Chapter 1

Strategies for an Economy Facing Energy Constraints

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1.1 Introduction

This chapter will be incomplete as the subject is quite vast, nor is there a unique strategy. The best we can do is give the reader directions of thought, establish some basic principles, and give references for further study. This work differs from the works of Ron Hopkins [24, 25] in that we spend more time trying to understand the eminent contraction phase of the economic (or business) cycle of fossil fuels from both empirical and theoretical standpoints. We feel this is necessary because many people make the mistake of thinking that the peak oil problem is a problem of high prices, while empirical and theoretical results indicate that peak oil is a low price problem. That is, market prices will not increase as fast as production prices causing production to fall. This consideration changes the strategies we advocate. This period is a time of many challenges, but also a time of opportunity. We have the opportunity of rethinking our goals, monetary system, political, and judicial systems, and we can attempt to transition to a sustainable economy. Today we have advantages such as better communication systems and more data than former citizens had facing similar problems.

The permaculture movement has been thinking about strategies for an energy challenged world since the 1970's. We will summarize the core principles of this movement.

Understanding secular or long economic cycles as described in [47] is an important step in developing strategies because these cycles give us symptoms which tell us where we are with respect to the economic cycle of energy as well as historical outcomes which we may want to avoid.

We review the way we measure economic output. Current measures are too narrow. Measuring monetary output alone can lead to very misleading measures. For many economists the 20th century was a very positive period because of the growth in economic production. However using other the metrics the 20th century was a disaster because of the loss of biodiversity, habitat, and the depletion of mineral resources. We think this is important to avoid past mistakes.

We look at technology that is currently not implemented which could be brought to market that could be used to mitigate the energy shortage.

Once we have a better idea of where we want to go, we look at strategies and preparation measures for what will ensue.

1.2 Measuring Economic Output

Before discussing the secular or economic cycles of the next section, we make some basic remarks on measuring economic output.

Units are a major problem in measuring economic production. If all economic production where apples, one could count the apples to evaluate economic production. But in an economy which produces apples, oranges, computers, software, and mathematical theorems among many other things, each unit one uses has its specific problems.

Different units have been studied by different authors to measure the economy. We feel each of the units have different advantages and disadvantages. Studying different units give different insights into how the economy functions.

1.2.1 Currency

The major success of currency as a unit is that it is common to all things measurable (objects with a price), allowing us for example, to compare software production to apple production. The unit of currency does have drawbacks.

Money or currency is many things. A monetary system is a social contract for the distribution of goods produced by the society. One aspect of money is that it is a measure of value on measurable objects. The so called market compares the price of computer software and apples allowing us to compare the relative values of very diverse objects. The value system is not democratic, as persons controlling large relative amounts of money have more votes in determining the value of an object than a large number of people without money. For example, if a large part of the population is starving, one might expect the price of food to be high, but this is not necessarily the case if the people who are starving have no money. The distribution of money or wealth thus significantly effects the price of goods.

Another aspect of money is that as it is a man-made construct, it can be manipulated so that there are distortions. Economists attempt to see through these distortions, for example by adjusting for inflation, using discount rates, and factoring in subsidies. It is nonetheless impossible to account for all distortions in a satisfactory manner. The success of the website Shadowstats attests to intensity of this debate with respect to inflation.

1.2.2 Energy

Many authors have worked on Energy Return on Energy Invested, or EROEI

$$\text{EROEI} \stackrel{\text{def}}{=} E_o/E_i, \tag{1.2.1}$$

where E_i is the energy invested to obtain the output energy E_o [18, 14, 40, 48]. Rather than using currency, these authors use units of energy to measure economic activity. Energy as a unit, is known very well in all the physical sciences. It is impossible to manipulate (though energy statistics can and are manipulated). The drawback of energy is that one does not consider what the energy is used for, and how well it is used for that purpose, primary concerns for those wishing to understand the economy.

Energy balance equations are fundamental to understanding all sciences. We feel that this should be an important area of future research.

When measured with the unit of energy, the economy resembles one or more electric circuit(s) in parallel with a power supply(s). Each good can be traced back to the origin of the energy that permitted its manufacture. Energy, or more properly, exergy, is different from money in that it is exhaustible. Exergy cannot circulate forever, spent exergy never comes back. It needs to be produced from a power supply. To people measuring the economy with energy, exergy production is the most fundamental aspect of the economy. The IEA has recently made interactive Sankey diagrams available, a valuable tool for people studying energy and the economy.

1.2.3 Useful Work I

Ayres and Warr [2] have introduced the idea of useful work

$$U \stackrel{\text{def}}{=} eE, \tag{1.2.2}$$

where E is energy production and e is efficiency. Since efficiency is a dimensionless proportion, U has the units of energy so it is really just an aid to study the unit of energy rather than an entirely new unit. Essentially, U represents energy production less the energy lost in (non useful) heat. Note that $0 < e < 1$ so that e is bounded.

This variable has the advantage of adding a measure of technological progress to measures of energy production. It also has the advantage of attempting to measure what is actually done with the energy, an improvement over just measuring energy production alone.

We define Useful Work Return on Energy Investment in a similar way to EROEI:

$$\text{UWROEI} \stackrel{\text{def}}{=} U_o/E_i = eE_o/E_i. \tag{1.2.3}$$

We do not divide by e in the denominator as we assume that this is accounted for in the computation of EROEI.

1.2.4 Useful Work II

One can take the idea of useful work a step further by measuring precisely what we do with energy in the economy. For example one can measure vehicle kilometers traveled, ton kilometers of freight transported, person kilometers traveled, processor cycles cycled, or page views on the web. Such measures are direct measures of economic activity, but unfortunately one loses a uniform unit and it becomes difficult to compare different activities. One obtains measures of different parts of the economy with incompatible units. If the goal is to transport people or goods one can also talk about efficiency, though it is not as well defined as in Section 1.2.3. One can measure for example ton kilometers per kilowatt hour. The larger the quotient, the greater the efficiency. We note that in terms of vehicle kilometers traveled, U.S. and Western European economies have contracted since 2007.

1.2.5 Labor and Food

Marx [34] noted the importance of hours of work in measuring value added. Again, different work requires different accounting methods. The amount of training and skill of workers varies. However, we can make meaningful averages based on population among other statistics. Population in turn can be estimated from food production. We believe that food production is the origin of labor specialization, and hence modern economies. In hunter-gatherer societies all labor is devoted to food production. When a percentage of the population accepts to produce food for a larger population, then some laborers are available for other work.

Because food is an essential ingredient of labor, we may substitute food production for labor. With food and labor, we can do analysis similar to EROEI analysis done with energy. Knowing the percentage of the population engaged in food production tells us how much labor is available for producing other things. It is a measure of the diversity of the economy. In the United States, this represents about 1% of the population, leaving 99% of the population available for other work. In Burundi 93% of the population is in agriculture leaving a mere 7% available to do other things.

