The Economic Effects of Energy Efficiency

An Investigation into the Conceptual Distinction Between Weak and Strong Sustainability, Rebound Effects, and Their Relations to Sustainable Energy Policy

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Dedicated to my family and friends

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Abstract

This thesis investigates how the economic effects of energy efficiency, the conceptual distinction between weak and strong sustainability, rebound effects and their relations to sustainable energy are used in energy policy. According to the Dutch sustainable energy policy, energy efficiency is beneficial to sustainability as it reduces the amount of energy resources needed to produce a similar amount of energy services. In this view, energy efficiency saves energy resources and cuts back CO2-emissions. For sustainability we should save some resources for future generations, and this suggests using resources as efficiently as possible. When energy efficiency improvements equal cost reductions, they provide an option space for savings and investments. If the energy efficiency stimuli actually lead to energy resources being saved this is compatible with ‘strong sustainability’. Yet, if the rents are invested in more energy consuming activities, this is not compatible with strong sustainability, but can still be compatible with ‘weak sustainability’. The case in which the rents of energy efficiency improvements lead to the use of more energy resources is generically called: rebound effects. These effects provide a problem for the popular idea of energy efficiency adding to the aims of sustainability. They show that the economic effects of energy efficiency can be counter-productive for actually achieving the aims of weak or strong sustainability, which contradicts the outcome as suggested by sustainable energy policies; because they are based on calculations without accounting for rebound effects. Energy efficiency and sustainability go hand in hand, at least, so it seems. Yet, when taking a closer look at debates about energy efficiency, I find that the relationship with sustainability is not as straightforward as suggested in the Dutch sustainable energy policy.

My thesis is that if, in the context of the Dutch sustainable energy policy, energy efficiency is assumed to lead to economic and environmental benefits by reducing the amount of natural capital needed for input to produce the same amount of output, than energy efficiency is ‘sustainable’ in a weaker or stronger sense. But, when energy efficiency leads to rebound effects, thereby increasing the use of natural capital, it is only ‘sustainable’ in a weak sense. Even more, when rebound effects result in an increased level of natural capital use compared to the situation without an energy efficiency improvement, than energy efficiency is not ‘sustainable’ in any sense. In the latter case, energy efficiency is not ‘sustainable’ in any of the two senses. The possibility of energy efficiency not being ‘sustainable’ is overlooked in the Dutch sustainable energy policy, which is rather naïve considering the underlying economic effects.

Keywords: energy efficiency, weak and strong sustainability, rebound effects, Dutch sustainable energy policy

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Abbreviations

EE = energy efficiency
ESI = environmental savings index
GHG = greenhouse gas
GSI = genuine savings index
KBP = Khazzoom-Brookes Postulate
RE's = rebound effects
SS = strong sustainability
SS1 = first school of strong sustainability
SS2 = second school of strong sustainability
WS = weak sustainability

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The road has been tough, but the company that came along has been an absolute joy ☺

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1. Energy Efficiency

The release of atomic energy has not created a new problem.
It has merely made more urgent the necessity of solving an existing one.

- Albert Einstein (Interview by Raymond Swing, 1945)

1.1 Fossil Energy Scarcity and the Sustainable Energy Transition

In the 21st century policy-makers are finally recognizing that the age of fossil energy has become old, but it is not dead yet (UNEP, 2012; IPCC, 2011). It is roughly estimated (EIA 2007) that fossil fuel takes up a 86.4% share in total energy consumption in the world.[1] The optimists cheer by the latest assessment of undiscovered oil and gas reserves[2], but the pessimists point out that the total amount of reserves is eventually based on educated guesses and, more important, they are finite. Gas is often suggested to be the alternative for oil in the middle half of the 21st century. However, estimates of producible gas that were made in the 20th century have already undergone substantial reduction, partly due to inaccurate methodology and too optimistic estimations.[3] As with oil, there are other potential, but expensive, sources of non-conventional gas that may become available during this century. But for both conventional oil and conventional gas, the double peak distribution pattern fits the existing data fairly well: it seems likely that the distribution of hydrocarbons in the earth's crust contains small peaks of gas and liquid petroleum, and larger peaks of coal, heavy oils, and shale, which may be part of a single distribution pattern (see figure 1).

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[1] http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm (last visited 21 February 2013
[2] http://www.opec.org/opec_web/en/publications/2203.htm (last visited February 2013)
[3] http://www.eia.gov/analysis/studies/worldshalegas/ (last visited 21 February 2013)

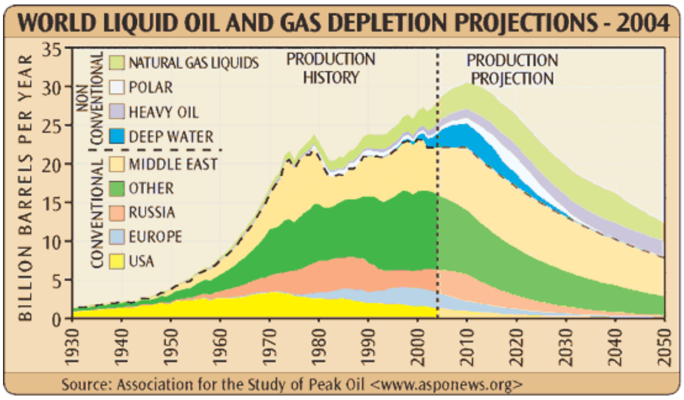

Figure 1 - World Liquid Oil and Gas Depletion Projections

The bottom line is this: at the current rate of consumption both profitable conventional and non-conventional oil and gas resources will be (almost) exhausted somewhere at the end of this century. In theory, this leaves us only with coal and nuclear for fossil energy stocks, which are not be sufficient to keep up with rising global energy use due to population and economic growth (IEO, 2011; OPEC, 2012). Proverbially speaking, there may be enough oil for us, enough gas for our children, and enough coal for our grandchildren, but fossil energy resources will not last for the generations to come afterwards. Rephrasing Einstein’s quote at the beginning of this chapter: The release of fossil energy resources has not created new problems. It has merely made more urgent the necessity of solving existing ones, namely their finitude and necessary substitution with sustainable energy. Thus, to keep up with energy demand throughout the second half of the 21st century - leading to a successful sustainable energy transition whereby renewables fully replace fossil fuels - will require rapid development of vast amounts of sustainable energy for substitution (see also Verbong and Loorbach, 2012).

Aside its finitude and substitution, using fossil energy contributes to another problem, namely environmental degradation, such as oil spills and the emission of harmful gasses. It is estimated that the use of fossil energy in 2008 resulted in 40 billion metric tons of CO2 along vast quantities of other harmful emissions into the earth’s atmosphere (IEA, 2007 and 2011). Emissions of greenhouse gases (GHG’s) – including CO2 - have risen more than 30% over the past two decades, and a further 36% increase is estimated between 2006 and 2030 (DOE, 2006). Problems with fossil energy supply and use are related not only to GHG-emissions and global warming, but also to other environmental concerns such as air pollution, acid precipitation, ozone depletion, forest destruction, and emission of radioactive substances. In other words, the use and substitution of fossil fuels adds to sustainability concerns other than their depletion and replacement. These concerns have become popular news items and subjects of policy reform in Western societies ever since the 1970s.

At present, it is a widely shared belief that energy-related sustainability issues are of highest importance (IPCC, 2012; UNEP, 2012). For example, the first Afro-American president of the United States – the second largest economy in the world, responsible for using most fossil energy resources globally and thereby causing a substantial amount of GHG-emissions - has set out to pro-actively develop sustainable energy resources, address energy resource depletion, and mitigate GHG-emissions and climate change.[4] Another example closer to home is the Netherlands, whose government has invested the last 20 years in stimulating the Dutch energy transition towards sustainable energy, intended to mitigate the rising costs of energy due to increasing scarcity of fossil fuel reserves and accompanying environmental degradation (NMP4, 2001; Verbong and Loorbach, 2012).[5] Most countries now recognize the urgent need for a sustainable energy transition, whereby the dependence on fossil fuels is lowered and their use phased-out by substitution with sustainable energy. Ideally the energy transition from fossil to sustainable is completed when sustainable energy has fully replaced fossil energy. In the future, this would drastically cut back total GHG-emissions, and decrease the role of energy in sustainability concerns. Even more, some scholars argue that sustainable energy is imperative for developing a fully sustainable economy (Braungart et al., 2007).

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[4] http://www.bloomberg.com/news/2012-09-06/renewable-energy-is-obama-goal-for-next-term-aide-says.html (last visited 14 March 2013).

[5] The Dutch Energy Transition project was officially cancelled on 1 January 2012.

For more than 40 years, sustainable energy has been a staple part of academic energy debates (e.g. see *Energy* and *Energy Policy* 1970-2010). Consistent with the Brundtland definition of sustainability (WCED, 1987, p. 43), ‘sustainable energy’ generally refers to the provision of energy that meets the energy needs of present generations without compromising the ability of future generations to meet their energy needs. Moving towards a global economy based on sustainable energy will require massive changes in meeting present energy needs, the way energy is used, and reducing the total amount of energy required to power economies. The recent ongoing debate about sustainable energy can be framed by four general approaches (for an overview see Prindle and Eldridge, 2007): (a) a shift to renewable energy sources, (b) an emphasis on savings through energy efficiency, (c) an effort to reduce demand, and (d) an embrace of end-of-the-line technological fixes, such as carbon capture, storage, and use. Of these four themes (b) - i.e. savings through energy efficiency - appears to offer the easiest and least costly way forward. It does not require major capital investments in technological innovation such as (a) and (d) do, and partially coincides with (c). Because of its potential to reduce total energy use and its cost-effectiveness in doing so, energy efficiency is of great interest to energy policy makers, as a relatively cheap way to reduce energy use and accompanying emissions.

At its simplest, sustainable energy requires (b-c) and (a-d), or “Twin Pillars” (ibid.), namely energy efficiency (EE) and innovations. EE can be defined as the percentage of total energy input that is consumed in useful work. Stimulating EE is regarded as essential to decreasing growth of overall energy use, while renewables substitute fossil energy resources, and both help cut back GHG-emissions; along other innovations. The popular view on EE is ‘doing more with less’, or, reducing the energy intensity of growing economic activity. If total demand increases, EE can help to curb the increase of total energy use and emissions. EE can reduce the amount of energy input needed to produce the same output level of energy service, thus it can save ‘natural capital’ (e.g. oil, gas, coal, atmosphere, oceans, etc.) whether demand grows or stays the same. At least, so it is commonly suggested in present policy and policy evaluation indicators (see also Patterson, 1996).

The popular assumption that underlies current energy policies is that improving EE will simultaneously lower the burdens of energy use on the economy and the environment, creating a win-win situation. A major concern for developing sustainable energy is that if overall energy use and GHG-emissions grow too rapidly, substituting fossil energy resources with renewables will be like chasing a receding target that moves too fast to aim for with any accuracy. Therefore, a serious sustainable energy policy requires a commitment to EE from the outset, in order to slow down the pace of growing energy demand and associated emissions. This strategy assumes that EE always decreases the amount of energy input needed to produce the same level of energy service output, and total energy use and emissions will decrease while total demand can stay the same. In this thesis I will critically examine this assumption, and investigate the venue leading off into the opposite direction, namely that EE leads to more energy use and emissions.

As will be argued for in this thesis, a commitment to EE may not at all slow down the pace of growing energy demand and associated emissions, but only speed up the pace of energy use and emissions. The assumption that EE always leads to energy savings and less emissions is mistaken when taking into account the economic effects that can follow EE improvements. These effects imply that EE improvements do not always lead to slowing down the pace of growing energy use and emissions, but quite the opposite.

1.2 Sustainable Energy Policy and Rebound Effects

Energy intensity is an economy-wide measure, which is calculated as units of energy (Btu) per unit of GDP (euros). Simply put, energy intensity measures how many Btu's are used to produce an euro of GDP. EE is normally considered able to reduce energy intensity; making it cheaper to produce a euro of GDP. According to the EE index for energy consumption in the industrial, household, and transport sectors in the Netherlands, energy intensity has decreased in the period 1990-2007, indicating higher levels of EE. The average annual decrease of total energy intensity of the Dutch economy was about 1.2%. Despite decreasing energy intensity, between 1990 and 2007 overall energy related CO2 emissions have increased in the Netherlands. Decomposition into different factors shows the contribution of different developments, of which some factors increase the emissions, like growing GDP, but other factors result in a lower emission, such as improved EE and fossil energy resource substitution with renewables (CBS 2007). This decrease of energy intensity accompanied by an increase in CO2 emissions I take as an indication that calculating and measuring the economic and environmental benefits of EE is not as straightforward as suggested by the Dutch Action Plan policy-makers. According to their view, increasing EE leads to decreased levels of energy intensity paired with a decrease in associated GHG-emissions. The Dutch stats on energy intensity and GHG-emissions in the period 1990-2007 contradict this view.

My main concern is that present Dutch policy overlooks the possibility of unintended consequences of EE improvement, namely rebound effects, whereby the economic and environmental benefits are not fully obtained and EE is partially or wholly counter-productive as a twin pillar of 'sustainable' energy. 'Rebound effects' is an umbrella term used to describe the economic effects that the lower costs of energy services, due to increased energy efficiency, has on consumer behavior both on the individual (firm or household) level and the national level. The term refers to the amount of energy savings produced by an efficiency improvement that is ‘taken back’ by consumers in the form of higher consumption. Economic and environmental benefits calculated at the beginning of a period are here referred to as ‘EE in principle’, and benefits defined in terms of measurements made at the end of a period are referred to as ‘EE in practice’ (see also Myrdal 1939, 46-47). The Dutch Action Plan 2007-2020 suggests ‘plain’ EE policies, which are based on blackboard calculations of EE in principle without any concern for RE’s or accompanying abatement policy for preventing the EE rents to be invested in more energy consuming goods and services. I will try to show that not accounting for RE’s when estimating EE in principle leads to too optimistic assessments of economic and environmental benefits, and not accounting for RE’s when measuring EE in practice leads to overlooking the real impact of EE policy and possible unintended consequences. In my view, RE’s following EE improvements should be taken up in the calculations and measurements of future Dutch energy policies.

The past years many energy policies have already been drawn up and implemented that try to stimulate EE to pace growing energy use and curb GHG-emissions, but also to mitigate the costs associated with pursuing other sustainability goals such as the development and deployment of renewable energy sources (OECD/IEA 1994; OECD 2011; IPCC 2011). In the EU directive each member state is advised to set its own incremental targets, and present a national EE action plan every three years.[6] To illustrate its relative success, EE improvements in 16 EU countries led to energy and CO2 savings of 15% and 14% in 2005 (16 EJ and 1.3 Gt CO). This translates into cost savings of at least 146 billion Euros that year (IEA 2008). By

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[6] http://www.europarl.europa.eu/news/nl/pressroom/content/20120614IPR46817/html/MEPs-seal-the-deal-on-energy-efficiency (last visited 8/8/2012)

adopting the EU directive, the Netherlands hopes to achieve its target of using 20% less energy by 2020.

The first Action Plan in 2007 contained an agreement that eventually 100% of central governmental procurement will take EE criteria into account. The plan states that due to the increased attention to EE in energy policy, the next years may well show an increasing amount of opportunities to exploit the many possibilities for improving EE in households, firms, sectors, and even in the Dutch economy. But, it does not mention the possibility of RE's at all (Dutch Action Plan 2007). A few Dutch organizations provide information on opportunities for improving EE to consumers, small and medium enterprises, and other industrial market parties. On their website, *Milieu Centraal* informs consumers that EE is easy, profitable, good for the environment because it saves natural resources.[7] *Energiecentrum MKB* informs small and medium enterprises that EE is profitable as a sustainable investment that pays itself back via cost-reductions on energy bills.[8] In this sense, EE is a win-win situation that benefits the economy as well as the environment. In my view of RE's, the Dutch overlook the possible negative effects of the policy by focusing solely on the calculated benefits of EE *in principle*. Thereby they tend to overlook the theoretical and practical problems that are posed by the presence of RE's for the development of sustainable energy.

As pointed out by many economists (Jevons, 1865; Khazzoom, 1980; Brookes, 1978; Saunders, 1992), in theory, when the EE of an economic process is improved this makes it relatively cheaper to conduct, compared to the situation without the EE improvement. EE can induce rebound effects (RE's) whereby producers and consumers increase their energy use

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[7] http://www.milieucentraal.nl/themas/energie-besparen (last visited 8/8/2012).
[8] http://www.energiecentrum.nl/energiebesparing (last visited 8/8/2012).

along the cost reduction, and thereby draw more upon fossil fuel resources and the natural environment. There has been an extensive debate in the energy economics/policy literature on the existence and impact of RE’s, which questions the amount of economic and environmental benefits that can be obtained via EE policy. This debate primarily focuses on the expected impacts of EE on reducing energy intensities are partially, or possibly even more than wholly, offset as a consequence of producers and consumers responding to EE stimuli. The discussion led to formulate the so-called “Khazzoom-Brookes Postulate” (KBP – Saunders, 1992), which asserts that EE stimuli on the micro- and macroeconomic level can actually cause an increase of total demand for energy. In addition, EE improvements can lead to an increase in associated GHG-emissions, thereby nullifying the anticipated environmental benefits.

