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Is ‘Renewable Energy’ a Myth?

A Comparison between Muscle Work and Agrofuel Energy in Agricultural Production

Andreas Roos

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Human Ecology Division
Department of Human Geography
Faculty of Social Sciences
Lund University

Author: Andreas Roos
Supervisor: Alf Hornborg
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Department:	Human Ecology Division, Department of Human Geography
Address:	Geocentrum I, Sölvegatan 10, 223 62 Lund
Telephone:	046-222 17 59

Supervisor:	Alf Hornborg

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Abstract:

This study emerges from the rising concern that the now widespread faith in renewable energy systems—as a way to deal with the ecological crisis—may be unfounded. Drawing on inspiration from the global peasant movement Via Campesina and their hypothesis that small-scale agriculture is a strategy for “cooling down the Earth”, this study seeks to discuss the reasons for the widespread belief in renewable energy systems based on how they differ from animate energy systems that have proven successful in the past. As a basis for discussion, the energy efficiency—measured in “energy return on energy investment” (EROI)—of a traditional agricultural system driven by muscle work is compared to the energy efficiency of a modern day agriculture driven by agrofuel. The results show that the energy efficiency of a traditional agriculture driven by muscle work is ten times more energy efficient than modern day agriculture driven by agrofuel. With the theory of techno-fetishism and the concept of ecologically unequal exchange it is argued that agrofuels may be a mechanism for capital accumulation by the unequal exchange of energy dispersion in the world economy. In contrast, traditional small-scale agriculture driven by muscle work may be a promising energetic foundation for local societies and a potential healing strategy for environmental justice, based on its ability to accumulate biomass on Earth. Finally, drawing on these results and discussions, this study critically analyses the principally Western beliefs that underscores the global installation of renewable energy systems as a valid strategy for a just and sustainable future.

ACKNOWLEDGEMENTS

First and foremost I would like to thank my family who have supported me tremendously in every way imaginable throughout my years of studying (which is more or less my whole life). In my family I also count Anna Plowman whom I would like to thank for the many inspiring evenings of discussion in our square cave by the sea. An extra thanks goes to my sister Cecilia Roos for reviewing this thesis, and for continually being an endless source of inspiration. I also wish to extend my deepest gratitude to all inspiring people in the CPS program whom I feel have helped me greatly in sensing what is most important in the world. I truly hope that these two years was only the beginning.

Four years ago I enrolled in the basic course in Human Ecology with a hunch that it might be an interesting subject, and today I can barely imagine whom and/or where I would be if I had not. As such, my deepest appreciation is extended to the Human Ecological Division for providing a great learning experience. Andreas Malm, Pernille Gooch, Alf Hornborg, Vasna Ramasar and Anders Burman: Thank you for all of your inspiring lectures and idiosyncrasies, and an extra thanks to Alf for your great support and encouragement as my supervisor.

TABLE OF CONTENTS

TABLES AND FIGURES

1 INTRODUCTION

“Complexity is a problem-solving strategy ”
Joseph Tainter

“What I’ve observed is that nature builds on previously established levels of complexity. This is a great general natural law that your own senses will confirm for you, but that has never been allowed into the canon of science”
Terrence McKenna

“The sun has driven the development of life on Earth for billions of years, so why do we believe that we will be able to construct machines more efficient at capturing solar energy than photosynthesis?”
Alf Hornborg

1.1 Agriculture: an ancient renewable energy system

Quite recently the global peasant movement Via Campesina[1] released a booklet with the title *Small Scale Sustainable Farmers are Cooling Down the Earth,* in which they argued that small-scale agriculture could be seen as a strategy for “cooling down the Earth” (Via Campesina 2009). This “bold hypothesis”, as Martinez-Alier (2011:151) called it, has for me worked as an incentive to explore the idea that the most efficient means for an ecologically harmonious and socially just society have everywhere already existed for millennia. If small-scale agriculture is “cooling down the Earth”, why are we[2] debating solar panels as opposed to garden plots? Why are we meddling with carbon capture and storage? And why is nuclear energy even on the agenda? It seems, even with the increasingly visible effects of social-ecological decline, that the reason why nations and regions would prefer one above the other is not altogether clear. I believe, however, that this can become more clear by looking deeper into the conjunction of history, culture and power. As such, this study is at once an attempt to further the understandings of what renewable energy systems really are, what we think they are, and how we can understand them in contrast to agricultural systems that have undergone millennia of evolutionary testing.

My inspiration for this topic is manifold, but no one that I know of has reflected upon this notion more provocatively than Staffan Delin (Delin 1985). In an attempt to compare what he calls the “technology of nature” with the “technology of humans” Delin concludes the following:

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[1] A global peasant movement advocating for local based agricultural subsistence.
[2] A rhetoric “we” pertaining to the global wealthy/North.