1.2.6 Ecological Measures

Mollison and Holmgren [37] studied human systems with standard measures of species robustness. Economic activity cannot be positive if it destroys our ecosystem. The success of intensive agriculture can be relativised by ecological measures. Intensive mechanized agriculture has the advantage that few people can produce food for many permitting labor specialization. From an ecological point of view however, the biomass produced by intensive agriculture is frequently less than the biomass produced by wild systems. The advantage for human economies is that, with the aid of chemicals and pest control, a very large percentage of the biomass produced is for human consumption. But at great cost to natural ecological systems. Notably soil quality is destroyed and biodiversity is lost [37, 12, 38, 6, 26].

1.3 Secular Cycles

1.3.1 Empirical Description

Turchin and Nefedov [47] empirically identified recurring secular or economic cycles in agrarian societies. The cycle begins with a period of growth, in population and living standards lasting one or more hundreds of years. Then comes a period of stagflation in which population density approaches the carrying capacity of the land (one says increased population pressure) lasting on the order of half a century. During the stagflation period peasants leave the countryside for cities, the difference between the elite and the commoners increases, and the price of food rises relative to wages. Population ceases to grow in the working class because food production ceases to grow. At first the elite are somewhat better off in the stagflation period because wages are low and they can employ a larger number of former peasants who have left the countryside. As the stagflation period progresses, the ratio of elite population to working class population rises (the working class have a lower birthrate and a higher mortality rate due to malnutrition and cramped living conditions in cities) creating competition among the elite. Social mobility increases, mostly downward as elites lose their status. The inter-elite competition creates fissures which lead to civil war and the final crisis stage lasting a few decades in which population decreases and the state breaks down. There follows an inter-cycle lasting on the order of 100 years before a new growth period ensues.

1.3.2 The Cost Share Theorem

Many empirical studies [12, 43, 38, 19, 44, 3, 29, 16] show that food and energy are key quantities to consider when evaluating economic production. The "cost share theorem" from neoclassic equilibrium theory [3, Appendix A] says that cost share is proportional to the elasticity or scaling factors of the variables in the production function equation. Because the cost share of labor is almost 10 times the cost share of energy in the economy, many economists discount the idea that energy is important for economic production. In Appendix A we prove Theorem A.1.1 which shows that the cost share theorem is extremely speculative in either a growing or shrinking economy. We make the following remarks relative to the cost share theorem and Theorem A.1.1:

Remark 1.3.1.

1. *Because the cost share of oil decreased during the 20th century, some have said that dependence of the economy on oil decreased. This is a necessary condition for superlinear dependence (because the price was roughly constant). In other words a necessary condition for very strong dependence was used as a justification for weak dependence.*

2. *Theorem A.1.1 shows that in a growing or shrinking economy, the dynamics of the cost share is the important consideration, not the size. For important quantities, the derivative of the cost share is negative, that is, in a growing economy the cost share of important quantities decreases and the cost share of unimportant quantities increases. This makes sense. Important quantities such as oil permit the growth of less important parts of the economy.*

3. *Equilibrium theory studies steady states. The economy is dynamic. A dynamical system might converge to a steady state but one does not expect a dynamical system to be in a steady state while it is changing.*

4. *In the above cited articles empirical evidence did not support the Cost Share Theorem. Rather than question the hypotheses on which the theorem is based, the authors attempted to save equilibrium theory by introducing constraints (thus introducing a Lagrange multiplier to explain the importance of energy in the economy). We believe these attempts are artificial and think a dynamical system approach to understanding economic production and prices would be more useful as in [35, 36, 5].*

5. *Theorem A.1.1 says that the scarcity rent of an important item in the economic production function will be lower than that of an item of less importance in some sense. This can be understood by the fact that scarcity of an important item causes the economy to decline, decreasing the market for the good. On the other hand, the cost share of the item will increase, decreasing ecodiversity.*

The cost share theorem is a major problem for neoclassical economic theory. Not only is this theorem not verified empirically, intuitively it does not make sense either.

1.3.3 An Economic Theory of Secular Cycles

Secular cycles can be seen as a business, or economic cycle in food production [47, 12], that is, food is the key economic motor (as defined in Definition A.1.1) of growth. We see modern economies as a superposition of interacting business cycles where the motors of growth of the cycle are the key quantities to study. We present a theory to explain these cycles which we hope will be useful to foresee problems and elaborate procedures to mitigate the ill effects. We make the following hypotheses:

(H1) Profits are spent on culture and growth.

(H2) The principle of conatus.

Hypothesis (H1) is to be understood quite broadly. It is in fact similar to Darwin's theory of natural selection [9]. Darwin felt that populations grew creating a diversity of traits and species until resources constrained the growth. This resulted in a competition which the species with the best adapted traits survived. Hypothesis (H1) says that businesses with profits will grow, but will also create ecodiversity by investing in culture. This growth continues, if unchecked, until limits are attained.

Hypothesis (H2) is Spinoza's principle that all things strive to continue their existence promoted for economic entities by Frédéric Lordon [32, 31].

The business cycles of several energy sources will go into contraction in the 21st century. According to Uppsala Global Energy Systems, the first of these will be oil, which in fact comports several different business cycles classified by the means of production. With the above hypotheses, and Theorem A.1.1 on can qualitatively describe the economic cycle of oil as follows:

The Growth Phase. Production of oil is profitable. From Hypothesis (H1) this encourages the production of oil consuming capital: internal combustion engines, oil burning turbines, space heaters, etc. If the price of oil drops, production stagnates but oil consuming capital grows creating more demand which increases prices. The increase in price causes an increase in production. Because oil is an economic motor, its cost share decreases, thus there is an increase in ecodiversity. This creates many opportunities for work, and in general salaries are high. Abusive employers do not find quality workers willing to work for them.

People are in general happy with political leaders because their conatus is in general satisfied.

The Stagflation Phase. This phase is characterized by increasing oil prices relative to wages while quantities increase marginally if at all due to the decreasing quality of oil reserves (the sweet spots are produced first). The phase is also characterized by decreasing profits both in oil production and consuming industries. In this phase the motivating factor shifts to Hypothesis (H2). Economic agents attempt to prolong their existence and the status quo, that is to say increased production and profits. The cost share of oil increases (in family budgets). The economy loses it's ecodiversity due to less excess profits to spend on culture. Wages fall as the choice in jobs falls and decreasing wages are used as a tool to maintain profits. Stress and competition increases.

From Theorem A.1.1 we anticipate that prices do not increase as much as anticipated because the oil economy ceases to grow and some parts begin to contract. Oil becomes less and less affordable through higher oil prices and lower incomes due to less ecodiversity. In other words, the concentration of wealth leads to lower incomes puts downward pressure on oil prices. People can fall out of the oil economy either through unemployment or through joining parallel non oil based economies. The difference between the elite class and ordinary workers increases. As stagflation continues competition to remain in the elite class increases.

Politically, people are less happy with leaders because their conatus is less satisfied. Initially this dissatisfaction occurs only in the lower classes, but as stagflation continues, the dissatisfaction spreads to higher classes.