Stanley Jevons (1865), one of the founding fathers of neoclassical economics, was the first to argue by using statistical analysis that RE’s follow EE improvements. Studying Watt’s innovations in the EE of steam engines on the firm-level, industrial expansion on the sector level, and increasing fossil energy use at the national level, Jevons argued that EE improvements can lead to increased demand for energy throughout the whole economy. Recently the House of Lords in the UK has acknowledged Jevons’ insight, and now recognizes that EE stimuli alone might not deliver the expected energy savings and environmental benefits due to RE’s (Allen et al., 2006). The UK Energy Research Centre’s Technology and Policy Assessment has produced a report on RE’s stating that they “need be taken more seriously by analysts and policymakers than has hitherto been the case” (Sorrell, 2007, 92). This recognition of possible RE’s is not internationally shared, which I personally find problematic in the case of the Dutch Action Plan 2007-2020 because it can lead to too optimistic assessments of energy efficiency improvements as a pillar of ‘sustainable’ energy.

Some scholars have argued that the case for RE’s is already overplayed in relation to energy policy, because they are empirically found to be relatively small. The theory of RE’s has often been used to criticize (and stall) EE policy, so it can be a distraction from further pursuing the benefits of EE stimuli (Gillingham et al. 2013). While RE´s found in empirical studies may be small, their existence and impact are still problematic for the Dutch Action Plan, I think, because RE’s are not ‘found to be small’ but are completely overlooked in the calculations. The Dutch policy-makers just looked at the economic and environmental benefits of EE calculated without RE’s, and thereby were bound to overlook the economic effects in play. In this setting, I will critically investigate the conceptualization and application of EE without accounting for RE’s, as presented in the Dutch Action Plan 2007-2020. My aim is not to argue against the use of EE policies to mitigate fossil fuel use and associated sustainability issues – quite on the contrary - but to highlight fundamental shortcomings of present ones in order to help formulating more accurate energy policy performance assessments for the future. As the title suggests, I will forward my aim by drawing on the insights of economists debating EE, the conceptual distinction between weak and strong sustainability, the existence and magnitude of RE´s, and the Dutch sustainable energy policy 2007-2020.

1.3 Energy Efficiency Policy and Weak and Strong Sustainability

In this thesis, I will focus only on the Dutch Action Plan for the period 2007-2020. The policy displays assumptions about the economic and environmental benefits of EE in principle, as well as a lack of assessments of EE in practice, both in light of RE’s, that suggest that it makes up a rather naïve strategy for developing sustainable energy. Before the Dutch run out to buy more EE utilities, appliances, vehicles, buildings, machinery, and other technologies, I suggest, they might want to consider the problematic relation between EE, RE's, sustainability, and the doubtful assumptions found in present energy policy. Another look at the first pillar of sustainable energy, namely EE, will show that sustainable energy policies do not always deliver as much EE as what was calculated, particularly, due to overlooked RE's. The Dutch Action Plan simply assumes that EE leads to certain economic and environmental benefits, but in light of RE's, EE can also increase total energy use and GHG-emissions. Whether EE with RE's adds to sustainability depends on one's preferred definition of the concept.

There is some consensus among economists about the principal definition of 'sustainability' as: non-declining average human welfare over time (Pearce et al. 1989). This definition is consistent with the Brundlandt definition (i.e. fulfilling present and future needs - WECD 1987, 43). It implies a departure from the strict neoclassical principle of optimizing in traditional growth models, which does not include any concern for the welfare of any other but the individual. But otherwise this concept of sustainability does not require a grand departure from conventional neoclassical theory (Stern, 1997). After settling on the definition as non-declining average human welfare over time, the question now is: whether one assumes (i) that natural capital could and should be substituted by the same or other forms of capital, especially human-made capital, or (ii) that natural capital cannot always be substituted and should be saved? The answer to either (i) save or (ii) substitute natural capital basically boils down to the choice between weak sustainability (WS) and sustainability (SS) (e.g. see Turner, 1992; Pearce and Atkinson, 1993; Hediger, 1999; Ayres, Van den Bergh, and Gowdy, 2001; Neumayer 2003; Steger et al., 2005; Dietz and Neumayer, 2007).

The economist David Pearce (1976) is widely credited for the establishment of the concept of natural capital and the linkages to WS and SS later during the 1980s. He was the first economist to publish on the subjects as a way of introducing ecological sensitivities into mainstream economics. In the famous 'Blueprint' (Pearce et al. 1986; see also Pearce and Barbier, 2000) his early notions of WS and SS can be found. The WS and SS approaches to sustainability both start from the Brundlandt definition of sustainability (WCED, 1987), but the main difference is that for WS the concept of sustainability allows for natural capital stocks (e.g. oil, gas, and coal) to be fully depleted in case they can be substituted by equivalent substitutes (Solow 1996). In contrast, according to SS the concept of sustainability aims to fulfill present and future needs without fully depleting some critical natural capital stocks (e.g. the atmosphere) and/or permanently damaging their continuity (Daly 1995).

WS has become an approach within ecological economics which holds the position that human capital is directly substitutable for natural capital. Human capital incorporates resources such as infrastructure, labor and knowledge, whereas natural capital covers the stock of environmental assets such as fossil fuels, biodiversity and other ecosystem services. WS is mostly based upon the work of Robert Solow and John Hartwick. This particular approach to sustainability has enjoyed increased political attention with the advance of 'sustainable development' discourse in the late 1980s and early 1990s. A key landmark for the WS approach was the Rio Summit in 1992 where the vast majority of nation-states committed to 'green growth' by signing *Agenda 21*, a global plan for action on sustainable development.[9]

Opposed to WS, SS has become a notion in ecological economics which holds that the stock of natural resources and ecological functions are most often, or always, irreplaceable. SS basically suggests that economic policy has a responsibility to the greater ecological world, and that sustainable development must therefore take a different approach to valuing natural

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[9] http://sustainabledevelopment.un.org/index.php?page=view&nr=23&type=400&menu=35 (last visited 7-5-2013)

resources and ecological functions than forwarded by proponents of WS. Adherents of both WS and SS can suggest EE to advance their individual aims, respectively: (i) savings and investment, or (ii) just savings. Analogously, according to the Dutch Action Plan, EE can lead to both savings of natural capital (e.g. oil and GHG's being emitted into the atmosphere) as well as investment opportunities in substitutes (e.g. renewables and carbon capture). Here the distinction between WS and SS is helpful for the analysis of such policies in terms of their purpose to advance sustainable energy.

However, the distinction between WS and SS (see also Ayres et al., 2001) should be accompanied by the following note of caution (Van Den Bergh, 2010, 2049):

> Most likely, the opposition is a bit farfetched, and what is really required is an estimation of the degree of "weakness/strongness", and relatedly the degrees of substitution between different types of capital (manufactured, natural, human, or within natural). The reason is that these make up critical factors behind one's expectations of, and optimism about, sustainable economic systems and developments.

Even though the opposition is a bit farfetched, the concepts of WS and SS fit to represent two rivaling approaches on how to use natural capital. The concepts even underlie two very distinct sustainability indexes (Böhringer and Jochem, 2007). These indexes show different expectations of, and optimism about, the purpose and use of natural capital stocks, according to the WS or SS approach.

As a means to reduce the use of natural capital, both WS and SS suggest that EE can be beneficial to their individual aims; i.e. opening up substitution and/or savings opportunities. In this sense, EE can be considered 'sustainable' in a weak or strong sense. But, when RE's are taken into account I find it doubtful that EE can be comaptible with both kinds of sustainability because it leads to investments. This thesis will try to show that EE cannot categorically be considered beneficial to the aims of both WS and SS, as well as the development of sustainable energy via EE, especially when the amount of savings and investments following EE stimuli are not properly accounted for. When the debate on EE is extended to fit the discussion on WS and SS, it highlights conceptual problems for EE being considered 'sustainable' when the investments take-back some, or even all, of the savings. If RE's are taken into account, EE can be less beneficial to the aims of the WS or SS approach. Instead of saving natural capital, or generating rents to invest in substitutes, EE can result in more natural capital than can be considered 'sustainable' in terms of the WS or SS approach.

1.4 Research Claim

For the sustainable energy transition much effort must be devoted not only to developing renewable energy resources, but also to increasing EE to curb total use and associated environmental degradation. Energy resources and their utilization are related to natural capital depletion, which brings it into the domains of WS and SS. Due to increased awareness of the benefits of EE improvements, many Dutch agencies have started working along the lines of EE to advance 'sustainable' energy. Taking on board the distinction between WS and SS shows that on the one hand the Dutch EE policies have been developed to reduce present levels of fossil energy consumption and energy-related GHG-emissions (or, natural capital), which is compatible with the SS approach. On the other hand, they have been developed to reduce costs and open up investment opportunities, thereby possibly stimulating natural capital use which is compatible only with the WS approach. Eventually EE may turn out to be a rather 'unsustainable pillar' of energy policy, when a part or all of the savings stemming from EE stimuli are forgone due to RE's.

In the following chapters I set out to present and defend the following claims that underly my worries about the Dutch energy policy 2007-2020:

> If EE is assumed to lead to certain economic and environmental benefits by reducing the amount of natural capital needed for input to produce the same amount of output, than EE can be beneficial to the aims of WS or SS; thus, EE can be considered ‘sustainable’ in a weak or strong sense. However, when EE leads to RE´s, thereby increasing the use of natural capital, this can be beneficial only to the aim of WS and not to that of SS; thus, in this case EE can only be considered weakly ‘sustainable’. Even more, when EE stimuli result in an increased level of natural capital use – due to RE’s - compared to the situation without EE improvement, EE is not beneficial to the aims of WS or SS. Thus, in this case EE cannot be considered ‘sustainable’ in one of these senses. If RE´s counteract upon the aims of WS and SS, and can be found in calculated EE in principle, then there is a case in which EE is not sustainable in principle. In case RE´s counteract upon the aims of WS and SS, and can be found in measured EE in practice, then there is a case in which EE is not sustainable in practice. Combined, finding such cases will lead me to conclude that EE due to RE’s cannot always be considered ‘sustainable’ in a WS or SS sense.

Assuming these claims are correct, I find it worrying that RE´s are not taken into account in Dutch sustainable energy policy, which in the worst case is mislabeled ‘sustainable’. The policy overlooks that if RE’s are properly taken into account in calculations of EE, measures can be taken to counter RE´s stemming from energy policy. And, if they are taken into account measuring EE, this provides evidence directing at the possibility that the EE policy does not deliver what was assumed at first, namely sustainability. The present sustainable energy policy seems rather naive, in the sense that it assumes EE can always be considered 'sustainable', thereby assuming EE improvements almost automatically adding to the sustainable energy transition. But, the economic effects following EE improvements show how energy policy-makers should reconsider the assumptions in the present policy, and take into account RE's counter-acting upon their efforts.

I will set-out to show how EE, due to RE's, is not always compatible with the WS nor SS approach, and therefore cannot always be considered to be 'sustainable'. I will defend the assumptions that EE does not always (a) lead to less energy use, and (b) helps to cut-back GHG-emissions. If true, this presents a problem for upholding the popular belief displayed in the Dutch energy policy that EE always has certain economic and environmental benefits. If the assumptions about the sustainability of EE must be reconsidered also the policy stemming from them must be re-assessed. I will argue that the assumption about EE stimuli always leading to certain economic and environmental benefits by EE in principle, adding to the aims of the WS and SS approach, must be reconsidered, because RE's are shown to occur in theory. This takes away some of the optimism about the benefits of EE for sustainability in principle. Secondly, I will argue that the assessments of EE in practice must be reconsidered as well, because RE's are shown to occur in the real world, which not always adds to either the WS or SS approach. This takes away some of the optimism about the benefits of EE for sustainability in practice.

From here on, I set out to show that there is a case in which EE does not add to sustainability in any of the two senses in principle nor in practice, which renders EE as a pillar of ‘sustainable’ energy policy less promising than is suggested by the Dutch policy-makers. My thesis will be substantiated by showing that EE not only follows from the WS approach, as it can also be shown that it follows from the SS approach, but in turn can conflict with both WS and SS approaches when taking into account RE´s resulting in backfire. I will argue that EE with RE’s is not always ‘sustainable’ in terms of WS or SS, and therefore a less promising pillar of ‘sustainable’ energy policy as is presented in the Dutch Action Plan 2007-2020.

1.5 Thesis Structure

In chapter 2, I will sketch a short story of EE. From doing less work with more energy, EE also has turned into doing more work with less energy. Doing more ‘x’ with less ‘y’ saves a certain amount of ‘y’. Yet, when EE reduces costs of doing ‘x’, the cost savings open up new investment possibilities (e.g. buying more ‘y’ and doing more ‘x’), that may add to or take away from the aims of sustainability, in the sense of WS (Solow, 1974; Hartwick, 1976) or SS (Georgescu-Roegen, 1971; Daly, 1980). On the one hand, investing in EE improvements raises energy resource constraints because less input is required to produce a similar amount of output; which is in line with the aims of WS or SS. But, on the other hand it is constrained by the ultimate limits of an energy resource stock. How to use these stocks is debatable from the WS and SS point-of-view, as presented in this chapter.

In chapter 3, I will shown how EE can lead to RE’s on multiple levels by using micro- and macro-economic models (Jevons, 1865: Khazzoom, 1980; Brookes, 1978; Saunders, 1992). There is some consensus among energy analysts that parts of the savings from EE are taken in the form of higher levels of consumption and production (for an overview of the early literature see Greening and Greene, 1998). Thus, RE’s imply that significant environmental benefits via EE can only occur if other policies (e.g. taxes, subsidies, etc.) are adopted aside the EE stimulation policies (see also Dincer and Rosen, 1999). Because increased EE effectively decreases the price of non-renewable energy, and possibly even renewable energy, EE rents must account for the benefits being actually saved, or reinvested in sustainable energy, and not spent on more non-renewable energy use, or non-renewable natural capital use more in general. The question of the extent and causality of RE's lies at the heart of controversies in EE debates. The Dutch policy overlooks the possibility that increased EE can lead to an increase in energy use on the micro- and macro-level. Even more, when RE's result in an increased level of natural capital use, EE is not beneficial to the aims of sustainability in a weak or strong sense. This chapter is intended to show that RE's are problematic in principle (i.e. theoretical investigations) and practice (i.e. empirical investigations) when assuming that EE categorically delivers the benefits as expected based on the calculated savings.

In chapter 4, I turn to the analysis of energy policies in principle and practice, with and without RE's. The Dutch method to assess sustainable energy policy is primarily based on calculated savings - which is commonly done in sustainable energy policy assessments - and does not empirically measure realized results (ECN 2009; IPCC 2007). More important, this method does not take into account RE's before or after policy implementation. In this chapter I will show that the policy-making and assessments present an analogy with the distinction between WS and SS, as well as them presenting similar problems with RE's. Taking into account RE's suggests that the policy starts from a mistaken assumption about the economic effects of EE, and that EE may not follow from, or lead to, any of the two kinds of sustainability. This chapter is intended to elaborate on the notion that RE's following EE in principle present a case in which EE is not weak nor strong sustainable. In addition, actually finding RE´s following EE in real life situations present a case in which EE cannot be considered weak nor strong sustainable, in practice.

Combined, these cases lead me to conclude that EE in principle and in practice, under the influence of RE’s, is not always sustainable in terms of WS or SS. In chapter 5, I will present my conclusions that if EE leads to one hundred per cent materialization of calculated savings, it is compatible with SS, otherwise it is not. Whether less than one hundred per cent savings is compatible with SS or WS depends on the levels of investment. When there is a certain level of investments this is compatible with the WS approach, and when there are no investments this is compatible with the SS approach. Yet, when the investments lead to negative total capital, more use of fossil fuel energy, and GHG-emissions, EE is neither compatible with the SS nor WS approach. Analogously, in the Dutch policy, EE is assumed to lead to calculated savings, and a reduction of natural capital use which is beneficial to the aims of the WS or SS approach. However, when calculations and measurements of EE in principle and in practice show RE’s leading not to calculated savings but to increased natural capital depletion without substitution or savings, EE cannot be considered ‘sustainable’ at all.

2. Energy Efficiency and Sustainability

And what is a man without energy? Nothing – nothing at all.

– Mark Twain (Letter to Orion Clemens, 1860)

2.1 Is Energy Efficiency Really All that 'Sustainable'?

Without the sun's energy there simply would not be life on this planet as we know it today. For most of the earth's existence organic life depended on solar power for energy, but also wind, water, and other renewable energy sources. During the Industrial Revolution humans started to substitute renewable energy resources for fossil fuels, which are based on solar energy captured by plants and animals thousands of years ago. During the first half of the 20th century there seemed to be an abundance of fossil fuel resources, but, with the end of the 'Age of Oil' looming at the end of the 21st century, the problems associated with using fossil fuels are now becoming more apparent to the public-eye and policy-makers concerned with energy. A simplified conceptualization of EE makes pursuing it a 'no brainer', as it takes a minimum amount of computing power; simply weighing costs and benefits to highlight the less costly option of doing the most amount of work with the least amount of energy. In this view, for producing more energy services with less energy input, EE is imperative for developing sustainable energy: less fossil fuels are needed to produce a similar level of output, thereby decreasing (or stabilizing) total energy demand, and generating rents which can be invested in substituting fossil energy with renewables.