> You could of course calculate what it would require to develop a technology equal to those of the plants. You would then find that plants are approximately a hundred billion billion times better than our industrial technology when it comes to putting atoms into useful structures. Therein lies the explanation to the fact that they can draw on sunlight in order to build themselves from waste. Another conclusion is that the ability of the plants to handle atoms leaves little to be wished for. It is simply not possible to develop a better technology than that which they are already using. This means that even if we theoretically would be able to develop an ideal technology, we would still not be able to surpass the technology of the plants. In turn, this means that we already now have access to the best technology we could possibly imagine (Delin 1985:49-50, my translation).

Thus, plants and animals can be seen as remarkably more efficient and productive than any human-made technology, and we can deduce that humans have throughout millennia interacted with this 'technology'[3] in different ways either as foragers, cultivators, pastoralists or extensive agriculturalists[4] (see Smil 1994). Hence, agriculture can be seen as one of the first human-induced renewable energy systems solely and truly based on organic energy. The muscle work of humans and draft animals in combination with the photosynthetic ability in plants as well as the active, living components of the soil and the atmosphere make up the foundations for the very complex ecological (energy) system that we call traditional agriculture.

Nikiforuk writes that "[a]griculture was, after fire, the world's first energy innovation" and "[w]hen it took off nearly ten thousand years ago, it created a truly Promethean revolution" (Nikiforuk 2012:75). As such, agricultural systems in different shapes and forms may indeed have functioned as the energetic basis for almost all past civilisations (see Smil 1994; Nikiforuk 2012)[5]. In the words of Smil "animate labor and the kinetic energies of water and wind were the only prime movers before the diffusion of industrial civilization fueled by coal" (Smil 1994:93). Only fossil fuels, it seems, could displace the agricultural energy systems that had been the 'provider' of energy (or food, clothing, shelter, etc.) for societies for thousands of years. Hence, it was only recently, with the rise of fossil fuel intensive inputs,

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[3] Single quotation marks (' and ') are used throughout this study to mark that a word is used aesthetically and/or figuratively.

[4] Extensive agriculture is characterised by small inputs and low labour requirements, and it is used here to contrast 'intensive agriculture'.

[5] Agricultural cultivation as an energy system have not always been socially just. Slavery, for instance, can in some sense be seen as the example *par exellence* of the power relations and the domination needed for the upper classes to maintain their positions as exergy originated from slave work, or rather, the agricultural produce it made possible (see e.g. Wolf 2010:315-317; Moore 2007). During a certain period in the Roman Empire slaves were more or less seen as "humans reduced to the state of sources of energy" (Hughes 2007:31).

that agriculture became—as Via Campesina argues—an energy *consuming* rather than an energy *producing* activity (Smil 2000;Via Campesina 2009). Indicative of this shift was that agriculture became dependent on the stocks of energy from the Earth's crust whereas it before had been based on the organic flows of energy from the Sun running through ecosystems.

Contemporary agriculture, apart from being an energy consuming activity, is above all a financial activity endorsing high yields/profits based on artificial nitrogen, monocropping, pesticides and biotechnology. In the course of history, however, the two hundred years (at the most) of mechanical agriculture is a very short time and the increasing levels of carbon in the atmosphere, the rift in the global cycle of nitrogen and the rate of biodiversity loss as well as the pending effects of peak oil and uncertainties of genetic manipulation begs for the modern model of agriculture to be reconsidered (Wackernagel et al. 2002; Rockström et al. 2009; Shiva et al. 1999; Murphy & Hall 2010). The step to consider agriculture again as an energy producing activity is thus a leap that is not far at all. Not surprisingly, current proponents of renewable energy systems suggests precisely this, but the focus is not on small-scale traditional agriculture driven by muscle work but on agricultural work driven by *liquid agrofuels*[6] such as ethanol and biodiesel. It has been argued that mechanical agriculture can function as the basis for the transformation of organic energy into fuel meant to drive further mechanical work (Demirbas 2008, 2009; Puppán 2002). It has also been argued that such a process might contribute to the 'development of the global South' (Shepley 2009; Swedbio 2009).