Contraction Phase. In this phase the feedback cycle that characterized the growth phase goes into reverse. High prices will reduce the market for capital transforming oil into useful work with stagnant production. Low prices reduce production and people will use the remaining oil transforming capital to prepare for a future with less oil.

We then reach a bifurcation point in history. The solution is not unique. Civil war is a possibility. Substitution of energy sources is a possibility, (as the oil based economy replaced the whale economy of the 19th century [1]). We discuss this in greater detail in the next section.

Current Assessment. Between 1998 and 2005 the price of oil doubled (from close to its 20th century average). Production rose by 14%. Between 2005 and 2013 the price doubled again. Wages in OECD countries fell. Production rose by 3%. Concurrently we have a concentration of wealth [42]. Empirically, we can put the beginning of stagflation for the oil cycle in 2005. According to Uppsala Global Energy Systems, the contraction phase in oil production should start in 2015 [1].

1.4 20th Century Strategies

We look at countries confronted with energy shortages in the 20th century.

Japan 1918–1945. In the face of fuel shortages between 1918 and 1945, Japan embarked on several military campaigns. Japan's leaders aspired to be a global power and thought that military conquest was the best means of assuring the raw materials necessary. Mistakes were made in the choice of targets [13] and the attempt ultimately failed. Japan's oil consumption could only increase after the World War II after the U.S. embargo had ended.

North Korea 1990's North Korea has no oil reserves. After the fall of the Soviet Union, oil shipments to North Korea fell by 90% [17]. This caused a cascade of industrial failures. Transportation was curtailed. As a consequence electricity generation fell because transportation of coal to power plants was hampered. Lack of electricity (for irrigation pumps) and fertilizer caused food production to fall. Increased use of biomass for energy exacerbated food problems. An estimated 3% to 5% of the population died of hunger [17]. The elite class clamped down on the population and switched from Stalinian industrialization to politics of systemic scarcity [13]. Petroleum products were reserved for military use and other parts of the industrial economy declined sharply. Outside of food production, the North Korean government has been relatively successful at running the country and maintaining power. There is still an endemic food scarcity in the country and a danger of famine [13]. We note that the fuel shortage in North Korea was not like the typical secular cycle described by Turchin and Nefedov because there was no stagflation period and the shortage comes from an exterior source. In such a case, it is easier for governments to remain in place and manage the shortage.

Cuba. Like North Korea, Cuba has no oil reserves. Cuba suffered perhaps a greater industrial collapse than North Korea when the Soviet Union collapsed [13]. Both the Cuban government and people managed the situation far better than North Korea, in part because the Cuban government was more humanitarian. The key to Cuban adaptation was local resilience. Cuban agriculture had been mostly intensive production of sugar cane for the export market. Without fuel, fertilizer, or pesticides production dropped precipitously. Per capita caloric intake fell in a like manner. The government requisitioned all available plots of land in the cities and obliged people to begin producing food. Australian permaculture designers showed Cubans ecoagricultural techniques allowing the Cubans to raise food production to pre-Soviet collapse levels with a twentieth of the pesticides. Cuba was able to attain the highest standard of living for a country living with the sustainable criteria established by the Global Footprint Network. Rather that cut access to foreigners, Cuba opened up tourism.

The Soviet Union. The Soviet Union was the largest oil producer in the world in 1985 when oil prices began to collapse. The low price caused Soviet oil production to peak in 1986. This is exactly the scenario that our theory of secular cycles predicts. Adapting to lower oil production in a major oil producing nation is perhaps more difficult than in a non producing nation because of Hypothesis (H2). Because oil production and use is so entrenched in the culture, it is very difficult to imagine a different scenario. The oil production industry will suggest state aid to boost production rather than policies aimed at adjusting to declining production.

Dmitry Orlov [41] has described the Soviet leadership blindness to the meaning of destruction of natural resources, outsized military expenditures, and encroaching insolvency. Hypothesis (H2) is the basis of all sorts of false justification for continuing nonsustainable practices. Because of diminishing returns on investments, the Soviet economy collapsed. Soviet citizens typically lost about 90% of their savings after the collapse. When a state is collapsing much analysis is done as to what went wrong. The people of the Soviet Union had parallel local economies that functioned outside of the main economy. These parallel economies helped people to adapt when the main Soviet economy collapsed. Unlike many authors, we expect the same fate as the Soviet Union to befall oil producing countries.

A slow decline in energy production is harder to manage politically than a fast collapse as in the case of Cuba and North Korea. A fast collapse in a non oil producing region can be seen as a problem coming from outside, while a slow contraction following a stagflation period uncovers corruption and flaws in the political system exacerbated by increased wealth inequality. As Turchin and Nefedov observe, governments collapse only when fissures appear in the elite class. That is only when the elite class runs up against limits.

1.4.1 Interactions

From these case histories, we see that energy shortages interact with other areas of the economy. At the same time that we are facing a crisis in energy shortages, we are facing other critical issues and interactions with the oil economy.

Food. Intensive agriculture which has enabled an extraordinarily small percentage of the population to produce food for a great number is unsustainable and the food cycle will roughly coincide with the oil cycle. Nitrogen fertilizers are reduced from fossil fuels (usually natural gas). Phosphorous comes from mines in North Africa. Ploughing the earth destroys the organisms of the soil and its natural robustness leading to soil degradation and reduced yield [37, 12, 38, 6, 26]. The system is unsustainable even with the required inputs of fossil fuels and fertilizers.

Financial system. The current international financial system was designed for constant economic growth. Stagflation is already straining the system. In the event of a prolonged energy contraction, the system will cease to function.

Climate change. Declining fossil fuel production is excellent news for climate change. Man has been affecting climate for millennia [12]. A sustainable economy means implementing robust systems mitigating climate change.

Loss of biodiversity and habitat We are experiencing the sixth great extinction of the planet [28]. Such a development cannot be deemed an economic success. Measures of the biosphere must be incorporated into measures of economic production.

Increased military tensions We see that shortages often increase military tensions and activities.

1.5 Permaculture

Permaculture is one of the most popular strategies followed to prepare for an energy constrained future, though it is often not understood that permaculture was specifically designed to reduce problems associated with an energy constrained future [45]. We review the ground breaking work of of Mollison and Holmgren and its evolution.

Fundamentals. The underlying assumptions of permaculture stated in [21, 22] are:

- The environmental crisis is real and of a magnitude that will certainly transform modern global industrial society beyond recognition. In the process, the well-being and even survival of the world's expanding population is directly threatened.

- The ongoing and future impacts of global industrial society and human numbers on the world's wondrous biodiversity are assumed to be far greater than the massive changes of the last few hundred years.

- Humans, although unusual within the natural world, are subject to the same scientific (energy) laws that govern the material universe, including the evolution of life.

- The tapping of fossil fuels during the industrial era was seen as the primary cause of the spectacular explosion in human numbers, technology, and every other novel feature of modern society.