In theory, EE improvements raise energy resource scarcity limits because less (natural capital) input is required to produce a similar amount of output. How to use the 'saved' amount of energy, here considered to be natural capital, is debatable from the WS and SS approach. The general aim of WS and SS is that present generations do not deplete all natural resources to their 'individual' liking, but that resource depletion should sustain non-declining average human welfare over time (Pearce et al., 1989; Pearce and Atkinson 1993). When EE reduces the amount of natural capital needed for input to produce the same amount of output, then it can be beneficial to either the WS or SS approach.

In section 2.2 I will sketch a ‘short introductory story’ of EE and the sustainable energy transition, leading up to my discussion of the distinction between WS and SS in economics. Further introduction of the WS and SS approaches leads me to ask what role there is for EE improvements as a sustainability strategy for the development of sustainable energy? In section 2.3 I will introduce the possible relation between EE and economic growth. Limits to growth are crucial for SS, but not for WS, as the first aims to retain some critical natural capital stocks at the cost of growth, while the latter aims to substitute any natural capital adding to growth. In section 2.4 I will raise the problem that the approaches of both WS and SS suggest that EE advances the aim of more efficient energy resource use, but whether it really is beneficial to their individual aims also depends on how the efficiency rents are invested, that is, how the opportunity for savings and substitution of natural capital is seized.

2.2 The Story of Energy Efficiency and Sustainable Energy

The imperative of EE seems as old as the use of energy itself. For most of human history the use of energy was limited to the amount of work that could be done by individual human beings, alone or in groups. Over time, humans learned to domesticate animals and develop technologies to perform energy intensive tasks for them. EE first consisted mostly of ‘doing less with more energy’, but as technology progressed it also started to advance into ‘easier ways to get more work done with less energy’. The rise of steam engines during the 18th century is an example, by which increasing EE of the machinery eventually enabled humans to produce more mechanical work on industrial scales with relatively less amount of energy. It has been said that to a large extent the increasing EE of steam power is responsible for the rise of modern industrialized economies in the 19th century (Allen, 2010).

By the beginning of the 20th century, energy consumption per capita was accelerating in industrializing economies, while the global energy-consuming population grew rapidly (Ausubel, 2000). During the 20th century energy consuming appliances started to replace muscle power at home, and energy intensive machines increased production in modern industry and agriculture. Mass-scale produced automotive vehicles made transportation a major new consumer of fossil fuels. Fossil fuels quickly replaced wind for the propulsion of ships. And, international air travel became another major user of fossil fuels. At the same time it seemed that the available supply of fossil energy grew ahead of demand. The vast quantities of cheap fuel became a major input for large-scale economies. In the US, for example, huge generation plants were built to provide jobs and create new business opportunities via cheap energy during the Great Depression. After World War II, energy generation by nuclear fission became another major energy source. So, until the early 1970's, there was a popular belief among mainstream economists in increasing energy resource stocks and diminishing energy prices. As a result, EE was not considered a major concern for the economic profession, and did not come up as an issue to be concerned with for the general public, business, and governments.

What started serious EE worries were the oil crises in the 1970s, when suddenly energy prices rose dramatically (Ikenberry, 1986). Far more compelling to the public than the price-spikes, were the actual physical shortages of petroleum, and immediate threats of insufficient heating oil. The energy crises fed the realization that the provision of energy services might not always keep pace with growing energy demand in global energy markets. This was not a new idea for energy specialists in the field, but it was increasingly becoming an important insight among the public, business-leaders, and government officials. After the crises, a steady supply of cheap energy was no longer viewed as something that was always growing ahead of demand. Before the crises, EE had predominantly been a technical aspect for engineers to be worried about, but during the crises EE became a general concern that developed into a freestanding issue.

The growing rate of fossil energy resource depletion and GHG-emissions has directed policy-makers to seriously consider the more efficient use of a unit of energy resource. At present, it is globally accepted that EE is an important part of energy policy (WEC, 2012). EE is suggested to improve productivity while reducing energy intensity and leading to less emissions. Normally, efficiency innovations are costly and the process of developing them is uncertain (Sanstad and Howarth, 1994). But, nowadays EE improvements are much sought after because they can offset diminishing returns of energy intensive processes and come along with a decrease of emissions. In principle, by improving the EE of (i) non-renewable energy technologies, or (ii) renewable energy technologies the energy intensity of economic activities can be reduced. In this view, EE policy is not beneficial for the sustainable energy transition when the gains are only invested in improving the efficiency of existing non-renewable infrastructures. This leads to lock-in of existing non-renewable infrastructures (Perkins, 2003), and not to increased opportunities for a sustainable energy transition whereby renewable energy sources replace fossil fuels completely (Verbong and Loorbach, 2012). Thus, EE by itself is not necessarily beneficial for the development of sustainable energy when the investment of the EE rents are left unchecked and undermine the assumptions about the benefits of EE improvements for the development of ‘sustainable’ energy.

There is a major difficulty with adapting fossil fuel infrastructures: in order to sustain non-decreasing output with the same economic means, we should invest at least part of fossil fuel rents into development of fossil fuel-substituting technologies. In other words, we must create an ‘anti-fossil fuel market’ with the efficiency rents. Historical examples show that the development and the introduction of coal-based technologies took decades, despite the obvious benefit of the new technologies for the economy. The same can be said about the switch from a coal to an oil economy (Bhazanov, 2007). At present, we must consider the problem of switching to technologies based on renewable resources, not because they are economically more profitable to us now, but because of the anticipated shortage of profitable energy stocks in the nearby future, as well as the environmental costs of our use of fossil fuels for future generations.

2.2.2 Energy Efficiency in Economics

While economic theory has been widely used to inform and analyze energy policies, it has traditionally not been concerned much with the disposition and use of energy resources in the future, and for long basically ignored energy’s crucial role in fuelling industrialized economies. This changed during the last three decades of the 20th century when economists became more concerned with energy resources and the economic and environmental effects of their use. This general concern gave rise to new branches of economics, like resource-, ecological, and environmental economics (Buenstorf, 2004). In energy economics, energy is considered as an input into the production process of preferred energy services – for example, heating, lighting, and motion – rather than as an end in itself. In other words, energy by itself is considered to be rather useless, as it is the energy service produced with the energy that is important for economic activities. Normally, EE is defined as the percentage of energy services output per unit of energy input into the production of an energy service. For example, the EE of an electric heater can be determined as the output in degrees Celsius added to a cubic meter of air per kWh of electricity input. Energy saving refers to a reduction in the total amount of input for producing an energy service. It follows that energy use can be reduced with or without an increase in energy efficiency. Thus, energy saving is not necessarily a part of EE, nor vice versa. For this reason there is often a difference made in the literature between savings and abatement, of which only the latter refers to actual savings in terms of resources withdrawn from use. Here I will not use the term abatement, but instead ‘calculated savings’ to refer to one hundred per cent of the potential savings of EE (see figure 2).

EE can be acquired relatively cheaply, as the costs of saving energy in the existing system are lower than the costs of substituting existing energy technologies for more efficient models. Here I will use the term EE most of the time not referring to the this definition but to the first variant (i.e. percentage of energy input needed to produce a certain output of energy service). It is also important to distinguish the efficiency part of EE from the concept of efficiency in economics. Efficiency is a contested concept in economics, which definition is not agreed upon (e.g. see Buchanan 1985). Here I take economic efficiency to refer to an optimal input-output ratio of conducting an economic activity. Economic efficiency improvements can generally be divided into two categories: (i) those that are associated with improvements in overall productivity via exogenous (e.g. innovation) or endogenous (e.g. efficiency improvement) technological change, and (ii) those that are not, namely substitution. The latter is assumed to be induced by changes in the price of a specific input relative to the prices of other inputs into production processes. Determining the exact relation between substitution and technological

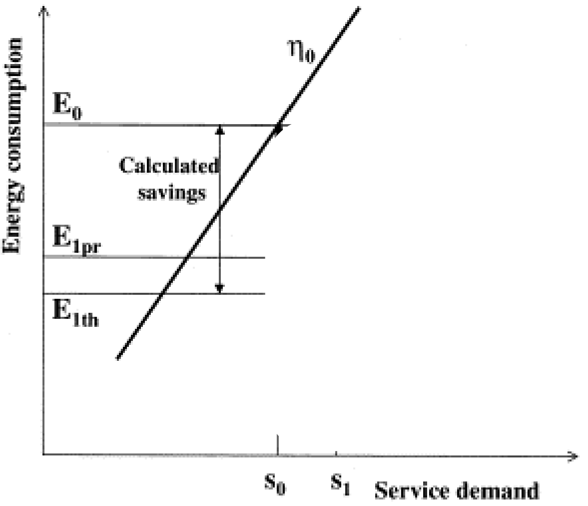

Figure 2 – Calculated Savings

innovation is problematic because changes in prices may induce innovation, but innovation may in turn induce changes in prices (Gomulka, 1990). Here I can only speculate that there is a synergistic relationship between the two, with each perpetuating the other as part of a positive feedback loop (see Ayres and Warr, 2002).

Innovation and economic development have been forwarded as aid to sustainability problems (Solow, 1974; Hartwick, 1976), but also as causes of sustainability problems (Boulding, 1966; Georgescu-Roegen, 1971; Daly, 1995 and 2005). The opposing views can be elaborated on by looking at the distinction between two approaches in ecological economics: WS and SS (e.g. see Turner, 1992; Pearce and Atkinson, 1993; Gutés, 1996; Faucheaux, Muir, and O’Connor, 1997; Gowdy and O’Hara, 1997; Hediger, 1999; Getzner, 1999; Ayres, Van den Bergh, and Gowdy, 2001; Neumayer 2003; Steger et al., 2005; Etkins et al., 2005; Dietz and Neumayer, 2007; Fashola, 2012).

2.3 Weak Sustainability

The distinction between WS and SS shows an adapted neoclassical position at one extreme, represented by so-called economic ‘efficiency optimists’ and proponents of WS (Solow, 1974 and Hartwick, 1977). WS refers to ‘constant or non-declining total capital stock’, which is achieved by having an economy’s value for each period to be greater or equal to the sum of the depreciation on all forms of capital by substituting natural for human made capital (Pearce and Atkinson, 1993). WS is basically a direct application of the savings-investment rule stemming from neoclassical growth theory, but now with exhaustible resources as added variables. The basic model was effectively founded in the mid-1970s by macroeconomists trying to extend neoclassical growth theory and welfare economics to account for non-renewable natural resources as a factor of production (Dasgupta and Heal, Solow, 1974; 1974;

Hartwick, 1977). The key question posed in these economic studies was whether optimal growth could be ‘sustainable’ in the sense of allowing perpetual non-declining welfare over infinite time? This was shown to be unlikely in a growth model including a non-renewable resource as a factor of production (e.g. coal, oil, and gas). As to be expected, the basic result was that economic growth stagnates due to resource constraints. Eventually production and consumption fall to zero in the long run (Solow, 1974).

For achieving sustainability (Pearce and Atkinson, 1993) it is necessary to come up with specific rules for allowing non-declining welfare over time, based on maintenance of the total capital stock. This was addressed by Hartwick (1977), who suggested that the returns from non-renewable resource depletion should be reinvested in human-made capital to maintain total capital over intergenerational timescales. Hartwick (1979) later argued that in order to have a stream of constant level of total capital per capita to infinity, society should invest a part of the current returns obtained from the use of the stock of non-renewable resources into substitutes. This is what is meant with the ‘savings-investment rule’, or Hartwick rule (see also Asheim, Bucholz, and Withagen, 2003), which according to Hartwick (1977) was already implicit in the earlier WS model of Solow (1974).

The Hartwick rule is derived using a Cobb-Douglas production function, which is notable for being the first economy-wide production function presented to the economic profession. This rule features a very simple economy using, besides human-made capital, the services of an exhaustible natural capital to produce its consumption good. The objective is to determine the inter-temporal paths of depletion of natural capital and of substitution with human-made capital, and whether natural capital gets entirely exhausted or not. Solow (1993) later demonstrated that given the production function with a variable representing natural capital, perpetual economic growth is only possible provided that the elasticity of substitution of human-made capital and natural capital exceeds a certain minimum that depends on the rate of growth and the discount rate. This finding has been generalized into a WS rule, which requires that net total capital investment must not be allowed to be persistently negative (Hamilton, 1994).

Solow (1986) showed how the savings-investment rule can be interpreted as stating that the stock of total capital – including the initial endowment of capital – is being maintained intact perpetually, or infinitely. This result was again derived by using a Cobb-Douglas function, assuming constant returns to scale without technological change and population growth. The economist explicitly states that the conclusions reached are not easily extended in the presence of technological change and/or population growth, and that even if the rate of technological change equals the rate of population growth, the savings-investment rule still might not guarantee a constant level of total capital per capita. Maintaining total capital per capita over intergenerational time scales need not entail the savings of specific sub-sets of natural capital, such as fossil fuels: if the social costs of depletion are offset by compensating investments in human-made capital (such as EE innovations), then a constant or increasing level of total capital per capita can be sustained (Solow, 1974).

Solow (1993) further suggested that the criterion of economic efficiency implies that both present and future generations benefit from the “judicious use” and depletion of natural capital. He explicitly warns that providing future generations with *in principle* entitlements to certain stocks of natural capital runs the risk of locking-in production and consumption patterns in a manner that could impair the improvement of economic efficiency and thus living standards over time. In other words, rather than trying to provide future generations with a world conserved to a level of natural capital as we know it today, we should try to provide them the more efficient world of the future with a higher level of total capital.

Thus, WS does not necessarily put restrictions on the degree of substitutability between natural and human-made capital. Human-made capital can, in WS principle, replace natural capital except for unique places such as the Grand Canyon (Solow, 1992 – taken from Ayres, 2007). An economy is considered 'sustainable' in terms of WS if and only if its savings-investment rate of total capital is greater than the combined depreciation rate on natural and human-made capital.

As said, the WS models of the 1970s imputed non-renewable and renewable natural resources into a Cobb-Douglas production function, which is characterized by a constant and unitary elasticity of substitution between natural capital and human-made capital. This premise entails the core-assumption of WS that natural capital can easily be substituted for other natural capital or human-made capital. For WS it must be true that:

a) natural resources are always substitutable;
b) the elasticity of substitution between natural and human-made capital is greater than or equal to one;
c) or technological progress can increase the productivity of natural capital stock faster than it is being depleted.

Critics argue that these assumptions do not always have to hold for WS, as the savings-investment rule does not necessarily indicate "sustainability" defined as average intergenerational welfare, and it does not necessarily require substitutability between human-made and natural capital (Asheim and Bucholz, 2000; see also Hartwick 1977). Maintaining a positive savings-investment rate is a necessary but insufficient condition for achieving WS (Dietz and Neumayer, 2007, 22). For my case, I will sidestep the criticisms because it is helpful to typify WS as holding these assumptions presenting a sharp contrast with SS' 'counter-views' arguing for a contrary position. In view of SS (Daly, Jacobs and Skolimowski, 1995), WS basically holds that if society invests in reproducible capital the rents from both the depletion of non-renewable resources and from the current net harvest of renewables, then, given substitutability between inputs and efficiency as before constant consumption can be maintained indefinitely. The basic idea is: if demand of renewable resources is limited to be only the increment of rents, which arises from the natural growth of the stock, then the duration of this demand is limited only by how long the stock itself exists (Dubourg, 1992). In terms of WS, via more efficiency and substitution, the duration of demand could be infinite if the savings-investment rule is maintained.

2.4 Strong Sustainability

Whereas the distinction between WS and SS shows economic "efficiency optimists" on one end of the spectrum, at the other end are the ecological "entropy pessimists" and proponents of SS (e.g. see Georgescu-Roegen, 1971, 1976, 1977; Daly, 1992, 1997). In terms of SS, even with more efficiency and substitution, the level of demand is always limited. In contrast to WS, SS rejects the possibilities of (a) and (b) mentioned in the previous subsection; as the concept is pitted against the full depletion of finite natural resources, and aims to protect natural resource stocks that are considered non-substitutable. SS accepts the possibility of (c), as this is a necessary but insufficient condition for maintaining certain critical levels of natural capital. Some proponents of SS argue that certain natural capital stocks are non-substitutable to a greater or lesser extent, and sometimes must be conserved for their own sake (e.g. the atmosphere and oceans).

