what conditions will current efforts of employing renewable resources state negative or positive externalities for future generations?" In order to determine the beneficiary as well as the range of benefits and costs caused by current resource depletion, the authors propose the approach of non-sustainable externalities by applying the concept of externalities. According to this concept current economic development is approaching a point in time when renewable substitutes are available at lower prices than non-renewable resources. If this point occurs before the transition towards the input of renewable resources is accomplished, there may emerge non-sustainable externalities from a continued employment of costly non-renewable resources if exceeding previous benefits.

A policy for sustainable development would seek to minimize non-sustainable externalities in order to facilitate a smooth transition towards a sustainable economic development. But a complex of mutually dependent factors poses obstacles to time the transition accurately and makes it difficult to determine an optimal path towards the employment of renewable resources. As well, the rate of depletion changes over time according to the development of new technologies, the employment of substitutes, new discoveries of natural resources, changes in consumer behavior, and changes of the structural framework of the global economy. Therefore, there is uncertainty about the actual price development of both renewable and non-renewable resources. Finally, governmental intervention is necessary where the market system itself does not take sustainability sufficiently into account.

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