- Despite the inevitable unique nature of future realities, the inevitable depletion of fossil fuels within a few generations will see a return to the general patterns observable in nature an pre-industrial societies dependent on renewable energy and resources."

Permaculture is a creative design response to building new sustainable societies in a world of declining energy and resource availability.

When U.S. oil production peaked around 1970, the effect on the world's economy in the 1970s caused people to realize how dependent western societies were on oil. Bill Mollison and David Holmgren, two academics in Tasmania, worked precisely on tackling what they considered the two biggest threats society was facing: climate change and peak oil (peak resources in general).

They considered that the first step in addressing these challenges was local production of food and basic raw materials. So they looked for answers to the question: how can a group of people live sustainably on the same piece of land? In other words, how should land be cultivated for it to be able to provide food and raw materials as long as possible?

This led them to develop the concept of "permaculture" with the idea that a society could cultivate the same piece of land indefinitely to sustain their needs (permanent agriculture). After years of research and personal experiments, they imagined this "permanent agriculture" to represent an "integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man" [37]. Finding inspiration from the study of natural ecosystems and existing sustainable human societies, they outlined basic principles and laws characterizing an agrarian system able to sustain itself. In short they attempted to understand how resources should be managed, leading to the conceptualization of resource optimization in a human made ecosystem.

A more current definition of permaculture given by David Holmgren [21, 22], which reflects the expansion of focus implicit in [37], is "Consciously designed landscapes which mimic the patters and relationships found in nature, while yielding an abundance of food, fiber and energy for provision of local needs." People, their buildings and the ways they organize themselves are central to permaculture. Thus the permaculture vision of permanent (sustainable) agriculture has evolved to one of permanent (sustainable) culture. Regenerative is implicit in Holmgren's understanding of "sustainable".

Ethics "are culturally evolved mechanisms that regulate self-interest, giving us a better understanding of good and bad outcomes. The greater the power of humans, the more critical ethics become for long-term cultural and biological survival" [46]. Permaculture ethics have been inspired by the ethics commonly found in indigenous tribal cultures, having existed in relative balance with their environment:

- Care for earth: ensure abundant resources for survival and continuation of all life on earth, with perhaps an emphasis on the life in the soil.
- Care for people: respect and value humanity, communities, and oneself.
- Fair share: Set limits to consumption and reproduction and redistribute surplus to those in need. Value staying within limits.

The design system Permaculture is a concept that leads to creating sustainable societies based on the functioning of natural ecosystems. It has many similarities and overlaps with Lovins' emphasis on design processes drawn from nature [20].

"For many people, myself included, the above conception of permaculture is so global in its scope that is usefulness is reduced. More precisely, I see permaculture as the use of systems thinking and design principles that provide the organizing framework for implementing the above vision. It draws together the diverse ideas, skills and ways of living which need to be rediscovered and developed in order to empower us to move from being dependent consumers to becoming responsible and productive citizens." [22].

The permaculture vision differs from most traditional societies that mostly evolve through trial and error by better focusing on understanding the interrelationships between things and using them to human advantage. This is called design: how to place different elements of the system in space and time in order to optimize the beneficial relationships. In short, it is thinking of energy optimization. This is the key tool of permaculture systems enabling a decrease in energy use while still maintaining a comfortable and healthy lifestyle.

Permaculture is a new paradigm for creating new civilizations. Permaculture seeks to build a new way of thinking, but is also centered on key values. It approaches the world with a different way of viewing things. The point of view shares more with the ecologist than with current neoclassic economic thought. Basically, it is a mode of viewing the world which underlies the theories and methodology of science in a particular period of history, that is to say a paradigm.

1.5.1 Strategies for change embedded in Permaculture

In [10], Jared Diamond says "[T]he values to which people cling most stubbornly under inappropriate conditions are those values that were previously the source of their greatest triumphs." Many people who are aware of our high energy lifestyles stay optimistic and believe in a "technology miracle", that is to say we will discover some way of "green tech" that will enable us to continue our current growth [24]. Permaculture more fundamentally, was predicated on the likelihood of some degree of collapse and breakdown in technology, economics and even society, which is actually a current reality for many people around the world. Going to a less energy intensive lifestyle is both inevitable and desirable if caring for the earth is part of our value system.

Bottom-up redesign processes. When one thinks of change, there are different levels of action, because the powers to drive things are dispersed in governments, markets, economy, society, international treaties, lobbies, scientific research, technologies, communication, etc. Most countries, even those classified as "democratic", are actually run by relatively small groups of politicians, which makes it hard for simple electors to communicate their ideas. One has to clearly identify our different means of action and estimate the degree of efficiency of each. A citizen can invest in government propositions, lobbies, but can also choose to change his buying habits, communicate in his neighborhod or simply change his living choices. All level of actions are important to investigate. But ideally, following the design principle "start small", permaculture emphasizes bottom-up "redesign" processes, starting with the individual and household as the drivers for change at the market, community and cultural level. Change is more a matter of changing individual psychology and reflexes. Local resilience is the priority. Rather than having a centralized food production system with few farmers, a system of local production with many part time farmers is a primary goal of the design process.

Build on new myths and values. "We can't solve problems by using the same kind of thinking we used when we created them" Albert Einstein. "Two types of choices seem to me to have been crucial in tipping the outcomes [of the various societies' histories] towards success or failure: long-term planning and willingness to reconsider core values. On reflection we can also recognize the crucial role of these same two choices for the outcomes of our individual lives" Jared Diamond [10].

Societies are built on myths and conceptions that are vehicles for values. The main obstacle of change is the way people think, and conceive of things. In other words, the conatus principle (H2).

The permaculture movement uses the permaculture flower to symbolize its principles. The the core values of permaculture are at the center of the flower the petals represent sustainable techniques and technologies used to realize those values.

Use existing wealth to rebuild natural capital. "Natural capital is easy to overlook because it is the pond we swim in. One can live perfectly well without ever giving a thought to the sulfur cycle or wetland functions. Only when the benefits nature provides are disrupted do we take notice." [20].

"The economies of the Earth would grind to a halt without the services of ecological life-support systems, so in one sense their total value to the economy is infinite" [8].

Soil fertility is the key to a healthy ecosystem [6, 38], thus a healthy society. That is why when one thinks of strategies to build a new society that would live sustainable, it is most important to consider the land uses and farming practices.

Permaculture gives priority to using existing wealth to rebuilding natural capital, especially trees and forests, as a proven storage of wealth to sustain humanity into a future with less fossil fuel. The first rule of sustainability is to align with natural forces, or at least not try to defy them.

Holistic Management: assure long term investments Pre-industrial societies are design models for resilience. Pre-industrial sustainable societies provide models that reflect the more general system design principles observable in nature, and relevant to post-industrial systems. For example fields were cultivated in China for 4000 years without loss of yield [11].

Inefficiency of the current dominant system is masked because growth and progress are measured in money, and money does not give us information about ecological systems, it only gives information about financial systems. Permaculture emphasizes holistic management techniques which include broader measures of human activity than currency (see Section 1.2).