Proponents of SS suggest that the second law of thermodynamics demands that entropy increases in all processes (Georgescu-Roegen, 1973; Daly, 1995). For this reason, they claim that perpetual economic growth (e.g. ever increasing economic efficiency), such as for example suggested by Solow (1994), is impossible according to the ‘laws of nature’, more specifically the second law of thermodynamics which considers the increase of entropy over time. The entropy of a system can be measured to determine the energy *not available* in producing energy services, such as loss of heat in energy conversion devices. Such devices can only be run by converted energy resources (i.e. exergy – Ahern, 1980; Rosen and Dincer, 1998). And they always have a theoretical maximum level of EE due to entropy. The most important contribution of SS to the field of economics has been said to be just this concept of entropy (Daly, 1995). The thermodynamic concept of entropy distinguishes SS economists from the WS economists drawing on the mechanistic foundation of neoclassical principles drawn from Newtonian physics (see also Mayumi and Giampietro, 2004). According to the first law of thermodynamics, energy is never lost, but changes from one form to another. ‘Exergy’ refers to the irreversibility of that process due to increases in entropy, as says the second law of thermodynamics. According to adherents of SS, this implies that perpetual economic growth is simply impossible in terms of a thermodynamic system with entropy, opposed to the proponents of WS who adhere to a more mechanistic system in which perpetual growth is possible; under the assumption, of course, that natural capital can be substituted for human-made capital to keep a constant level of total capital. In response, the possibility of constant substitution of natural capital is attested by advocates of SS.

According to SS, natural capital performs four categories of functions (Pearce and Turner, 1990; Ekins et al., 2003 – taken from Dietz and Neumayer, 2007):

1) it provides the resources for production and consumption, such as fossil fuels,
2) it assimilates the waste products of production and consumption, such as fossil fuel-related CO2 emissions,
3) it provides amenity services, such as the visual amenity of a Dutch landscape without plumes from coal plants or high-tech windmills, and
4) it provides the basic life-support functions on which the first three categories of natural capital functions depend, such as the earth’s atmosphere or oceans.

The fourth category is the so-called ‘glue value’ that holds everything together (Turner et al., 1994, 38). As said before, for a clear contrast with SS I assume WS to consider there to be an almost unlimited number of substitution possibilities between the first category of natural capital functions and human-made capital. One can argue that historic trends suggest that economies have overcome natural capital constraints in the past, and will do so in the future (Neumayer, 2000a; 2003). However, proponents of SS can counter argue that such historic analysis is no guarantee for accurately predicting future economic trends for overcoming present natural capital constraints. Even more, while it is possible to substitute some categories of functions of natural capital, such as natural waste assimilative capacity and amenity services, basic life support functions of the fourth category are impossible to substitute (Barbier et al., 1994). Natural capital of the fourth kind should be subject to an SS savings rule, and should not be subject to a WS savings-investment rule.

Two main schools of SS have been identified (Neumayer, 2003). One requires that in the case of non-renewable resources their use must be compensated by an investment in substitute renewable resources, for example, solar farms to replace fossil energy plants. More generally, the first school of SS (SS1) suggests that natural capital depreciation should be balanced by investment in so-called “shadow projects” (Barbier et al., 1990). The interesting feature of this concept is that it assumes, much like WS, substitutability between forms of natural capital and investment in substitutes. Natural capital of the first category, such as oil and gas, can be substituted for renewable alternatives, but in relation to available natural capital of the fourth kind, such as the earth’s atmosphere and energy-related GHG-emissions of the second kind, imply that some stocks of natural capital of possibly all four kinds should be conserved partially or fully.

The second school of SS (SS2) suggests a subset of natural capital to be preserved in physical terms so that its functions remain intact up to critical thresholds. This natural capital has been labeled Critical Natural Capital (CNC). It is difficult to rigorously define CNC, but following the second school of SS, one may ring-fence as CNC any natural capital that is strictly non-substitutable; the loss of which would be irreversible and entail immense costs due to its vital role for human welfare, or would be plain unethical to be fully depleted (Dietz and Neumayer, 2007). ‘Ring-fencing’ is a financial term that refers to a portion of assets or rents which are separated without necessarily being operated as a separate entity. One can consider CNC as savings which are part of a portfolio, but not to be touched, not even for investment in the substitution of non-renewable for renewable sources. However, as with energy-related sustainability problems, some use of natural capital of the first three kinds can influence the stock of the fourth kind. Thus, ring-fencing CNC is necessary for achieving SS, but it is not sufficient for protecting against spill-over effects resulting from the use of other natural capital stocks, such as energy-related GHG-emissions on the atmosphere.

2.5 Which Concept of Sustainability Suits 'Sustainable' Energy Best?

SS2 highlights protection of CNC stocks, while SS1 also highlights investments in so-called 'shadow projects', which is a form of restricted substitution. In contrast, WS is based on (unrestricted) substitution, and overlooks the necessity of protecting certain CNC stocks. In this section, I will look at the helpfulness of the distinction between WS and SS1/SS2 in relation to EE debates. According to WS, what is required for 'sustainability' is the maintenance of the stock of total capital (i.e. natural plus man-made capital), whereby it focuses on creating assets for sustainable growth (Brown et al., 2005). The WS approach can be considered a step closer to an accurate sustainability indicator (e.g. GSI – World Bank, 2012; see also Brown et al., 2005) in the sense that it allows for the possibility that depreciation of the existing capital stock is greater than gross investment, resulting in a declining and unsustainable stock of human-made capital. In contrast, the SS approach suggests that this concept of sustainability neglects the savings of certain stocks of natural capital that are crucial for the physical savings of vital ecosystem functions and economic provision, and thus cannot be substituted by human-made capital at all. SS1 and SS2 suggest to focus first on the natural capital savings, which implies indexes that account for physical stocks (e.g. Environmental Savings Index – Böhringer and Jochem, 2007).

Developing sustainable energy is generally considered a key to sustainable development strategies, and the first and foremost pillar EE is commonly believed to be beneficial for economic development (UN 2002 and 2012; IPCC 2012). Personally, I find that WS and the two schools of SS present a comprehensive framework for thinking about the sustainability of

EE improvements. WS and the two schools of SS go beyond standard growth theory by taking up the concepts of sustainability and natural capital. For sustainability, EE is intended to save natural capital stocks (e.g. fossil fuels, GHG's, and the atmosphere), which is compatible with SS2. But EE is also intended to exploit other stocks to keep running and be able to invest in substitutes (e.g. shale gas, photo voltaic cells, and wind mills), compatible with WS and the shadow projects of SS1. According to WS, EE can replace a part of fossil fuel resources and foster sustainable development. By simply using fossil fuels more efficiently, WS suggests, we use less natural resources, can invest the returns into substitution with renewables, and can keep a positive level of total capital. In contrast, if one subscribes to the SS view that at least some (parts of) CNC stocks are non-substitutable, then one has to choose from two basic rules to: either maintain the value of total natural capital or maintain physical stocks. Some conclude that only the latter rule is plausible for attaining SS, by which they refute SS1 and commit to SS2 (Dietz and Neumayer, 2007; Ayres, 2007).

In this view, EE is compatible with the concept of SS2 when focusing only on the restriction of depleting natural capital stocks. EE is compatible with the concept of SS1 when focusing on restriction of depleting natural capital stocks and investing in shadow projects. And, EE is compatible with the concept of WS when focusing on substitution without any restriction on depleting natural capital stocks. In conclusion, the concept that fits 'sustainable' energy best is decided by which kind of sustainability approach is preferred.

2.5.2 Natural Limits to Growth and Carrying Capacity

Econometric studies on energy consumption commonly try to demonstrate correlations between EE and economic growth, but the exact extent to which an increase of EE can be considered a result of increasing economic output, or vice versa, remains unclear (Sorrell 2009). Some economists suggest that technological innovation leading to EE improvements can substantially contribute to economic development (Ayres and Warr, 2005). In this view, energy policy-makers should not overlook the possible importance of EE improvements in obtaining energy as an input into production processes, commonly referred to as the "energy return on investment" (Madlener and Alcott, 2007). Without continuous EE improvements over time (producing energy services cheaper), the economic law of diminishing returns would render energy as input into production processes more and more expensive, thus making production in general more expensive.[10] Increasingly expensive energy would lead to substitution of energy input for alternative energy resources or other production factors to keep production processes profitable, thus economically viable. In this sense, EE is a necessary condition for economic development.

Proponents of the two schools of SS suggest that economic development is ultimately constrained by physical laws and by the finiteness of the planet's total natural capital stock. However, as forwarded by proponents of WS, total capital growth may not be similarly constrained, since human-made capital (e.g. innovation, institutional re-alignment, learning, etc.) may continue to present more efficient ways to squeeze added value from a stock of natural capital. Thus, economists concerned only with 'sustainability' in a WS-sense do not have to consider putting limits to economic growth in their concepts and models, as long as it is assumed that new ways are found to re-use and stabilize natural capital use. In this way, economies should be able to maintain an average intergenerational level of total capital as long as the savings-investment rates are positive on average, maintaining average intergenerational welfare which is at par with the Brundlandt (WCED, 1987) and Pearce et al. (1989) concept of sustainability.

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[10] For non-economist readers: Diminishing returns refer to decreases in the per-unit output of production processes as the amount of a single production factor (e.g. energy input) is increased, while the amounts of all other production factors are held constant.

In response to WS, proponents of the two schools of SS have pointed out that even before the Brundlandt concept of sustainability, *The Limits to Growth* study presented at the 1972 UN conference in Stockholm warned that the combination of economic and population growth in relation to the use and depletion of natural capital could not proceed on course without eventually having to lead to the collapse of whole ecosystems and even societal systems (Meadows et al., 1972). The actual international political response to this statement of planetary concern very quickly began to show underlying conflicts of interest between nations' individual economic interests and international sustainability concerns. After *The Limits to Growth* there seemed to be a widespread resistance among national policy-makers to give up sovereignty over natural capital and radically change policies favoring national economic growth, into ones favoring natural capital savings (Bernstein, 2002). According to its critics, in response to this conflict of interests 'sustainable development' emerged in the 1980s as the new concept of sustainability that aimed at economic growth in the context of equity concerns and environmental protection (Robinson, 2004). This concept clearly was a radical shift in framing sustainability since *The Limits to Growth*, which obviously tried to highlight the limits of economic growth. However, by the first meeting in Rio, the view got institutionalized that economic growth is consistent with, and even necessary for, international equity and environmental protection, which is compatible with the overarching goal of sustainable growth (Pallemaerts, 1994). By Rio20+, sustainable growth was forwarded as the main strategy to counter sustainability problems. In other words, the WS approach has become more popular in international sustainability policy than any of the two schools of SS.

Pezzey and Toman (2002 - and earlier Pezzey, 1992), reviewed the changing definitions of sustainable development from the 1970s to the 21st century. They have identified three periods:

(i) 1974–1986, response to The Limits to Growth,

(ii) 1987–1996, the emergence of (weak and strong) sustainability literature, and

(iii) 1997–2000, flourishing but still developing literature on sustainable development.

The researchers conclude that despite the growing amount of research on sustainability there is still a lack of understanding of policies considering sustainable development and economic growth. Especially considering the practical expression of the SS concept in terms of preservation of certain species, safe minimum standards for impacts on environmental quality, and sustainable use of renewable natural capital, the WS approach to sustainable development is unclear (ibid.).

From the start of international talks based upon the Brundlandt report, to the discussion of sustainable development in the 1980s and 1990s, up until the most recent focus on 'green growth', WS arguments have turned out to be crucial for the analysis that shapes responses to sustainability problems (Maréchal, 2007). As Gowdy and Mesner (1998, 153) have put it more bluntly:

> Document after document on sustainability, typified by the Brundtland report, begins with a sobering description of what human activity has done to the planet only to end with a call for more economic growth to bring us to environmental sustainability.

The threat of depletion of non-renewable energy and other resources, as well as environmental degradation through GHG-emissions and other pollutants are not traditionally perceived as significant barriers to economic growth, since it has long been assumed in economics that natural capital is non-scarce (Buenstorf, 2004). For the two schools of SS growth is never the solution to sustainability concerns. As forwarded by SS2, preservation of the physical magnitude of non-renewable resources means leaving them unused (Ayres, van den Bergh, and Gowdy, 1998).

Opposed to focusing solely on sustainable development and green growth, the two schools of SS in general focus more on saving (sub-) sets of natural capital that are critical for life-support functions and irreplaceable by human-made capital. A primary motivation for the two schools SS is based on recognizing the uncertain risk of irreversible damaging ecosystems and their functions. It would be rather disappointing to find that WS substitution of fossil for renewables has not been sufficient to counter environmental problems, and people actually should have maintained certain CNC stocks to avoid environmental calamities. According to the two schools of SS, human beings should therefore respect the carrying capacity of a biological species in a natural environment (Daly, 1979 and 1984a).

The notion that the human species may be up against a new kind of ecological limit has revived the Malthusian debate about ‘human carrying capacity’ (Seidl and Tisdell, 1999). Carrying capacity refers to the maximum population of a species that can be supported indefinitely in a habitat without permanently damaging the productivity of that habitat. However, because human beings are capable of increasing the human carrying capacity of the planet, for example, by eliminating competing species, by importing locally scarce resources, and through technological innovations, conventional economists and policy-makers have generally rejected this concept as applied to people. Daly (1986), a fierce proponent of SS, criticized that the prevailing WS vision on sustainable development assumes a world in which the economy floats free of any natural capital constraints. This is a purely theoretical world in which the earth's carrying capacity is continuously growing and therefore irrelevant as a limit to growth.

The issue raised here becomes more clear if we define human carrying capacity not as a maximum population but rather as the maximum entropic load that can safely be imposed on the global environment by human beings (Catton, 1986). Human load is a function not only of population but also of average consumption per capita. At present, the latter is rapidly increasing due to globalized trade, technological progress, and rising average incomes. In a certain sense, the world is required to accommodate not just more people due to population growth, but also 'larger' people due to income growth. As a result of this trend, human load pressure relative to carrying capacity is rising faster than is suggested by merely looking at increases of population. A study focusing on how much total capital countries with an abundance of natural capital would have had today if they had actually followed the WS approach, or "Hartwick Rule", over the last 30 years, suggests that narrowly following the rule would have led to unbounded consumption of natural capital in these countries (Hamilton, Ruta, and Tajibeava, 2006).

Proponents of the two schools of SS argue that unbounded consumption of natural capital leads to environmental havoc, and people should therefore limit their consumption in terms of their ecological footprint, which is a measure of maximum demand on the earth's ecosystems (Daly, 2005). The eco-footprint measures demand for natural capital that is contrasted with the earth's capacity to regenerate a similar amount of natural capital. If the limit for the capacity to regenerate is exceeded this leads to 'overshoot'. Overshoot occurs when a population's draws upon the natural environment beyond its regenerating capacity, whereby it eventually exceeds the long term carrying capacity of the natural environment. The consequence of overshoot is normally called an ecosystem ‘crash’ whereby species die-off (Catton, 1982). The second school of SS is mostly concerned with preventing crashes and decreases of biodiversity, therefore it focuses on saving natural capital and protecting ecosystem services. The first school of SS is also concerned with developing substitutes by investing in shadow projects.

To save natural capital one could start to use it more efficiently, as has been done throughout human history of technology. Efficiency rents can be saved and/or invested, for example, in substituting non-renewables for renewables, such as SS1 suggests. The main distinction between the two schools of SS and WS is that the latter holds no limits to substitution. Adding to the annoyance of the SS proponents , the WS approach does not take into account any level of carrying capacity, eco-footprint, or overshoot. The WS approach can thus be taken to represent the manner in which an economy is able to infinitely substitute natural capital for human capital, while remaining total capital, and the two schools of SS can be taken to represent the manner in which an economy is limitedly able to save natural capital from over-exploitation and protect ecosystem services from crashes. From the SS view, WS tells too little about the carrying capacity of the economy’s surruoundings, the levels of their degradation, and risk of ecosystem crash (Catton, 1982; Daly, 1984; see also Rockström, 2009).

2.5.3 Helpfulness of the distinction between WS and SS for EE debate

Usually microeconomic analysis ignores macroeconomic and global environmental effects of EE improvements and substitution, thereby underestimating the natural limits of growth (Stern and Cleveland, 2004). The WS concept, for example, assumes that there are substitutes to fill in a lack of certain resources. However, growth theory in Solow’s tradition is associated with the result of the efficiency improving activities of present technologies, which disregards any explanation of technological innovation (Blaug, 2000 – taken from Silva, 2004). Still, some EE improvements, such as more efficient gasoline engines, are definitely part of technological change. Studies of EE find that higher energy prices – e.g. due to increasing depletion – are associated with a trend towards greater efficiency (Anderson and Newell, 2004; Hassett and Metcalf, 1995; Jaffe et al., 1995). Some studies find that adoption of technological EE improvements is also determined by the elasticity of energy prices (for a review see Popp et al. 2009). Empirical estimates demonstrate a substantial degree of responsiveness of energy use, EE, technology adoption, and innovation, to changes in energy prices (Gillingham et al., 2009).

Early economic growth models have tried to incorporate technological innovation as an exogenous factor explaining its role for growth by ‘manna from heaven’ (Solow, 1956), whereby the costs of technological innovations were perceived as external to the system under consideration. New growth models do address technological change, but were developed long after the recognition that technological change can be an important driving force of economic growth. A popular argument now in modern growth theory literature is that technological innovation and substitution with human-made capital can effectively decouple economic growth from the consumption of natural resources, as forwarded by proponents of WS (Cleveland, 2003). In this view, economies can save natural resources via substitution and have economic growth at the same time. Reducing energy intensity adds to the savings-investment potential of WS by decreasing the energy cost of generating output. Thereby EE can help to not fully deplete fossil-fuel resources too fast, because fewer resources are needed to produce a similar or higher level of output.

However, from an SS viewpoint this is rather doubtful. As Birol and Keppler (2000, 468) have put it:

> While technological improvements alone will most likely not be able to reduce absolute energy consumption in a growing economy for any lengthy period of time, they are sources of overall productivity improvements and economic growth. An energy efficiency improvement remains a contribution to total factor productivity and to economic growth and is thus subject to potentially large rebound effects. As engineers and technicians complete admirable feats of technological progress, energy consumers continue to demand at effectively lower prices more and more energy-related services or energy-intensive goods.

As also suggested by the World Energy Council (2012), to develop more sustainable economies, one must draw upon existing fossil fuel energy resources, use them as efficiently as possible, and get access to renewable alternatives. But, while there has been a growing recognition that EE is a strategic investment factor, the majority of EE policies seem to be implemented in ignorance of the remaining conceptual and practical problems associated with improving EE.

Somewhat paradoxically, both WS and the two schools of SS can use EE to advance either potential, by reducing the amount of energy input needed to maintain a similar, or even higher, level of output of services. In principle, there can be an almost unlimited recycling of the first category of functions of natural capital as long as there is a large enough pool of available EE improvements (Ayres, 1999; Bianciardi et al., 1993; Mayumi, 1993). Here, the conceptual distinction between WS and the two schools of SS is helpful when EE is assumed to add to savings of natural capital, namely fossil fuels and associated GHG-emissions in the atmosphere (SS), or provide rents for investment in substitutes (WS).

The SS part that stands out in the EE debate is the observation that we are currently using up stored low entropy energy resources (i.e. oil, gas, coal, and nuclear) much faster than they were originally produced, which outpaces the regenerating capacity and is too fast for EE improvements or investment in shadow projects to keep up with. In addition, the WS part that stands out is that if demand grows too fast for fossil fuels to be substituted by more efficient alternatives and renewables, production and consumption eventually fall to zero. Fossil fuels are considered by many experts to be derived entirely from very long accumulations of vast amounts of biomass in the distant past, transformed by anaerobic bacteria, heat and pressure, which are not easily duplicated in large-scale production processes. In other words, in the long run fossil fuels cannot be substituted for fossil fuels. In this view, developing renewable energy sources is imperative for not running out of energy resources.

2.5.4 Weak or Strong Sustainable Energy

The conceptual distinction between WS and the two schools of SS leads to show differences in analysis of EE in relation to sustainability. WS refers to EE as to increase total capital and substitute natural capital for human-made capital, based on adapted models from neoclassical economics. SS1 refers to EE as to provide rents from natural capital for investment in shadow projects. And, SS2 refers to EE as to fully conserve the natural capital saved, based on adapted models from ecology and other natural scientific disciplines (Singh et al., 2012). SS1 and SS2 hold that CNC, such as breathable air, supplies vital inputs to production processes for which no substitute by natural or human-made capital is readily available. Therefore some sub-sets of natural capital must be maintained partially or fully for the economy to be able to subsist. Other natural capital may be identified as supplying important but not crucial inputs to production, for which some substitute is, or may soon become, available. Fossil fuels fall into this category, and can be part of the rents invested in an SS1 shadow project. But, one could argue along SS2 lines that also some fossil fuel stocks must be kept at a certain threshold not to run out too fast or completely. According to SS2, the implication is clear: the underlying assumption of WS that natural resources, such as oil and gas, can always be used more efficiently and eventually substituted is too simplistic, as it overlooks the physical limits of substitution, continuously improving EE, and running out of energy (Ayres, 2007).

From the literature I distinguish three possible outcomes of EE improvements to the aims of sustainability for which the distinction between WS and SS is helpful, namely natural capital is used more efficiently for:

(1) production of a similar or higher level of output with less input (WS and SS1/SS2);
(2) substitution with human-made capital (WS), or, “shadow projects” (SS1); and,
(3) absolute savings of CNC stocks (SS2).

On the one hand, (1) shows that EE can be considered sustainable in terms of both WS and the two schools of SS. On the other hand, (2) and (3) show that EE can be considered sustainable in in terms of either WS, or SS1, or SS2. Thus, EE can be compatible with the aims of WS and SS, and can therefore generally be labeled ‘sustainable’. In addition, EE can open up investment opportunities for substituting non-renewables with renewables to the aims of WS and SS1, therefore can be labeled ‘sustainable’ in terms of WS and SS1. Thirdly, EE can help save natural capital to the aims of SS2, therefore can be labeled ‘sustainable’ in terms of SS2.

Both WS and SS can consider the rents of EE respectively in terms of savings-investment or savings potential of natural capital. In the next chapter, I will examine EE in light of RE’s. Focusing mainly on calculated savings, this may overlook what could happen (and often actually happens) when EE policies are implemented. Some economists argue that increased EE at the micro-economic level, while leading to a reduction of energy use at this level, at the national, or macroeconomic level leads not to a reduction, but instead to an increase in energy use (see also Herring, 1999). There is some consensus among energy analysts that a part of the savings from EE are taken in the form of higher levels of consumption and production; generically called RE’s (for an overview of the early literature see Greening and Greene 1998).

RE’s imply that significant reduction in energy costs via EE can occur only if energy saving measures (i.e. abatement) are adopted aside the EE stimuli (Dincer and Rosen, 1999). Because increased EE effectively decreases the price of non-renewable and possibly renewable energy, energy savings measures must account for the rents being actually saved, or reinvested in sustainable energy, and not wasted on using more non-renewable energy (or non-renewable resources more in general). The next chapter is intended to show that the existence of RE’s can impede, take back, and even reverse the benefits of improving EE for both WS and the two schools of SS. Moreover, EE can only add to WS and the two schools of SS if it reduces the total amount of natural capital used to maintain a certain level of total or natural capital.

3. Energy Efficiency and Rebound Effects

Most people spend more time and energy going around problems
than in trying to solve them

- Henry Ford (My Life and Work, 1922)

3.1 The Rebound Effects of Energy Efficiency

In this chapter I will show how economists have demonstrated that EE can lead to RE’s, by using micro- and macro-economic models and applying them to evaluate energy policies. These studies suggest that, at least in some cases, EE does not save energy and does not help to decrease GHG-emissions. They show how RE’s can partially or completely take back the benefits of EE as determined by calculated savings (see also figure 3). This is mainly because increased EE effectively decreases the price of energy, whereby EE rents must account for the benefits being actually saved, or invested. Despite many economic studies, the Dutch energy policy-makers have overlooked that increased EE due to RE’s can lead to an increase in energy demand on the micro- and macro-level. In the Netherlands, EE is regarded as a ‘pillar’ of sustainable energy policy. But, when RE’s result in an increased level of natural capital use, EE is not beneficial to the aims of WS nor SS, thus, in that case EE cannot be considered ‘sustainable’ in one of these two senses.

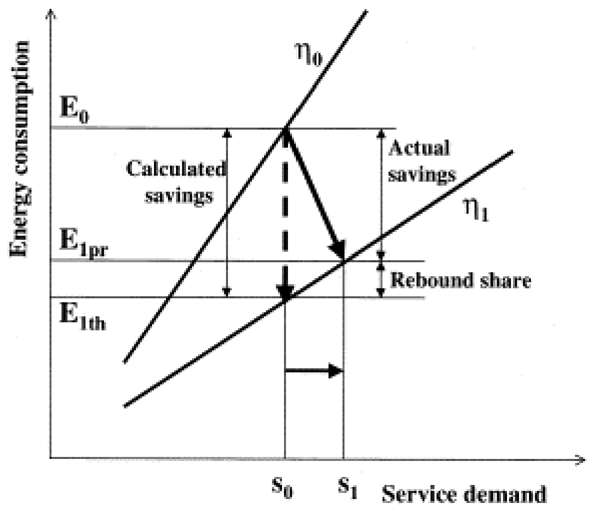

Figure 3 – Rebound Effects

Before delving deeper into this policy-making issue in the next chapter, in this chapter I will introduce the different RE’s found in theory and empirical studies on the micro- and macro-level. This exhibition is intended to show how RE’s are problematic for determining the potential savings and investments of EE improvements, in principle and practice. The existence of RE’s can impede, take back, and even reverse the benefits of improving EE. In light of the conceptual distinction between the WS and SS approach, EE can be considered ‘sustainable’ if and only if it actually reduces the total amount of natural capital used to maintain a certain level of total or natural capital; thereby improving the input/output-ratio of economic processes, which in turn have to put less strain on environmental degradation and open up opportunities for savings and/or investments.

RE’s contradict the optimistic picture of EE leading to guaranteed savings, or a certain level of investment. They suggest that in some cases EE is not beneficial to the ‘sustainable’ aims of the WS and SS approach at all. Calculated savings suggest that when one improves the efficiency, for example, of a car with 50% one saves half the energy needed to run the same mileage. The calculated energy saved, represents cost savings, but also opportunity to drive further, faster, and/or invest in another energy consuming activity. Similarly, when we improve the EE of a car industry with 50% we save half the energy needed to produce the same amount of cars. The calculated energy saved, represents cost savings, but also opportunity to produce more, faster, and/or invest in another energy consuming activities. In addition, improving EE on the macro-level may well lead to RE’s on the micro-level, by making cars cheaper to buy, drive, and substitute. The presence of indirect and direct RE’s suggest that EE will not lead to calculated savings, but to expansion of economic activities on micro and macro levels. In some cases we may therefore expect less savings than the calculated savings predict, or even expect backfire.

In section 3.2 a short history will be presented of the economic literature on RE's traced back to Jevons' Paradox, which serves as the inspiration and context for many recent debates. In sections 3.3 and 3.4, the micro and macro foundations of RE's will be exhibited along a number of empirical findings on the effects on the microeconomic and macroeconomic level. In the final section the distinction between WS and the two schools of SS in relation to EE and RE's will be discussed in depth. This leads up to a full discussion of EE, RE's, the conceptual distinction between WS and SS, and the Dutch sustainable energy policy, in chapter four.

3.2 Jevons' Paradox and the History of Rebound Effects

Jevons (1865) is usually credited for first addressing RE's in *The Coal Question*, therefore they are often referred to as "Jevons' Paradox" (Mayumi et al., 1998; Alcott, 2005; Polimeni and Polimeni, 2006; Sorrell, 2009). The paradox basically states that EE decreases the amount of energy needed to produce a certain output, thereby not decreasing total energy demand but leading to more total energy demand due to a relative decrease in price of energy. For illustration purposes I present a 'quick scan' of Jevons' Paradox, as it is presented in his book.

According to Jevons, James Watt's innovations made it possible that steam-powered energy conversion devices became "the agent of civilization". In his mind, it were Watt's EE improvements which made it possible that the steam-engine became the "mechanical workhorse of the Industrial Revolution", and steam-power made possible the relatively rapid growth of industry and the economy as a whole. In the mid-19th century the EE of the water-wheel had been engineered to its mathematical maximum, whereas the steam-engine only provided a small fraction of its full potential. Jevons observed (ibid, Ch. VIII, 92):

> The improvement of the engine has, in fact, caused it to be substituted successively in many mills before worked by water; and could its efficiency be again doubled, as is not impossible, hardly could the best water power in the country withstand the superior economy of steam.

Observing the rise of steam-power and ‘cheap’ energy, Jevons was highly concerned with coal as an energy resource fuelling the economy because of its economic potential for rapid expansion of economic activities and finitude (ibid., 8). Due to EE, the relative price of coal decreases, making it cheaper to run production processes, inducing production to increase, leading to economic growth, and increasing demand for coal until its stocks were used up.

In *The Coal Question* the main worry is that “coal in truth stands not beside but above all other commodities. It is the material energy of the country – the universal aid – the factor in everything we do” (ibid., 14). Jevons argued coal provided the energy which is metaphorically the “blood that runs through the veins of industrial societies”, as it powered all kinds of everyday economic activities. Due to its geological properties, being buried in ancient layers of the earth’s crust, extraction of coal would become more difficult and less economically viable over time. But even if the full amount of reserves could be extracted, the reserves were finite, therefore economic growth could not continue for ever in the way it had been in the past years (ibid., Ch. IV).[11] Due to population growth increasing the total demand for coal powered energy services, eventually its mass use would become highly problematic for the growth opportunities still open to the economy. More important for my case, increased EE only seemed to speed up the depletion process, as more efficiency led to lower energy

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[11] Somewhat ironically for Jevons’ concerns – but important for reconsidering his argument - coal reserves still make-up the largest part of total global fossil fuel reserves for the next decades (IPCC, 2007).

prices, stimulated energy demand, induced new technological innovations, and sped up national economic growth (ibid., Ch. XVIII).

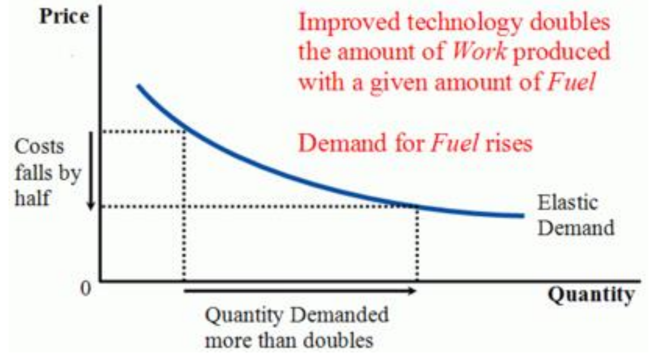

Figure 4 – Jevons' Paradox

The discussion of Jevons' paradox (see also figure 4) started and also ended with *The Coal Question*, as the economists of the 19th century traditionally regarded capital for economic production as non-scarce, or at least non-depletable (Alcott 2005). The traditional variables considered in growth theory (i.e. land, labor, and rent) do not include energy resources or other natural capital. Ever since, these factors have often been overlooked in 'mainstream' economics (Buenstorf, 2004). However, since the 1970s several economists inspired by Jevons' Paradox, and the two energy crises, have taken up scarce and depletable energy resources as variables in their analyses, and began to study the effects on economic processes. In the next section I will introduce the recent developments in the debates on RE's.

3.3 Khazzoom-Brookes Postulate: Recent Research on Rebound Effects

In the 1970s, Jevons' Paradox became better known as 'RE's', or the 'Khazzoom-Brookes Postulate' (KBP) named after the economists (Khazzoom, 1980; Brookes, 1978) that started to address RE's in micro- and macroeconomic models, respectively. The term 'RE's' is commonly used as a 'container term' for a variety of economic mechanisms that reduce the potential energy savings from EE stimuli (Sorrell, 2009, 1457). In many of the recent literature the magnitude of the RE's is distinguished as (ibid.):

(1a) a *weak rebound effect*, whereby efficiency improvements are not as effective as expected;

(1b) a *strong rebound effect*, whereby most or all of the expected savings of efficiency improvements do not materialize; and

(2) a *backfire effect*, whereby the efficiency improvements lead to increased energy use.

The literature discusses the following economic mechanisms underlying RE's (Greening et al., 2000; Sorrell et al., 2009):

1. *Substitution effects*: EE improvements that lead to increases in consumption of energy resources and services that have become more economically efficient.
2. *Income effects*: EE improvements that lead to an increase in available income as a result of the reduced price of the energy resource and service due to an increase in energy efficiency, which leads to other energy-consuming purchases.
3. *Input-output effects*: EE improvements that reduce the cost of energy resources and services to industry, which leads to price reductions of energy input into production process, cost reductions of producing commodities, price reductions of commodities, and hence increased production and consumption.
4. *Economy-wide effects*: EE improvements decrease energy resources and services prices, which results in more energy resources and services being used as substitution for more expensive production factors.
5. *Transformational effects*: EE improvements have the energy potential to change consumers' preferences, alter social institutions, and rearrange the organization of production processes, and societal systems more in general.

The first two effects, often referred to as ‘direct’ RE’s, are micro-economic effects that occur on the level of a single household or firm.[12] The latter effects, usually referred to as ‘indirect’ RE’s, are macro-economic effects that result from the interaction in the economy on the aggregate level (Hertwich, 2005, 87). The direct and indirect RE’s are determined via economic calculations and ‘hard data’, whereas transformational effects are not (Lélé, 1992). This chapter is confined to the discussion of RE’s in the mathematical framework of neoclassical economics in relation to the actual potential of EE to advance the aims of WS or SS. Given that WS is based on neoclassical economic growth models, and SS is based on ecological economic savings models, the discussion of transformational effects outside the scope of mathematical models is less relevant here.