1.6 21st Century Strategies

In the 21st century, we have seen the U.S. invade Iraq possibly in anticipation of eminent oil shortages as Japan did in the 20th century. We have seen political uprisings in Tunisia, Egypt, and Syria where local oil production has peaked and oil is becoming increasingly unaffordable.

The town of Güssing, Austria, population approximately 4000 transitioned to 100% renewable energy sources between 1994 and 2001. They did not institute a carbon tax, nor did they sign any international treaties. In the 1990's the price of fossil fuels was relatively low. Güssing was in one of the poorest regions of Austria with few local jobs. Many people who lived in Güssing worked in Vienna. The local authorities considered how they could revitalize the local economy and create jobs. They decided a transition to 100% renewable energy would save money and create jobs. The plan worked. Not only were local jobs created, but Güssing acquired technology which today is exported by the firm Güssing Renewable Energy GmbH. Güssing benefited from subsidies from the European Union for regional development. There was a strong collaborative effort by the villagers. What they could not pay for, they did themselves.

Güssing's example shows that it is possible to transition to renewable energy sources, it suffices to make renewable energy the goal and perhaps accept different lifestyles. More generally, we could use peak fossil fuel production as a catalyst for transitioning to a sustainable economy in the spirit of permaculture. By this we mean that we would like to transition to a society which damps large secular cycles. This entails transitioning to a society which stays away from limits. Therefore a cultural change is necessary because the natural tendency of Hypothesis (H1) must be restrained. Cultures exist in which (H1) is restrained. For example hunter gatherer societies, handle constraints in food and resources by voluntarily reducing population in times of resource stress (frequently through infanticide). Thus the aborigines of Australia have maintained an oral tradition that is 15,000 years old. In the Pyrenees a culture without growth existed for many centuries based on primogeniture. Only the eldest son in a household was permitted to marry and procreate. His brothers and unmarried sisters were expected to work for the family without reproducing.

To transition to a sustainable economy there are two key points we emphasize: The first is that there is not a unique solution. The second is the local nature of solutions. Solutions will change with respect to the local climate, terrain, culture, and resources.

We believe that the primary difficulty in transitioning is fighting those who would like to continue on the current trajectory of fossil fuel production and use along with the goal of economic growth. Homer-Dixon notes in [23] that the masters of the dominant energy form of an age dominate that age. In the 18'th century the Dutch mastered wind. The 19th century was dominated by the coal powered British and the 20th century was dominated by petroleum powered U.S. and Soviet Union. Why didn't the Dutch quickly adopt coal or the British adopt petroleum? Homer-Dixon attributes the lack of change to installed capital which would have had to be changed, another version of the conatus principle.

1.6.1 Technology

There is much technology available today, or which could be available shortly which would mitigate an energy shortage and some of the associated problems. We stress that any use of technology will reach limits if population continues to expand. Therefore there is no technological fix. The only fix can be cultural in that we change our culture to a culture without growth.

Composting toilets. One of the most important important aspects of ecoagriculture is dry toilets which conserve fresh water, improve soil quality, replace chemical fertilizers. When combined with composting, dry toilets eliminate pathogenes, are odorless, and destroy toxic chemicals [26].

Negawatthours All forms of energy production have drawbacks. Güssing's first step in attaining 100% renewable energy production was to reduce consumption by 50%. Currently an astonising proportion of energy is wasted. The most environmental form of energy production is the negawatt, that is, producing less energy.

According to the U.S. Energy Information Administration (EIA), 48% of household energy consumption in the U.S. for 2009 was used for space heating and cooling. We know how to weatherproof buildings using green architectural techniques which could reduce the quantity of energy spent on space heating and cooling considerably.

Electrical storage. A frequent objection to renewable power generation is that the source is intermittent, therefore is not feasible to use renewable power as the unique power source because electric power cannot be stored cheaply. This is not true. It is true that batteries which currently offer the highest energy density have high cycle cost. Technologies that have low cycle cost are:

- Pumping water. About 70% efficient but requires a great deal of space.
- Fly wheels. Today they spin in a vacuum and have magnetic bearings. Very flexible to use, but require a large initial investment.
- Heat pumped electrical storage. A relatively recent idea which should be relatively cheap. Energy is stored using a temperature difference. To store

electricity the heat pump uses a gas to create a temperature difference between two insulated containers, one hot high pressure container, the other a cold low pressure container. To recover the energy, the system works in reverse the gas expands from the high pressure tank into the low pressure tank driving a gas turbine (or the equivalent) creating electric power. Thermal mass is added to the containers to reduce temperature extremes.

High altitude wind power. Wind is both stronger and more regular at high altitude. High altitude wind has the potential of being cheaper and more respectful to other species than terrestrial wind turbines. The challenge to implementing high altitude wind power is to program computers how to fly kites or gliders. Contraction in oil production will undoubtedly reduce aircraft orders creating a glut in airospace engineers. These engineers would be well suited to find commercial solutions to high altitude wind power production.

1.6.2 Marketing

Combining concerns about climate change and an energy constrained future leads to very persuasive marketing if symptoms of peak fossil fuels are correctly communicated. Articulating the future lack of ecodiversity and bleak prospects of continued dependence on fossil fuels contrasted with the possibility of a dynamic local economy based entirely on renewable energy could sway many consumers. The price of renewable energy has been falling relative to that of fossil fuels and if Uppsala Global Energy Systems predictions are even close to being believed, this trend will continue [33, 1]. From a climate change point of view, the goal is to decrease the price of fossil fuels below their production cost which will decrease the financial and political clout of the fossil fuel industry.

Güssing's example is being followed by many so called transition towns. These towns are showing leadership that will be followed by others. Anticipating future changes facilitates transformations. When considering which energy source is the cheapist, one must consider how relative prices will evolve in the future. Since a coal fired power plant lasts about 40 years, one should seriously consider how the price of coal (and its transport) will evolve relative to a renewable source in the next 40 years before deciding whether the choice is really cheaper than renewable energy.

As renewable resources become the dominant energy source during the 21st century, many 20th century myths will be shattered. This will create an opportunity to change cultures and economic goals.

Permaculturists emphasis on food seems quite relevent as many farms require subsidies, either government or private, in order to produce [39]. This means that our food supply is much more fragile than the relative cost of food suggests.

1.6.3 Crises and Opportunities

We believe the probability that the current financial system collapses to be high. As an insurance policy, parallel local economies should be developed, perhaps with local currencies, that are able to provide essential services such as food and transportation in the event of a collapse. Perhaps such things as education could be provided in a parallel setting as well. For example permaculture design courses could be organized. Workshops in constitutional law should also be organized. Étienne Chouard correctly advocates practicing writing constitutions in the case of a government collapse. Usually when a government collapses people are not ready with a new constitution and politicians whose policies failed are able to seize power on their own terms.

Many ways of reaching collective decisions are being actively studied in acedamia [30, 7]. People should be actively thinking about new financial systems adapted to economic stagnation or contraction. Transparent ways of incorporating broader economic measures into our economic decision making must be thought out.

1.7 Conclusion

Many strategies for an energy constrained future are being actively carried out today, sometimes unknowingly. The most constructive are those implemented by transition towns strongly motivated by permaculture design ideas. Many people are not aware that much current social stress is caused by the current stagflation phase of petroleum production and even less aware that these forces will accentuate in the coming years as we move into contraction. In order to transition to a sustainable economy, cultural change is required. Currently we respect and praise a person who achieves great personal wealth. We must learn to respect and praise those who live rich and fullfilling lives without excessive use of resources. We are living in a time of great challenges, but opportunities are opening for reevaluating our goals.

Appendix A

We prove some basic results about general economic production functions and cost share.

A.1 Economic Production Functions

A.1.1 Definitions and Hypotheses

Let $Y(t)$ be the economic production of an economy expressed in currency where t denotes time. We make no assumptions about the structure of the economy other than the existence of a well developed monetary system to determine the distribution of wealth. Let $\mathbf{q}(t) \in \mathbb{R}^d$ be the measurable quantities in the economy (quantities with a price). We will make use of the following assumption:

H1

$$Y(t) = Y(\mathbf{q}(t), t) \tag{A.1.1}$$

is locally $C^1(\mathbb{R}^d \times \mathbb{R} \mapsto \mathbb{R})$ with $\mathbf{q}(t) = (q_1(t), \ldots q_d(t)) \in \mathbb{R}^d$. Prices are locally $C^1(\mathbb{R}^d \times \mathbb{R} \mapsto \mathbb{R})$ functions of quantities.

Remark A.1.1. 1. *The regularity assumptions are not essential to the theory developed below, their purpose is to simplify notation.*

2. *In the real world, $d = d(t)$. Care must be taken when applying results to new quantities or disappearing quantities.*

H1 is not a strong assumption, as the very fact that GDP is measurable, means we measure certain quantities and use prices to evaluate the value added by the domestic economy.

Let $p_i(t)$ be the cost per unit of $q_i(t)$ and let c_i be the *cost share* or *intensity* of q_i in the economy,

$$c_i(t) \stackrel{\text{def}}{=} p_i(t)q_i(t)/Y(t). \tag{A.1.2}$$

We make the following definitions.

Definition A.1.1. 1. *We will say that a currency is* adjusted for inflation *with respect to the variable q_i if $\dfrac{\partial p_i}{\partial q_i} = 0$.*

2. *A quantity* q_i *is called a* super linear motor *of economic growth if* $\dfrac{\partial c_i}{\partial q_i} < 0$ *in a currency adjusted for inflation with respect to* q_i.

3. *A quantity* q_i *is called a* drag *on economic growth if* $\dfrac{\partial c_i}{\partial q_i} > 1/q_i$ *in a currency adjusted for inflation with respect to* q_i.

Remark A.1.2. *The cost share of economic motors decreases in times of economic growth and increases in times of economic contraction.*

Definition A.1.1 is an artificial construct to simplify the proof and statement of Theorem A.1.1. However, during the 20th century, adjusted for inflation in the standard way, the price of oil and other commodities were highly volatile around a constant average [15], while their cost shares decreased and the economy grew, making them strong candidates for being economic motors.

We will denote by $Y_{q_i}(u) = Y_i(\overline{\mathbf{q}}_i(t), t, u)$, with $\overline{\mathbf{q}}_i(t) \in \mathbb{R}^{d-1}$, consisting of q_j, $j \neq i$, the quantity

$$Y_{q_i}(u) \stackrel{\text{def}}{=} \int_0^u \frac{\partial Y}{\partial q_i} q_i'(s)\mathrm{d}s. \tag{A.1.3}$$

We denote by $Y_u(u)$ when the above integral is with respect to the last variable. We define the functions $p_{q_i}(u)$ and $c_{q_i}(u)$ similarly.

The function $Y(t)$ can also be seen as a function of the prices $Y(\mathbf{p}(t), t)$, $\mathbf{p} \in \mathbb{R}^d$. When the above derivatives and integrals are with respect to p_i, they will be denoted $Y_{p_i}(u)$, etc.

For any function $x(t)$ and $(t_0, t_1) \in \mathbb{R}_+^2$, we define the *index* of x:

$$I_x(t_0, t_1) \stackrel{\text{def}}{=} x(t_1)/x(t_0). \tag{A.1.4}$$

A.1.2 Elasticity

Elasticity, or how quantities scale in the economic production function is very important. Suppose $d = 1$. One can write $Y(t) = Cq^{\alpha(t)}$. If $\alpha(t) \equiv \alpha$, a constant, then the production function is homogeneous of degree α and we call α the elasticity or scaling factor. If $\alpha = 1$ Y is *linear* in q, if $\alpha < 1$, Y is *sublinear* in q, otherwise, Y is *superlinear* in q. Scaling factors are important in many sciences and mathematics. One looks for constant or average scaling empirically by normalizing quantities at a start date, taking logs and performing linear regression.

A.1.3 Main Theorem

We prove

Theorem A.1.1. *Assume (H1), then*

1. *If* $\alpha_i(t)$ *is the scaling factor of* q_i, *then* $\alpha_i(t) - 1$ *is the scaling factor of* p_i/c_i.

2. *Assume that c_i is constant. Then sublinear scaling of Y in q_i occurs if and only if $p_i(q_i)$ is monotone decreasing, linear scaling implies price is independent of q_i, and superlinear scaling occurs if and only if $p_i(q_i)$ is monotone increasing.*

3. *Super linear economic motors have superlinear scaling in Y, economic drags have sublinear scaling in Y.*

4. *The greater $\dfrac{\partial Y}{\partial q_i}$, the smaller the scarcity rent in the in the sense of* (A.1.8) *(see discussion below).*

5. *The quantity $\dfrac{\partial Y}{\partial q_i}$ is negative if and only if q_i is a drag on economic growth. If q_i is a motor of economic growth, $\dfrac{\partial Y}{\partial q_i} > 0$.*

6. *The index of $Y_{q_i}(u)$ for any $(t_1, t_2) \in \mathbb{R}^2_+$ is given by*

$$I_{Y_{q_i}}(t_1, t_2) = I_{p_{q_i}}(t_1, t_2) I_{c_{q_i}}(t_2, t_1) I_{q_i}(t_1, t_2). \tag{A.1.5}$$

7. *The index of $Y_{p_i}(u)$ for any $(t_1, t_2) \in \mathbb{R}^2_+$ is given by*

$$I_{Y_{p_i}}(t_1, t_2) = I_{q_{p_i}}(t_1, t_2) I_{c_{p_i}}(t_2, t_1) I_{p_i}(t_1, t_2). \tag{A.1.6}$$

Proof. From (A.1.2) one immediately obtains

$$p_i(t) = c_i(t) Y(t)/q_i(t). \tag{A.1.7}$$

Properties (1) and (2) can be read directly from (A.1.7). Property (3) is also clear from (A.1.7) since for an economic motor, a negative cost share derivative means the cost share decreases with constant price implying superlinear scaling in Y. A similar statement holds true in the case of an economic drag.