3.3.2 Rebound Effects in Microeconomic Models

Direct RE’s can be found via microeconomic analysis of the effects of EE on individual household or firm energy consumption. Khazzoom (1980) is credited for starting to address micro-level RE’s in the scientific journal *Energy Policy*. This sparked an ongoing debate among economists which is highly critical of the assumed rents of EE for actually acquiring savings. Echoing Jevons’ Paradox, the central issue is that EE equal cost reductions, and the saved costs will most likely be invested in acquiring higher levels of production and consumption. The point is: EE is not helpful for curbing total energy demand on the firm or household level.

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[12] These first mechanisms have much (if not all) in common with the “Slutsky equation”, named after the economist Eugen Slutsky (1880–1948). The Slutsky's Equation breaks down a change in demand due to price change into the substitution effect and the income effect. Due to time constraints I have not been able to delve into the relation between Slutsky's equation and direct RE’s. I thank my supervisor for this remark, and promise him to pick up this line of research when I find the time to do so.

The original concept of direct RE’s is based on the neoclassical definition of substitution, as the change in the quantity of a commodity consumed relative to the change in its price (Khazzoom, 1980). It considers direct RE’s for a single commodity (i.e. single energy service), and measures the increase in quantity demanded of this commodity as a result of an EE improvement. Khazzoom’s original definition of direct RE’s is:

> The efficiency elasticity of demand for energy is equal minus the price elasticity of demand for the energy service minus one. The minus one corresponds to the calculated savings predicted by engineers.

For example, when electric heaters use less energy input per output of kWh per square meter, and we decide to consume no more heat than we did before the efficiency improvement, this results in one hundred per cent of the predicted savings. Suppose the electricity price elasticity for electric heaters is 0.10, and demand for electricity falls by 0.9% when the efficiency of the heater is improved by 1%. The direct RE is then equal to 10% (i.e. 90% of the calculated savings are actually realized). In contrast, if the elasticity is -1.10, then the efficiency improvement leads to an increase of energy demand by 0.1%. In this case the direct RE is equal to 110%, which is referred to as ‘backfire’ (Saunders, 1992), as the direct RE exceeds 100% (i.e. 0% of the predicted energy savings are realized, even more, the energy efficiency improvement has led to a 10% increase in energy demand). This shows that EE improvements may actually lead to an increase in energy consumption. It substantiates the argument against EE policy without considering direct RE’s, and when necessary (and possible) controlling for them. It suggests that policy intended to stimulate EE, must consider the possibility of rebound and backfire when calculating savings.

Extending Khazzoom's model, by taking on board multiple commodities (Lovins, 1988), income effects (Berkhout et al., 2000), distribution (Sorrel, 2009), and the distinction between superior and inferior commodities (Hertwich, 2005), only further complicates calculating direct RE's. For lack of space I will not discuss these issues here. For simplicity, I distinguish two possible feedback loops via direct RE's with multiple commodities, income effects, distribution, and different sustainable commodities:

a) energy efficiency improvements lead to an income effect and distribution pattern which lead to more energy-intensive commodities being bought and an increase of total energy use, or
b) energy efficiency improvements lead to an income effect and distribution pattern which lead to less energy-intensive commodities being bought and a decrease of total energy use.

In case (a), EE is counter-productive for saving energy and contradict the prediction of calculated savings, and in case (b) EE is more or less productive depending on the relative energy use of the original commodity compared to the alternative one, or the amount of energy-intensive commodities that is forgone. More important, also (b) can contradict the outcome predicted by the calculated savings, when not the full 100% savings materialize. The EE feedback-loops do not necessarily lead to calculated savings; the level of savings also depends on income effects, distribution and other variables. More important, in case (a) EE improvements are counter-productive for countering fossil fuel resource depletion and reducing associated GHG-emissions. And in case (b) EE is more or less productive depending on direct RE's and energy intensity of substitutes. Recently, more and more studies are trying to show that EE improvements are followed by direct RE's (Sorrel, Dimitropoulos, and Sommerville, 2009).

3.3.3 Case Studies of Direct Rebound Effects

Direct RE's are not only found via mathematical modeling, but are also backed by empirical results. Druckman et al. (2011) study direct RE's in relation to GHG-emissions. Their study makes some preliminary estimates of direct RE's associated with representative energy savings actions that may be taken by an average household, in the UK. The researchers consider actual energy savings (i.e. abatement action) as distinct from EE improvements, because it concerns reducing total use of energy, and not using it more efficiently (ibid., 3573). Normally studies of direct RE's focus on household and firm energy services, and examine the effect of improving the efficiency of producing such services. In contrast, Druckman et al. do not study EE but three energy savings actions that have the primary or secondary objective of decreasing GHG-emissions. Although savings are clearly different from efficiency improvements, the economic mechanism associated with these measures is often quite similarly, the actions are intended to reduce energy use and GHG-emissions at the same time. For this reason, I find the discussion of this empirical study still useful for illustrating the case of direct RE's.

The researchers clearly state the purpose and scientific limitations of their research, and present their results as somewhat biased and non-conclusive. Still, their conclusion is worrying for me here, because in the worst case scenario if households re-invested all their savings on the most GHG-intensive category (which was gas), the savings policy backfired. Rather than the hoped reduction of GHG-emissions resulting from the policy, the direct RE increased GHG-emissions by as much as 515% (ibid.).

This empirical result depends on a specific level of commodity disaggregation, which suggests that a more disaggregated analysis could have identified categories which have an even higher GHG-intensity than gas (e.g. coal). In this case the direct RE could have turned out to be even higher. The combination of EE improvements and energy savings actions may even lead to a higher direct RE. All and all, direct RE's are not just mathematical constructs but can be found in the real world. And, their magnitude depends on several factors overlooked by the approach based on calculated savings.

3.3.4 Rebound Effects in Macroeconomic Models

Brookes (1978) is normally credited for starting to address indirect RE's in *Energy Policy*. This was the beginning of another line of energy debate which is highly critical about EE for acquiring energy savings on the macro-level. In this section I will not follow Brookes (1978) line of study, but Saunders (2000), who has formulated Brookes' early claims into standard Cobb-Douglas production functions. Indirect RE's are economy-wide effects resulting from optimizing the input/output ratio on the aggregate level. At the macro-economic level, the theories of energy supply and demand usually rely on economy-wide production functions, or their dual equivalent cost functions. Because many of the policy issues surrounding indirect RE's involve aggregate levels of production and longer periods of time (resource depletion nor climate change are caused by a single household's or firm's daily energy consumption or GHG-emission), the 'growth aspect' of neoclassical economics is considered to be highly important for the study of indirect RE's. "Neoclassical growth theory provides the logical framework" to start analyze the economy-wide effects of EE improvements (Saunders, 2000, 440). In this view, improving EE is an integral part of optimizing economic activities.

Saunders (1992a) earlier has tried to show how Jevons' paradox is basically supported by modern growth theory (see also Sorrell, 2009). Thereby he used standard models to argue that backfire is a likely outcome of EE improvements without further policy intervention; which Saunders considers to be a form of technological change that improves EE while not affecting the productivity of other inputs (ibid.). Overall, his work is highly formal and based on restrictive mathematical assumptions, but nevertheless quite telling when considering the possible outcome of national EE policies. Saunders does not claim that his findings prove Jevons' Paradox, instead he claims to provide suggestive evidence in favor of their existence, given certain assumptions about how the economy operates on the aggregate level.

For illustration, let's define EE improvements as the parameter τ_F in the following function (taken from Saunders, 2000):

$$Y = f\,(K, L, \tau_F E)$$

Where (K) is capital, (L) is labor, (E) is energy, (Y) is economic output (measured in GDP), and (f) is the economy-wide production function. This formulation, according to Saunders, when combined with a dynamic investment equation and a standard set of assumptions about the production function, is the basis for Solow's (1956) macro-economic growth model. Interestingly, Saunders (2008) shows how the predicted magnitude of the indirect RE's depends almost entirely on the choice of the production function. Saunders (1992a, 1992b, 2000a, and 2000b) work suggests that EE improvements without further policy intervention are most likely to lead to indirect RE's, and even backfire. If indirect RE's vary in magnitude between different levels of analysis, Saunders (2008) concludes that standard economic approaches cannot be used to properly simulate them. The production functions used in this kind of research, based on the price elasticity of demand, are found to be able to simulate indirect RE’s of different magnitudes, but only if particular assumptions are made about how different inputs are substituted.

In other words, the assumptions co-determine the outcome. Since this form is widely employed within energy economic models, Saunders’ results raise serious concerns about the ability of economy-wide production functions to accurately account for possible indirect RE’s. Saunders (2000a, 2000b, and 2008) show that indirect RE’s have a sound theoretical basis in neoclassical growth theory, but their exact magnitude and importance are empirical questions that are hard if not impossible to test when based on standard economic analysis. Overall, his theoretical studies show that EE improvements are almost always followed by indirect RE’s, and for ‘optimal growth’ are almost bound to backfire.

3.3.5 Case Studies of Indirect Rebound Effects

Despite the serious shortcomings of defining and modeling indirect RE’s (Saunders 1992b), many studies have tried to empirically determine indirect RE’s. Early evidence from the UK suggests that energy efficiency stimuli do have a beneficial impact on reducing energy consumption to the extent of more than half of any efficiency gain (Allan et al., 2006). But, overall the studies suggest that EE can be followed by indirect RE’s, which reduce the benefits of EE stimuli as suggested by the calculated savings. Hanley et al. (2009) use growth models to explore indirect RE’s in the Scottish economy. They find that EE improvements result in an initial fall in energy consumption, but this is eventually reversed. Holm and Englund (2009) compare energy resource use and energy intensity for the USA and six European countries (not including the Netherlands) from 1960 to 2002. The researchers expected to find a negative relation between per capita energy use and the proportion of GDP that can be attributed to the service sector, because it is commonly assumed that information societies are characterized by a high level of human-made capital use in relation to natural capital use (see also Picton and Daniels, 1999). The study indicates that EE improvements are insufficient to prevent further global energy resource depletion, as the results contradict the assumption that movement towards an information society leads to decreased use of natural capital. This finding is supported by other studies (Holm and England, 2009, 884), which conclude that the growth of the service sector during the last decades in the wealthiest countries has increased their overall economic activity and associated natural capital consumption. Polimeni and Polimeni (2006) find indirect RE’s from 1980 to 2002 for North America, Central and South America, Western Europe, Asia, Africa, and the Middle East. Their results echo Jevons’ Paradox, as they suggest that the “likely reason for increased consumption is that increased efficiency decreases the cost of using the product (energy), thus promoting more consumption”, and that only through the recognition that EE will not solve the energy-related problems, but will only make them worse, will lead to new solutions being suggested and alternatives being created (ibid., 352).

It must be noted here that empirical evidence of indirect RE’s are often obscured by energy/GDP ratios, because it is mathematically possible for energy/GDP ratios to decline even in the face of backfire when the economy is growing more rapidly than the increasing use of energy. As Saunders has shown in his studies, the choice of the production function in theoretical and empirical studies of indirect RE’s influences the conclusions. This leads to the so-called “Quebec City hypothesis” (Saunders, 2000a): because of indirect RE’s, the proper choice of EE policy tools requires a deep understanding of the energy-elasticity of substitution; i.e. the amount and speed with which energy and EE substitute other inputs into the production process. Without a deep understanding of direct RE’s it is merely misleading to treat energy savings as a possible energy supply source, or EE improvements as a mean to advance energy security and counter depletion of fossil energy resources, let alone counter grand scale problems such as climate change. Here I would like to emphasize that, in light of RE's, EE policies cannot be relied upon to deliver reductions in the energy intensity of economic activities on their own, let alone to secure a decline in the level of GHG-emissions.

3.4 Measuring Rebound Effects

A common critique on EE policy evaluations is that they either ignore or inadequately account for RE's and focus solely on calculated savings; in other words, they expect 100% of the savings to materialize after the policy is implemented. This overlooks the fact that EE improvements decrease the marginal cost of producing energy services, thereby possibly inducing less-than-proportional increases in energy use. There is an extensive debate in the literature about the existence and impact of RE's in the context of EE policy standards (see Gillingham et al., 2006 for a review), but empirical evidence suggests RE's may be numerically smaller or larger case per case (Dumagan and Mount, 1993 – taken from Gillingham et al., 2009, 20). If RE's are indeed significant, their implications for current EE policy-making in respect to advancing sustainability, in terms of WS and SS, are profound. Significant RE's could effectively undermine the sustainability potential of EE.

A disclaimer is needed when determining the existence and exact impact of direct and indirect RE's following EE stimuli, because, to determine RE's the actual measurement needs to be compared with a counterfactual estimate of energy consumption, which has at least two sources of error (Sorrell et al., 2009, 1358):

1) the energy consumption that would have occurred without the EE improvement, and
2) the energy use that would have occurred following the EE improvement had there been no change in the amount used due to the decrease in its price.

The first gives an estimate of the energy savings from the efficiency improvement, while the second isolates the RE's. Estimates for the latter can be derived from calculated savings, price elasticity's, and empirical data on the circumstances of individual equipment and their use patterns, but they are only limited in relation to the variables that are *not* included and the measurements *not* taken (e.g. income, distribution, etc.). Therefore research on RE's should not be regarded as conclusive, but rather as an indication of the economic effects of EE improvements that contradict calculated savings, and dampen the optimism of EE policy delivering certain economic and environmental benefits.

Now, aware of the possible existence and magnitude of RE's, in the next chapter I will take another look at EE and the distinction between WS and SS in light of the Dutch policy. In this view, the possible growth of economic activities and RE's following EE improvements get overlooked by energy policies focusing just on the calculated savings. When energy policies backfire they cannot contribute to any of the two schools of SS, but can still contribute to WS as long as total capital is maintained. But, when total capital decreases due to backfire, EE policies do not contribute to WS nor SS. In other words, while EE can contribute to the aims of WS and SS, in light of backfire they do not have to contribute to their aims per se. The Dutch policy overlooks these arguments that increased EE leads to an increase in energy use on the micro- and macro-level. Even more, when RE's result in an increased level of natural capital use, EE is not beneficial to the aims of WS nor SS. Thus, EE cannot always be considered to add to sustainability in this sense. The next chapter is intended to show that RE’s are conceptually and practically problematic for EE being considered a pillar of ‘sustainable’ energy policy.

4. Energy Efficiency in Principle and Practice

It takes as much energy to wish as it does to plan.

- Eleanor Roosevelt (Tomorrow is Now, 1963)

4.1 Thinking about Energy Efficiency in Principle and Practice

Considering the theoretical proof and empirical evidence of direct and indirect RE's following EE improvements, in this chapter I will argue that the assumptions about the economic and environmental benefits of EE forwarded in the Dutch energy policy are more a display of wishful thinking than rigorous planning for a sustainable energy transition. This naïve strategy overlooks the possibilities of RE's in the policy calculations and in the measurements after policy implementation. In my view, the policy-makers have simply assumed that EE improvements automatically add to sustainability, without stating whether this is a distinct form of the WS or SS approach. EE is thought to result in savings and investment opportunities, without explaining what this could mean in economic terms aside the calculated savings. Similarly, proponents of the WS approach and the two schools of SS can forward that EE in terms of calculated savings aids their ends. Analogously, for 'sustainable' energy in terms of WS or one of the two schools of SS, people can improve EE and save and/or invest the rents according to preset targets, as is omitted in the Dutch energy policy. Therefore, I think, the policies make-up a naïve strategy, especially in light of direct and indirect RE's.

In this chapter I will examine when EE actually aids the aims of the WS approach or one of the two schools of SS. Throughout the chapter I will follow the framing of economic topics which was first introduced by Gunnar Myrdal (1939, 46-47), looking at EE *in principle* before the policy implemented and EE *in practice* after the policy is implemented. Considering the conceptual distinction between WS and the two schools of SS is helpful for looking what policy-makers think EE improvements should do (e.g. lead to calculated savings) and what it actually does (e.g. lead to backfire). I will refer to 'EE in principle' as the rents determined during policy-making based on assumptions about the economic effects of EE. Determination of EE in principle rents is not based on empirical measurements or the level of actual savings, but on blackboard calculations. I will refer to 'EE in practice' as the rents determined after policy implementation based on empirical measurements of the economic effects following EE stimuli.

In this chapter I will argue that the possibility of RE's following EE in principle leads to reconsider the role of EE in policy-making, and the existence of RE's following EE in practice leads to different measurements of the effects on multiple levels in the economy in different periods after policy implementation. The mistaken assumption underlying the Dutch energy policy 2007-2020 is based on the conviction that calculated savings always fully materialize. The Dutch method to assess the policy performance is based on EE in principle – more specifically, calculated savings taken from the blackboard, which is commonly done in EE policy assessment (ECN, 2009; IPCC, 2007). The policy implications are not empirically measured; EE in practice is thus not (yet) a part of the Dutch energy policy performance analysis. More important, the Dutch method does not take into account RE's on the policy-making drawing board, or RE's occurring after the policy implementation.