Taking the derivative of (A.1.7) one obtains

$$\frac{\partial p_i}{\partial q_i} = \frac{\partial c_i}{\partial q_i}\frac{Y}{q_i} + c_i \frac{\dfrac{\partial Y}{\partial q_i} q_i - Y}{q_i^2}. \tag{A.1.8}$$

The scarcity rent of a quantity varies inversely to its importance in the economic production function in the following sense. The more important a quantity in the economic production function, the greater the partial derivative of Y with respect to that quantity. But from (A.1.8), we see that the price is an increasing function of the partial derivative of Y with respect to q, or price decreases as quantity decreases, a negative scarcity rent [1]. This proves (4).

[1] Of course, for an important quantity one would expect the derivative of the cost share to be strongly negative and dominate the positive term

Solving (A.1.2) for Y, taking logs, and then the partial derivative with respect to q_i, one obtains

$$\frac{\partial Y}{\partial q_i} = Y\left(\frac{\frac{\partial p_i}{\partial q_i}}{p_i} - \frac{\frac{\partial c_i}{\partial q_i}}{c_i} + \frac{1}{q_i}\right). \tag{A.1.9}$$

The sign of the left hand side of (A.1.9) is the same as the sign in parentheses on the right hand side. Using a currency adjusted for inflation with respect to q_i the first term in parentheses is 0, this proves (5). To obtain (A.1.5), we multiply (A.1.9) by $\frac{\mathrm{d}q}{\mathrm{d}t}/Y$ and integrate from t_1 to t_2 and take the exponential of the resulting equation. The proof of (A.1.6) is similar. □

Remark A.1.3. *1. Equation* (A.1.8) *should not be considered a precise model because different quantities in the equation move at different speeds. Prices move more quickly than does the reaction of the economy to price changes.*

2. Equation (A.1.5) *can provide a method for measuring the relative contribution of a quantity in $I_Y(t_1,t_2)$ in cases where $c_{q_i}(t)$ or $c_{p_i}(t)$ can be estimated. Note that*

$$I_Y(t_1,t_2) = I_{Y_u}\prod_{j=1}^{d} I_{Y_{q_j}}(t_1,t_2). \tag{A.1.10}$$

Note also that the order in which $I_{Y_{q_j}}(t_1,t_2)$ is computed in (A.1.10) *can change it's value because this changes the values of the $q_i(t)$, $i \neq j$ in* (A.1.5).

3. In most cases one has

$$I_{c_{q_i}}(t_1,t_0) \leq I_{c_i}(t_1,t_0). \tag{A.1.11}$$

In order for the inequality to be strict in (A.1.11), *another independent quantity must increase. See Section A.2.*

4. If useful work $U = eE$ is used as a variable, we can write $Y(U(t)) = Y(e(t)E(t))$ (A.1.7) *becomes $p_E = c_E Y(eE)/q_E$. One sees that energy efficiency increases the price per unit of energy assuming $c_E(t)$ remains constant. We thus have a very simple explanation of the empirically observed Jevons paradox or the rebound effect [27, 4].*

5. The "cost share theorem" from neoclassic equilibrium theory [3, Appendix A] says that cost share is proportional to the scaling factors of the variables in the production function equation. Equation (A.1.9) *suggests strongly that in a growing economy a large scaling factor should be associated with a shrinking cost share, thus the interaction between variables gives some variables larger scaling. We can think of many reasonable scenarios in* *which this theorem is not verified (see Section A.2). We believe that the hypotheses from which the cost share theorem is derived are speculative and that empirical evidence should be inspected carefully before accepting this theorem.*

A.2 An Example

We suppose a very limited economy produces 3 quantities: $q_1 = E$, $q_2 = G$, and $q_3 = F$. We assume prices are adjusted for inflation for the 3 quantities and we normalize all prices to one. The size of this economy is

$$Y(t) = \sum_{i=1}^{3} p_i q_i \tag{A.2.1}$$

$$= E + G + F. \tag{A.2.2}$$

Now suppose that E is a motor of economic growth in the following sense, when E grows 10% this produces a growth of 5% in both G and F in the next time period. Growth in G has no effect on E or F. However F is a drag on economic growth since a 10% growth in F causes a 5% percent contraction in E and G. We can name our quantities to make the example more realistic. We call E energy production, which permits us to produce more of G and F. Let us call G gold production and F fun production. Fun decreases growth in E and G because in fact many people do not like producing energy or mining for gold, so as soon as there is a fun event, they stop work to enjoy the fun which reduces production of E and G.

Let us assume that $t = n \in \mathbb{N}$ and that the initial conditions are $E_0 = G_0 = F_0 = 1$. Now assume that population growth would cause growth of 10% in each time period, but the interactions occur in the next time period. Thus $E_1 = G_1 = F_1 = 1.1$ but $E_2 = 1.21 - .055 = 1.155$ because of the fun interaction. We have $G_2 = 1.21 - .055 + .055 = 1.21$ and $F_2 = 1.21 + .055 = 1.265$. We see that the cost share c_E has dropped from 1/3 to 0.32, c_G is unchanged and c_F increases from 1/3 to .35, while $I_Y(0, 2) = 1.21$. Computing the index of each quantity separately (assuming the other quantities constant at the t_0 value, that is, assuming the index is computed as if it was computed first in (A.1.10)) we find $I_{Y_E}(0, 2) \approx 1.1$, $I_{Y_G}(0, 2) = 1.07$, and $I_{Y_F}(0, 2) \approx 1.04$. Note that $c_{q_1}(q_2(t_0), q_3(t_0), t_1) \approx 0.366 > c_E(t_1) = 0.32$ so that $I_{c_{q_1}}(t_1, t_0) < I_{c_E}(t_1, t_0)$. This is because E does not explain all the growth in Y. The individual scaling factors of E, G, and F are respectively .52, .35, and .19. Repeating the calculations with $E_0 = G_0/2 = F_0/2 = 1/2$, we obtain $E_1 = .55$, $G_1 = 1.1$, $F_1 = 1.1$, $E_2 = .575$, $G_2 = 1.21$, $F_2 = 1.26$. With these initial conditions, c_E decreases from .2 to .19, c_G is almost unchanged and c_F increases from .40 to .41. In this case $I_Y(0, 2) = 1.22$ so that a smaller initial cost share of the economic motor produces greater overall growth. From these initial conditions, the individual scaling factors of E, G, and F are .5, .42, and .28 respectively.

Remark A.2.1. *Not all quantities that drag on economic growth are fun.*

Bibliography

[1] Kjell Aleklett. *Peeking at Peak Oil*. Springer, 2012.

[2] Robert Ayres and Benjamin Warr. REXS: A forcasting model for assessing the impact of natural resource consumption and technological change on resource consumption. *Structural Change and Economic Dynamics*, 2006.

[3] Robert Ayres and Benjamin Warr. *The Economic Growth Engine: How Energy and Work Drive Material Prosperity*. Edward Elgar Publishing, 2009.

[4] Robert U. Ayres and Benjamin Warr. *Energy Efficiency and Sustainable Consumption: The Rebound Effect*, chapter Energy efficiency and Economic Growth: the 'Rebound Effect' as a Driver. Macmillan, 2009.

[5] Ugo Bardi. *The Limits to Growth Revisited*. Springer, 2011.

[6] Claude Bourguignon. *Le sol la terre et les champs*. Sang de la Terre, 2008.

[7] F. Brandt, V. Conitzer, U. Endriss, J. Lang, and A. Procaccia, editors. *Handbook of Computational Social Choice*. Cambridge University Press, 2015.

[8] Robert Costanza, Ralph d'Arge, Rudolf de Groot, Stephen Farberk, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Suttonkk, and Marjan van den Belt. The value of the world's ecosystem services and natural capital. *Nature*, 387:253–260, 1997.

[9] Charles Darwin. *The Voyage of the Beagle*. John Murray, 1845.

[10] Jared Diamond. *Collapse: How Societies Choose to Fail or Succeed*. Penguin Group USA, 2011.

[11] Franceys et al. A guide to the development of onsite sanitation. Technical report, W.H.O., Geneva, 1992.

[12] Evan Fraser and Andrew Rimas. *Empires of Food: Feast, Famine, and the Rise and Fall of Civilizations*. Free Press, 2011.

[13] Jörg Friedrichs. Global energy crunch: How different parts of the world would react to peak oil scenario. *ScienceDirect, Energy Policy*, 38:4562–4569, 2010.

[14] Nathan Gagnon, Charles Hall, and Lysle Brinker. A preliminary investigation into the energy return on energy investment in the global oil and gas industries. *Energies*, 2:490–503, 2009.

[15] Gérard Gaudet. Natural resource economics under the rule of Hotelling, 2007. Presidential address delivered at the 41st annual meetings of the Canadian Economics Association.

[16] G. Giraud and Z. Kahraman. How dependent is growth from primary energy? Output energy elasticity in 50 countries. Working Paper.

[17] Stephan Haggard and Marcus Noland. *Famine in North Korea: Markets, Aid, and Reform*. Columbia University Press, 2007.

[18] Charles Hall, Stephen Balogh, and David Murphy. What is the minimum EROI that a sustainable society must have. *energies*, 2:25–47, 2009.

[19] James Hamilton. Causes and consequences of the oil shock 2007-08. *Brookings Papers on Economic Activity*, 2009.

[20] Paul Hawken, Amory Lovins, and Hunter Lovins. *Natural Capitalism: Creating the Next Industrial Revolution*. Little, Brown, & Company, 1999.

[21] David Holmgren. *The Essence of Permaculture*. David Holmgren, 2002. Free download http://holmgren.com.au/downloads/Essence_of_Pc_EN.pdf.

[22] David Holmgren. *Permaculture: Principles and Pathways Beyond Sustainability*. Hepburn, Victoria: Holmgren Design Services, 2002.

[23] Thomas Homer-Dixon. *The Upside of Down, Catastrophe, Creativity and the Renewal of Civilization*. Random House of Canada Limited, 2006. http://www.theupsideofdown.com.

[24] Rob Hopkins. *The Transition Handbook: From Oil Dependency to Local Resilience*. Chelsea Green Publishing, 2008.

[25] Rob Hopkins. *The Transition Companion: Making Your Community More Resilient in Uncertain Times*. Chelsea Green Publishing, 2011.

[26] Joseph Jenkins. *The Humanure Handbook*. Joseph Jenkins Inc., 2005.

[27] William Stanley Jevons. *The Coal Question (2nd ed)*. London: Macmillan and Co, 1866.

[28] R. T. Kingsford, J. E. M. Watson, C. J. Lundquist, O. Ventor, L. Hughs, E. L. Johnston, J. Atherton, M. Gawel, D. A. Keith, B. G. Mackey, C. Morley, H. P. Possingham, B. Raynor, H. F. Recher, and K. A. Wilson. Major conservation policy issues for biodiversity in oceania. *Conservation Biology*, 2009.

[29] Reiner Kümmel. *The Second Law of Economics, Energy Entropy and the Origins of Wealth*. Springer, 2011.

[30] Jean-François Laslier and Remzi Sanver, editors. *The Handbook on Approval Voting*. Springer, 2010.

[31] Frédéric Lordon. *Conatus et institutions : pour un structuralisme énergétique*. Presses de Sciences Po, 2003.

[32] Frédéric Lordon. *La Société des affects Pour un structuralisme des passions*. Seuil, 2013.

[33] Amory Lovins. *Reinventing Fire: Bold Business Solutions for the New Energy Era*. The Rocky Mountain Institute, 2011.

[34] Karl Marx. *Value Price and Profit*. New York International Co., 1969.

[35] Donella Meadows. *The Limits to Growth*. Universe Books, 1974.

[36] Donella Meadows, Jorgan Randers, and Dennis Meadows. *The Limits to Growth: the 30 year update*. Earthscan, 2005.

[37] Bill Mollison and David Holmgren. *Permaculture One*. Corgi, 1978.

[38] David Montgomery. *Dirt: The Erosion of Civilizations*. University of California Press, 2007.

[39] Jaclyn Moyer. What nobody told me about small farming: I can't make a living. Salon, 2015. http://www.salon.com/2015/02/10/what_nobody_told_me_about_small_farming_i_cant_make_a_living/?utm_source=digg&utm_medium=email.

[40] David Murphy and Charles Hall. Energy return on investment, peak oil, and the end of economic growth. *Annals of the New York Acadamy of Sciences*, 1219:52–72, 2011. Ecological Economics Reviews.

[41] Dmitry Orlov. *Reinventing Collapse: The Soviet Example and American Prospects*. New Society Publishers, 2008.

[42] Thomas Piketty. *Capital in the 21'st Century [Capital au XXIe siècle]*. Seuil, 2013.

[43] D. B. Reynolds. *Scarcity and Growth Considering Oil and Energy: An Alternative Neo-Classical View*. The Edwin Mellon Press, 2002.

[44] Douglas Reynolds and Jungho Baek. Much ado about Hotelling: beware the ides of Hubbert. *ScienceDirect*, 34(1):162–170, 2011.

[45] Julia Schindler. What is permaculture? a handful of opinions given under the shadow of environmental crises. Master's thesis, Agrocampus Ouest, Rennes, 2011.

[46] Staff. Southern California permaculture convergence website, 2013. https://www.facebook.com/SoCalConvergences.

[47] Peter Turchin and Sergey Nefedov. *Secular Cycles*. Princeton University Press, 2009.

[48] D. Weissback, G. Ruprecht, A. Huke, K. Czerski, S. Gottlieb, and A. Hussein. Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants. *Science Direct*, 52:210–221, 2013.