Here I will turn to the discussion of EE in principle and practice, adding to 'sustainable' energy policies in terms of the WS approach or one of the two schools of SS, with and without direct and indirect RE's. With the relevant literature and the concepts treated in the previous chapters, I will take another look at the assumed economic and environmental benefits of EE improvements as found in the Dutch Action Plan 2007-2020. This chapter is intended to elaborate on the possibility that RE’s can follow EE in principle and that there are theoretical cases in which EE in principle does not add to ‘sustainable’ energy in terms of the WS or SS approach. In addition, RE’s can be found in the real world following EE in practice and there are empirical cases in which EE is does not add to sustainability in terms of the WS and SS approach. Combined, these cases lead to conclude that EE is not always beneficial to ‘sustainable’ energy in terms of the WS or SS approach.

In section 4.2 I will look at RE’s and the distinction between the WS and SS approach in relation to EE in principle. Here I will examine the benefits of EE in terms of the WS approach and the two schools of SS, and try to determine the savings and investments levels before the policy implementation. For EE in principle, both the WS approach and the two schools of SS assume a relative or absolute lower level of total energy use. In principle, the possibility of backfire contradicts this assumption. In section 4.3 I will turn to RE’s and the distinction between the WS and SS approach in relation to EE in practice. Here I will examine the approaches as they are determined in terms of realized savings and investments after the actual implementation of EE stimuli. Section 4.4 will forward that the widespread belief in the economic and environmental benefits of EE found in the Dutch energy policy is seriously flawed: it assumes that the amount and pattern of energy dependent economic activities will remain rigidly fixed while the implicit price of energy falls. However, when the implicit price of energy falls, RE’s will result in an increased level total energy as well as natural capital use, possibly with a negative savings-investment ratio and surpassing shadow investments in renewables. In this case EE is not beneficial to the aims of the WS approach or the two schools of SS, thus, cannot be considered ‘sustainable’ in this sense.

4.2 Weak and Strong Sustainability and Energy Efficiency in Principle

In the Dutch EE Action Plan 2007-2020, the savings due to EE policies are calculated using a reference scenario without policy intervention. By 2016, in the Netherlands EE is expected to result in 51.190 GWh energy savings in total. The savings represent just calculated savings, estimated for the package of policies applied to certain economic sectors; no exact savings per policy are individually calculated. It is suggested that given the connections between energy policies, such an extensive calculation is not feasible (EEAP 2007). The savings are calculated before the policy implementation as the difference between the scenario with existing policies and the scenario without policy. The calculated savings due to new policies are based solely on scenario calculations for the national program 'Clean and Efficient', and not on measurements to determine the realized savings. This clearly overlooks the possible negative economic effects resulting from direct and indirect RE's. The results from the calculations for 2011 and 2020 are by interpolation converted to savings for 2010 and 2016, thereby taking into account when measures will become effective (taken from Dutch Action Plan 2007). Similar calculated savings – compared to a reference scenario without policy intervention - can be found in the World Energy Insight (2012). The WEI 2012, EU directive and the Dutch EEAP 2007 only use calculated savings to measure EE improvements and do not take into account the possibility of RE's before and after policy implementation.

In this section I focus on EE in principle, RE's, and the distinction between WS and the two schools of SS. I will re-examine the concepts as they are determined in policy as calculated savings *before* the policy implementation. This kind of framing is based on blackboard theorizing about the future materialization of calculated savings and/or investments following EE policies. This framing is 'normative', because it suggests what is assumed, or ought, to happen as a result of the policy, and disregards what actually happens after policy implementation. Such framing, as exemplified in the Dutch EE policy, provides no guarantee that when people actually adopt EE improvements they always save an amount of energy resources and associated GHG-emissions. As seen in the previous chapter, the calculated savings also represent cost savings and an opportunity to expand economic activities, increasing total energy use, both on the microeconomic- and macroeconomic-level. Thus, calculated savings should be considered as just a benchmark of total potential savings and not as the certain outcome of EE policy. For my case, determining EE in practice may well show that what was assumed based on EE in principle does not lead to a positive savings or saving-investment rate at all.

Aside not looking beyond the calculated savings to assess policy performance, another omission in the Dutch sustainable energy policy is the lack of clarity of which kind of sustainability it is exactly that EE is supposed to benefit? EE can be compatible with the WS approach and SS1 approach if the savings-investment rule or shadow projects and CNC thresholds are respected, but not always with the aim of the SS2 approach; i.e. saving certain CNC stocks fully. As shown in the third chapter, in case of RE's, EE does not reduce natural capital use, therefore it does not add to the aim of the SS2 approach. In case of backfire, whereby the expansion of economic activities reduces total capital by using more natural capital (i.e. fossil fuels and the atmosphere) in a faster pace than can be substituted with alternatives (i.e. renewables and portable oxygen tanks), EE does not add to either the WS or SS1 approach. This section sets out to exhibit when EE in principle adds to the aims of the WS approach, or one of the two SS approaches.

4.2.2 Weak Sustainability and EE in principle

In the Dutch energy policy the calculated savings are assumed to fully materialize, and direct and indirect RE's are supposedly not occurring for the full period 2007-2020. This idea of EE is not ‘sustainable’ in a WS sense, but a SS sense, namely SS2. However, the narrative seems somewhat compatible with the WS approach, as the EE rents are considered able to benefit substitution with renewables, even though the exact savings-investment rate is not made explicit. According to the WS approach, EE can help save natural capital (e.g. fossil fuel, CO2, atmosphere) and allow for investment in substitution of natural capital for human-made capital (e.g. renewables, electric vehicles, carbon storage, etc.), to keep a constant level of total capital. For simplicity I suggest to consider the WS investment of EE rents also as RE’s; i.e. rents drawn from the calculated savings following EE improvements. EE can add to the aim of the WS approach when RE’s account for investments in substitutes. Calculated savings are only indicative for what we may expect from EE improvements in the best case scenario. In addition, the rate of investment in substitutes must also be determined. In this view, EE in principle with RE’s can be compatible with the savings-investment rule of the WS approach.

The WS approach suggests that non-renewable energy resources can be fully depleted, as long as their depletion sustains total capital. But, when EE improvements backfire and the new levels of fossil energy use and GHG-emissions exceed the previous levels, total capital decreases. In this case, the EE rents are fully on the investment-side of the WS savings-investment equation. Without substitution adding to total capital this can result in a negative savings-investment ratio, and thereby not add to the aim of WS. Thus, in case of backfire – when investments following EE improvements lead to a negative total number - EE does not advance sustainability in terms of WS. EE in principle only adds to the aims of WS when the calculated savings do not fully materialize and RE’s do not exceed the positive savings-investment ratio. At the end of the day, the Dutch policy is only based on calculated savings without accounting for RE’s, which is certainly not compatible with the WS approach. The

Dutch policy seems to display a rather naïve version of the SS2 approach, whereby EE improvements lead to 100% savings.

4.2.3 Strong Sustainability and EE in principle

Again, the Dutch energy policy assumes the calculated savings to fully materialize. Thus, the notion of sustainable energy found in the policy documents cannot be considered ‘sustainable’ in an SS1 sense, but only in an SS2 sense. The narrative (as found in the documents and websites), however, I find more compatible with the SS1 and not with the SS2 approach, because the EE rents are suggested to be invested in substitution. Again, the investment rate and exact shadow projects are not made explicit. Progress on the national level could be measured by the Environmental Sustainability Index (ESI), which is based on SS-models. It assumes that a country is more likely to be ‘sustainable’ to the extent that its vital CNC stocks are maintained at healthy levels, and to the extent to which levels are improving rather than deteriorating.

EE can be considered compatible with the sustainability aims of both schools of SS, just in case the rents are saved, fully according to the SS2 approach, or partially invested in shadow projects according to the SS1 approach. Again, calculated savings are not a sufficient indication for what to expect from EE for the aims of the two schools of SS. The SS1 approach suggests that EE should predominantly be used for natural capital savings, and a part for investing in shadow projects. In this view, rents should be used to further withdrawn fossil energy from present use and decrease GHG-emissions. For simplicity, I consider the investment in shadow projects a part of RE’s; i.e. rents drawn from the calculated savings following EE improvements. Partly resembling the WS savings-investment rule, according to SS1, EE saves natural capital (e.g. fossil fuels) and part of the rents can be invested in substitutes (e.g. renewables). Thus EE can be in accordance with the savings and shadow project investment rule of SS1. But, again, backfire can counter-act upon the potential of savings actually being invested in merely shadow projects, which does not advance the aim of SS1.

From the SS2 viewpoint, EE in principle should add to fossil energy being withdrawn from use and prevent associated GHG-emissions. In this view, EE saves natural capital. Thus EE can be in accordance with the savings rule of SS2 whereby sub-sets of physical resource stocks are conserved completely or up to critical thresholds. On the other hand, RE's are never compatible with the savings rule of the SS2. In this view, savings are not to be used under any circumstances, such as savings of natural capital of the fourth kind (e.g. the atmosphere). If EE improvement leads to growth beyond the additional costs of investments in shadow-projects, let alone backfire, this does not add to any of the two school of SS. In this view, EE in principle can add to the aims of SS2 if the calculated savings materialize, and RE's do not occur. EE in principle adds to the aims of SS1 only when the calculated savings do not fully materialize and RE's do not exceed the shadow projects investment ratio. But in case of backfire EE does not help to advance any of the two schools of SS at all. The Dutch energy policy is compatible with the SS2 approach, but not intentionally, as it disregards any kind of substitution.

4.3 WS and SS in relation to Energy Efficiency In practice

In this section I will focus on EE in practice, with measured RE's, and the conceptual distinction between the WS and SS approach. I will assess the levels of savings and investments after EE policy implementation; based on empirical research, actually measuring EE and RE's in the real world, and determining what happened after the policy was implemented in relation to the WS and SS approach. This framing is descriptive, because it labels what actually happened after implementation in terms of what was initially assumed to happen in terms of EE in principle. This helps to assess the accuracy of assumptions about the potential of EE policies to add to the ‘sustainable’ aims of either the WS or SS approach. Starting off from assumptions about EE in principle, determining calculated savings and potential RE’s, empirically checking whether the assumptions hold can be considered an indication to which aim EE stimuli have added.

4.3.2 Weak Sustainability and EE in practice

According to the WS approach, the savings following EE in practice must materialize and be saved up until a certain level, thereby curbing the optimal economic output in the new situation compared to a full investment situation (i.e. backfire) in which there are no savings at all. As we have seen in the previous chapter, the effects of RE’s following EE cannot easily be measured, due to the bias of choosing production functions, different scales of measurement, various levels of disaggregation, numerous micro-level investment options, and counterfactual assumptions. Progress on the country level can be measured with the Genuine Savings Index (GSI), published yearly by the World Bank. It is based on WS models where a positive number indicates sustainability, and vice versa. Users of the GSI assume that “the Hartwick rule (Hartwick, 1977; Solow, 1986) offers a rule-of-thumb for sustainability in exhaustible-resource economies…” (World Bank, 2005, 49). In this way they can discuss the rate at which ‘national wealth’ (i.e. GDP disaggregated in human-made capital and natural capital) is being produced or consumed (Pearce and Atkinson, 1993; Hamilton, 1994). Figures are published annually in the World Bank’s ‘World Development Indicators’ and regularly used in policy debates. For monitoring the national development of sustainable energy, this approach has advantages over other types of national environmental accounting indexes because it provides a single positive or negative number representing the whole economy. Constant negative results are interpreted to indicate that an economy is pursuing an unsustainable path that will have negative environmental effects in the long run (Hamilton et al., 1997).

From the SS viewpoint, there are a number of omissions when using the GSI to monitor ‘sustainable’ progress. The World Bank's natural resource accounting uses only market-valued non-renewable and renewable natural capital. Many other factors are excluded, either because of measurement uncertainties or because resources are viewed only as inputs to production. Omissions include accounting for ecological and life-support functions of natural capital, as well as the value of retaining the choice to use a resource in future, and the value people place on the existence of assets regardless of their consumption.

The effects of RE’s following EE in practice can more easily be measured at the micro-level of the firm, the household, or the individual, than on the macroeconomic level (e.g. see DeCanio and Watkins, 1998; Boyd and Pang, 2000). Especially once it becomes possible to assess the energy content of individual production and consumption by energy conversion and other devices giving feedback to a smart-grid. A cross-section of initially identical test households and firms could be selected, and their EE and total energy use studied over longer periods of time. For the aim of the WS approach, one can expect to find households and firms saving a certain part of EE rents, and investing another in substitution. This assumption can also be found in the narrative of the Dutch energy policy, but it is not present in the calculations. Even more, the policy lacks measurements, thereby only displaying assumptions about EE in principle. It is only assumed that households and firms will take-up an accurate savings-investment rate and automatically add to the development of sustainable energy. An exact savings-investment rate for households and firms is lacking, and without this benchmark it is impossible to assess the success of EE in practice for sustainability in terms of WS. For now, Dutch energy policy, does not measure anything, and is strictly based on assumptions and blackboard calculations of savings.

4.3.3 Strong Sustainability in Practice

In the Dutch energy policy, EE as pillar of sustainable energy is not exclusively used as concept for saving fossil energy in order to invest in renewables, nor is there an index to measure the success of the policy. But, for advancing sustainable energy in terms of the WS and SS1 approach this is imperative. According to the WS approach, trying to keep a positive saving-investment ratio in the long run requires the rents of using finite fossil energy stocks more efficiently to also be invested in renewables to replace them. Similarly, the SS1 approach requires investments in shadow projects to replace the use of fossil fuels. So for EE to be a part of the WS and SS1 approach the calculated savings should not follow EE in practice. In contrast, for the second school of SS the calculated savings should follow EE in practice. In the Dutch Action Plan 2007-2020 the calculated savings are assumed to fully materialize and no RE's are supposed to occur. Thus, the notion found in the calculations is not 'sustainable' in a WS sense, but in an SS2 sense. However, in the policy documents the calculations suggest that EE in principle leads to savings, but the narrative also considers investments in substitutes. So, whereas the calculations are in accordance with the SS2 approach, the accompanying narrative is more like the SS1 approach, or rather WS approach (as there are no explicit limits to substitution).

In contrast to the WS approach, EE in practice for the SS approaches cannot be determined by typical economic tools based on conventional neoclassical techniques, such as underlying the

GSI (see also Goodman and Ledec 1987; see also Van Den Bergh et al. 2006a; Van Den Bergh 2004 and 2010). For the SS approaches, EE in practice must be determined in terms of the maintenance of CNC stocks and thresholds that are vital for the subsistence of economies for an indefinite period of time. Energy policy decision-making which relies exclusively on the WS approach can effectively address only short-term economic efficiency and longer-term total welfare, and not many of the other important factors which co-determine a broader SS-approach to sustainability. As pointed out by early ecological economists, these factors include fair income distribution, intangible ecological values, non-substitutable natural resources, and the prospect of a safer ‘common future’ that can be achieved only by very long-term savings rules (see Daly, 1977 and 1984).

As suggested in chapter two, in contrast to the aim of saving fossil fuel energy resources by EE in practice, policy-makers are actively increasing the option space for economic expansion (Giampietro and Mayumi, 2006). Due to the new possibilities within more efficient systems, modelers of such systems must always be prepared to face a healthy dose of uncertainty and ignorance, as they know they do not know exactly when and how new EE opportunities will enter their models (i.e. an unknown error-term). In addition, this requires a continuous updating of models, formal identities, and what we intend to mean with improving EE in principle before we can measure EE in practice. In this perspective, researchers have to consider the co-evolution of a sound relationship between a selected set of narratives and the resulting set of selected models and calculations, also in different periods (ibid.). If we take the SS approach as starting point for assessing EE in practice, and the calculated savings materialize this is also in accordance with the aim of the WS approach as long as total capital is maintained or increases. In case of RE’s, the SS1 approach is somewhat difficult to distinguish from the WS approach (for simplicity, overlooking the maintenance of thresholds of natural capital), as long as the investment in shadow projects equals a positive saving-investment ratio. In contrast, the aim of the SS2 approach is forgone when not all calculated savings materialize and CNC stocks increasingly decrease.

EE is normally not explicitly considered as a concept for saving fossil energy resources in order to invest in renewable substitutes. But, for advancing sustainable energy in terms of the WS or SS1 approach this is imperative. Trying to have some kind of sustainable energy future in the long run requires some EE rents to be invested in substitution with renewables. In contrast, according to the SS2 approach the rents of EE should be exactly the same as the calculated savings predict. When the calculated savings materialize and are actually saved, this is not in accordance with the aims of the WS and SS1 approach.

The Environmental Sustainability Index (ESI) by Yale Center for Environmental Law and Policy is based on the SS-approach. It states that a country is more likely to be sustainable to the extent that its environmental systems are maintained at certain levels, and to the extent to which healthy levels are increasing rather than declining. Comparing the ESI with the GSI, the trends show that countries with a high level of growth do well in the GSI compared to the ESI, mainly because the latter does not reflect investments mainly due to assumption of non-substitutability between human-made and natural capital. Thus, countries with fast GDP growth are most likely to do well in the GSI and poorly in the ESI. There are many more contrasting assumptions and results between these two indexes for measuring sustainable growth. More important here is that these indexes of WSG and SSG exemplify measurements of national sustainability that go beyond growth in terms of GDP, and according to "best practices" try to assess a weaker or stronger sustainable level of economic growth (see also

Fashola, 2012). The Dutch sustainable energy policy lacks such an index, and measuring it's success has only been done in terms of calculated savings.

4.5 Different Paths to 'sustainable' Energy

In light of the existence of direct and indirect RE's, the assumptions about EE in principle in the Dutch energy policy are seriously flawed: the amount and pattern of energy dependent activities in the economy will not remain fixed when the implicit price of energy falls. In other words, one should not assume an economy with a high level of EE potential to have a stable level of total energy use under the influence of EE policies and RE's. When the implicit price of energy falls, RE's will result in an increased level of total energy as well as natural capital use, possibly with a negative savings-investment ratio and surpassing shadow investments in renewables. As suggested in this chapter, EE leading to calculated savings, without RE's, are compatible with the SS2 approach, whereas EE leading to investments, with RE's, can be compatible with the SS1 and WS approach. In this view, an economy with a high level of EE can be expected to display one of four trends in economic activities (see also figure 5):

(1) an increase in economic activities beyond the WS savings-investment rate,
(2) an increase in economic activities equaling the WS savings-investment rate,
(3) no increase in economic activities equaling the SS1 investment rate in shadow projects, or
(4) a decrease in economic activities equaling the SS2 savings rate.

The calculations of EE in principle in the Dutch energy policy is only compatible with the SS2 approach. But, the narrative also speaks of investment opportunities, implying two possible outcomes EE in practice which can be compatible with the SS1 and WS approach. In other words, without further clarification we may expect from the Dutch policy not just these two but any of the four trends displayed in Figure 5, in contrast to the assumed 100% materialization of calculated savings.

In addition, the extent of RE's following EE policies depends on parameter values whose EE in practice determination is an empirical issue. Such measurement is lacking in the Dutch Action Plan 2007-2020. I think it is rather naive to determine the effect of EE just in terms of calculated savings. In an open economy such as the Dutch, it is virtually inconceivable that there would be no RE's associated with EE in principle and in practice, since this would require a set of extreme conditions under which the amount and pattern of energy dependent economic activities will remain rigidly fixed when the implicit price of energy falls. Secondly, while the presence of RE's can reduce the environmental benefits of EE in principle practice, and backfire more than offset the benefits relative to what would be expected from the calculated savings. This is why I find the Dutch energy policy 2007-2020 to be 'naïve'.

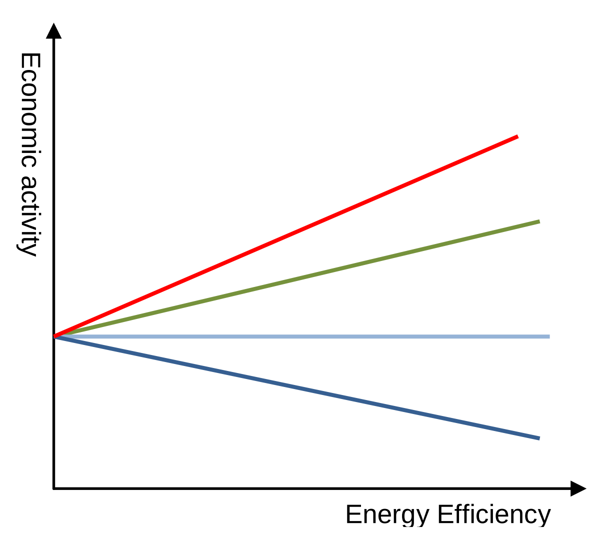

Figure 5 – Representation of four possible trends of EE in practice. The red line represents backfire, the green line WS, the light blue line SS1, and the dark blue line SS2.

As shown in the previous sections, EE can add to the aims of the WS and SS approach. In light of RE's, EE can add to the WS and SS1, but not to the SS2 approach. The following three 'normative' paths can now be distinguished for EE in principle:

(1) WS: EE → rents → positive saving-investment ratio → RE's are investment until threshold of keeping to positive saving-investment ratio.

(2) SS1: EE → rents → investment in shadow projects → RE's are investment until threshold of keeping to shadow projects.

(3) SS2: EE → rents → full savings → RE's are 'non-existent' or countered.

These normative paths show that the distinction between the WS and SS approaches is useful for the analysis of EE in principle, as it prescribes what 'ought to' happen with the EE rents for adding to the aims of 'sustainable' energy in terms of WS or SS1 or SS2. Furthermore, EE in principle, as found in the policy documents, can be considered 'sustainable' in the sense of SS2. Unfortunately, the calculations in the policy documents are not compatible with the narrative, as the former do not consider investments while the latter does. The aid of EE in principle for developing 'sustainable' energy, whereby the EE rents are invested is compatible with the SS1 and WS approach, is present in the story but left out of the equation. I find this a serious short-coming of the policy, especially considering the amount of research that has already been done on the economic effects of EE on the households and firm level, and the economic effects at the national level.

Direct and indirect RE's have been shown to be possible in the real world, which in principle can account for a certain amount of the investments following EE policy. The previous sections have shown that EE with RE's can be considered 'sustainable' in a WS or an SS1 sense, but not in an SS2 sense. RE's can lead to the opposite of what was intended to follow from the sustainable energy policy, namely full savings, whereby it is not to be considered ‘sustainable’. When looking at the period after policy implementation, the distinction between the WS approach and the two schools of SS is helpful again, mainly because EE in practice can be expected to show either:

(a) calculated savings fully materialized, which adds to the aim of SS2; or,
(b) RE’s occurred, which adds to the aims of WS or SS1; or,
(c) backfire, which does not add to the aims of WS and the two schools of SS.

The conceptual distinction between WS and the two schools of SS in light of EE in principle can be ‘verified or falsified’ by measuring EE in practice. The distinction between the WS and SS approach is helpful in case that (a) calculated savings materialize and RE’s do not occur adding to the aim of the SS2 approach, (b) RE’s occur and not all calculated savings are actually saved but invested adding to the aims of the SS1 or WS approach, and (c) backfire, whereby all calculated savings are actually invested beyond the thresholds of the positive savings-investment rule and shadow projects, and savings, thus not leading to advance the aims of either the WS, SS1 or SS2 approach. The main problem I find with the present Dutch energy policy is that unaccounted RE’s lead to overlook that the expansion of economic activities due to EE improvements can exceed the thresholds of the saving-investment rule, the investment in shadow projects, and even of saving completely, rendering EE not ‘sustainable’ in any of the three familiar senses.

Without accounting for RE’s, in calculations of EE in principle and measurements of EE in practice, one cannot properly calculate and monitor the savings and investments of EE rents resulting from EE policy, let alone anticipate counterproductive results of policy with ‘sustainable’ ambitions. In theory, EE rents are needed for substituting non-renewables with renewables and developing sustainable alternatives, thus it has not been calculated in this way. But, in the Dutch policy all economic actors are assumed to fully save the amount of energy resources calculated of EE in principle. But, as shown in the previous chapters, this is all but the full picture. In my view, the Dutch sustainable energy policy pays too little attention to the possible outcomes of EE in principle and EE in practice and the dynamics of RE's, which in case of backfire can be counterproductive for the aims of the WS or SS approach.

In addition, to account for direct and indirect RE's does not only require measurement of energy use and intensity, but also monitoring of all other economic activities that stem from EE rents, and their weight on natural capital stocks. Aside the income effects, many other effects such as the energy content of the materials should also be accounted for. Work on the energy content of materials, namely 'energy accounting', which had its heyday in the 1970s, has been revived by the 'ecological footprint' concept (Herring 1999). Now, calculating ecological footprints of households and firms is only partially helpful as it does not consider the complete footprint throughout consumption and production chains. For example, not only the fossil fuel used for industries contains energy, but also the other materials that make up the physical content of the real world economy. Materials such as the steel present in factory buildings, vehicles for transport, machines, and other factors in the production chain. In light of Jevons' Paradox, improving EE of one factor in the production chain decreases total production costs, which open up opportunities for expansion of economic activities throughout the chain, and even the whole economy. Even more, in a global economy the RE's could spread, backfire, and cause more total energy use and GHG-emissions, but also increased use of other natural capital . In case of backfire, EE in practice is not beneficial to the aims of the WS approach when the level of investments exceeds the level of savings.

For developing sustainable energy some savings have to be invested in substitution with renewables, this basic idea is absent in the calculated savings viewpoint of the Dutch policy-makers. A too rigid distinction between the WS and SS approach also overlooks such savings-investment steps of developing sustainable energy. The dominant focus on EE in principle leading to calculated savings overlooks that the conceptual distinction between the WS and SS approach helps to define the 'sustainable' aims. In this debate, more attention must be put on the substitution of fossil energy resources for renewables, and the role of sustainable energy policies in supporting this transition. Changing from unsustainable to sustainable energy systems requires to think about both EE in principle and EE in practice, with and without RE's, as well as calculating and coordinating investment and savings in relation to each other.

5. Conclusion

Almost every way we make electricity today, except for the emerging renewables and nuclear, puts out CO2. And so, what we're going to have to do at a global scale, is create a new system. And so, we need energy miracles

- Bill Gates (@TED, 2010)

5.1 Energy Efficiency is Partially Helpful for Sustainable Energy

In the 21st century we must transition towards a new sustainable energy system, and we don't need a miracle. We need clear policies built on a plan that goes beyond EE rents and calculated savings. This thesis has critically assessed EE and its relation to WS and SS, RE's and Dutch energy policy. I found that if EE leads to one hundred per cent materialization of calculated savings, it is compatible with the SS2 approach, otherwise it is not. Whether less than one hundred per cent savings is compatible with the SS1 approach and WS depends on the levels of investment. Yet, when the investments lead to negative total capital, EE is neither compatible with the SS1 nor WS approach. In this case EE does not add to 'sustainable' energy in a WS or an SS sense.

This thesis has looked at debates about EE, RE's, and the distinction between the WS approach and the two schools of SS by using arguments and problems drawn from debates in economics. As shown in the first and second chapter, energy resources and their utilization are related to both WS and both schools of SS. Trying to attain sustainable energy much effort must be devoted not only to developing renewable energy resources, but also to increasing EE. Due to increased awareness of the benefits of EE improvements, Dutch institutes and agencies have started working along the lines of EE to advance saving-investment opportunities. On the one hand, Dutch EE policies have been developed intended to reduce present levels of fossil energy consumption, energy-related GHG- emissions, and save consumers and producers money. On the other hand, these EE policies have been developed intended to reduce costs and open up investment opportunities. Investing the rents is compatible with the WS approach and the first school of SS, respectively as long as the saving-investment rate is positive and kept within the boundaries of shadow projects. Investing the rents (i.e. RE’s) is not compatible with the second school of SS.

The conceptual distinction between the WS approach and the two schools of SS is helpful: when EE leads to 100% materialization of calculated savings this is compatible with the second school of SS, otherwise it is not. Whether less than one hundred per cent savings is compatible with the SS1 and WS approach depends on the levels of investment. But, when the investments lead to negative total capital, more use of energy and GHG-emissions, EE is neither compatible with the WS approach nor the two schools of SS. In this case the distinction is less helpful for thinking about EE as a pillar for the development of sustainable energy, because the outcome is not ‘sustainable’ in a WS, or SS1, or SS2 sense.

5.2 Energy Efficiency Cannot Always be Considered ‘Sustainable’

In the context of the Dutch EE policy, EE is not as beneficial for developing ‘sustainable’ energy as made to believe, because it cannot always be considered to add to sustainability in the sense of saving natural capital and/or investing in substitutes. However, without accounting for RE´s in principle when drawing up policies and measuring the impact of EE and the presence of EE in the real world, we are blind sighted for the economic effects that can be counterproductive for the aims of sustainable energy policy.

Positions in sustainability debates can be generally divided into the popular WS approach and the less popular schools of SS. EE can be part of both a WS and an SS energy policy instrument. The distinction between WS and the two schools of SS is helpful, especially as this thesis has shown that EE cannot only add to the aims of WS, but also to the aims of the two schools of SS, or neither of them. The problem of RE’s does not refer to a problem with

WS if the rate of substitution of natural for human-made capital is not exceeded by the rate of natural capital use by EE. The problem of RE´s does refer to a problem with the two schools of SS if the rate of natural capital use is increases. Indeed, one can quite reasonably talk about EE and RE’s with WS as well as with SS1 vocabulary. However, both place EE and RE’s in completely different perspectives. In case of backfire, EE is not beneficial to the aims of WS or SS1. In this case, EE is not adding to sustainability in any of the familiar senses.

Analogously, in the context of the Dutch sustainable energy policy, EE is assumed to lead to certain benefits – i.e. calculated savings - by reducing the amount of natural capital needed for input to produce the same amount of output, in this view EE is beneficial for the sustainability aims of the WS and both schools of SS approaches. However, when EE leads to RE´s, thereby increasing the use of natural capital, this can benefit only the WS approach and not the SS1 or SS2 approach; thus, in this case EE can be considered a pillar of ‘weak sustainable’ energy. Even more, when RE’s result in an increased level of natural capital use, EE is not beneficial to the sustainability aims of WS or SS1. Thus, in this case EE cannot be considered sustainable. This case I find conceptually and practically problematic for EE being considered ‘sustainable’ in the Dutch sustainable energy policy. RE´s can be found in theory and there is a case in which EE in principle is not sustainable in the sense of SS2. Backfire can be found following EE in principle and there is a case in which EE is not conceptually sustainable in the senses of the WS or SS1 approach. RE´s can be found following EE in practice and there is a case in which EE is not really ‘sustainable’ in the sense of the SS2 approach. Backfire can also be found following EE in practice and there is a case in which EE is not really sustainable in the senses of the WS or SS1 approach. Combined, these cases lead me to conclude that EE is not always ‘sustainable’ in a WS or SS sense, and can therefore not be considered a proper pillar of sustainable energy without accounting for RE’s.

5.3 Policy Recommendations

Going beyond a strict WS versus SS debate about sustainable energy, a more dynamic approach of sustainability could be beneficial for taking into account the immanent opportunity for change in an extended option space such as made possible by EE improvements. This also requires measuring and governing RE's, and monitoring and controlling for the (unintended) economic effects of EE improvements. From the EE and RE debates, I take that economic activities do not only need to make use of energy resources more efficiently, but also have to be monitored and controlled concerning the substitution of non-sustainable energy resources and services for sustainable ones. Therefore I suggest to use a hybrid concept of 'sustainable' energy that entails notions taken from the WS and SS approach: investment in some energy resources and services and savings of some CNC stocks. Just static investment or savings do not help to address sustainable change from non-sustainable to sustainable systems. Nor does a rigid dichotomization of WS and SS help to study the dynamics of the sustainable energy transition.

The Dutch energy policies, however, statically conceptualize EE as calculated savings and thereby overlook the needed investment rates in sustainable change. Instead of WS growth or SS-savings, I take sustainable energy to also require a dynamic change from non-sustainable to sustainable systems. In energy debates this requires attention for a change from non-renewable to renewable energy resources and services. In this way, a WS versus SS style characterization is helpful for EE debates because it point outs the possibility of sustainable change beyond just saving, in contrast to focusing just on calculated savings. The debates could be concerned more with the investment rate in substitution with renewables, and shadow projects, as well as respecting the carrying capacity of certain CNC stocks. Calculated savings provide little guidance for what to do with EE rents, and how to adequately invest them in either savings of natural capital or investment in substitutes. WS and the two schools of SS are normative about what to do with the rents, but can also be used to describe what actually happened after policy implementation (i.e. savings and/or investments). In light of the EE debates and RE's, the distinction between WS and the two schools of SS also highlights a great potential for (more rapid) change towards sustainable energy, primarily made possible by improving EE, and increasing the option space for expansion of economic activities in the field of renewable energy. Producers and consumers can adapt their behavior to the expanded option space that comes along EE stimuli, once made clear what to do with the calculated savings. In this view, RE's are not 'unintended consequences', but can be used to create opportunities for nudging producers and consumers into a direction of weak and/or strong sustainability.

I think, the energy policy debates should also concern more fundamental discussions on the rate and speed of sustainable change, which involves both investment and savings decisions depending on the situation at hand. At least, three non-exclusive policy recommendations follow in light of the WS versus SS debate:

- For WS, EE rents should be (partially) invested in the substitution from non-renewable into renewable and human-made capital so that welfare per capita remains the same as last period;
- For SS2 EE rents should be invested in the natural environment so that the critical thresholds of natural capital stock can be maintained;

- For both WS and SS1 EE should be used for either increasing sustainable production and consumption or saving the natural environment and goods and services related.

Investment in non-renewable energy systems could enable investment opportunities in renewable energy systems. Secondly, investment in renewable energy systems (e.g. solar panels) could enable saving of non-renewable energy systems. Thirdly, saving of non-renewable energy systems could enable investment in renewable energy sources and technologies. Fourth and finally, saving of renewable energy systems could induce more saving of non-renewable energy systems. All, of course, while accounting for RE's to calculate and measure the savings and investments of EE.

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