Thus two different 'strategies' seem to offer the same principle, i.e., *that work can be based on organic energy*, but with the decisive difference that one is pertaining to mechanical work while the other is pertaining to muscle work. Agriculture facilitates an interesting intersect from which I in this study will discuss the larger concern of technological progress and the faith in renewable energy systems as opposed to the faith in biological system and local traditional solutions. But can technology really be based on organic energy? Why would mechanical work and not muscle work be the favourable choice? There are numerous questions and equally many ways of approaching this issue. In this study, however, I will attempt to contrast a contemporary agriculture based on liquid agrofuels with a traditional

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[6] Throughout this study I refer to agrofuels rather than biofuels which is a broader term that can also include e.g. firewood and dung. Agrofuels are, on the other hand, explicitly referring to fuels based on agricultural produce.

agriculture[7] based on the muscle work of humans and draft animals. The foundation upon which this discussion will be built will be my own calculations on energy efficiency and land requirements derived from secondary data.

1.2 The emerging critique on renewable energy systems

The increasingly accepted measures to mitigate the ecological impact of human societies have over the past years manifested in a number of technologically sophisticated renewable energy systems. Photovoltaic solar power, wind power, hydropower and agrofuels, such as biodiesel or ethanol, are some of the preferred alternatives that have been suggested to someday displace fossil fuels as the foundation for a 'new continued' civilisation in which human societies world-wide will live from the organic energy flows derived from the heat of the Sun (Jacobson & Delucchi 2011; Delucchi & Jacobson 2011; Schwartzman 2012). A wide range of social groups stand behind these solutions, and the cry is surprisingly similar across the ideological spectrum (see e.g. Schwartzman & Schwartzman 2011; ESMAP/World Bank 2013). The general idea seem to be that with only enough political determination, the transition to an all renewable society will be well underway. Although with different societal outlooks and objectives ideological friends and foes rally behind the flag of renewable technologies that have been described as energy efficient, fossil fuel mitigating and environmentally sustainable.

There are pragmatic reasons to admire the consensus around renewable energy systems (I must admit that I certainly do), but in the face of still rising social-ecological costs and inequalities, the Promethean action plan centring on *technological* solutions becomes increasingly dubious. A shift in the human relation to biophysical limits and boundaries through renewables is, it seems, not taking place as initially expected. This becomes apparent not only in the figures from official environmental reports such as those from the Intergovernmental Panel on Climate Change (2013) or the WWF (2014), or from various scholars (Schaffartzik et al. 2014) but even more so through the voices of the marginalised social groups upon whom the ecological crisis is created through exploitation and abuse (Ferguson 1990; Bunker & Ciccantell 2005; Shiva 1991). It is often agreed that political change must accompany technological change, but where the political change has taken place—the technologies in question seem to be exclusively available for the global wealthy

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[7] Traditional agriculture is throughout this study defined as a form of cultivation that is based locally, with little or no use of technology but very knowledge intensive.

(Smil 2000:14). This reflects a different type of relation between technologies and politics. One where technology is not ‘allowed’ or ‘discouraged’ by political policy but made possible through the very inequalities facilitated by the global political landscape (Hornborg 2001, 2010, 2014).

A body of scattered literature forms the generic critique[8] towards the notion of a continued civilisation run by renewable energy. From what I have gathered these can be presented as five overarching concerns that each undermines the notions of renewable energy systems as renewable, fossil free, efficient, feasible and politically neutral. These are:

- Processes of production and discarding (Zehner 2010)
- Fossil fuel dependency (York 2012; Smil 2009; Murphy & Hall 2010:110)
- Land and labour requirements (Pimentel 2008a)
- Transition inertia (Smil 1994, 2008)
- Environmental injustice (Hornborg 2014a)

Albeit theoretically smaller in magnitude than the ecological devastation of the fossil economy, renewable energy systems pose non-negligible social and ecological issues. Specific issues of production linked to these technologies are the mining for raw materials, infrastructure requirements and discard of obsolescent infrastructure (Zehner 2010). Also, when considering the renewable energy systems transition, one “both inexplicably neglected and extraordinarily important” issue is the matter of coke-production (Smil 2009). Coke as a key necessity in steel production requires the burning of coal, and still no feasible alternative exists (Ibid.). Without a hundred percent recycling rate[9] of steel materials, societies based upon energy from technologically advanced systems will therefore remain dependent on the burning of fossil fuels. Being one of the main components of nearly all modern infrastructure, including the structures of solar power, wind power and dams (see Jacob & Delucchi 2011a, 2011b), steel might just be the largest material challenge yet for the installation of an all renewable future.

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[8] The critique presented here is critique derived from scholars and social groups who are concerned over the social-environmental effects of modern civilisation. I do not include e.g. pro-fossil or pro-nuclear positions as part of this critique.

[9] However, due to the second law of thermodynamics—that everything tends to heat equilibrium and entropy—a hundred percent recycling of matter is not possible (see Horborg 2014a for a discussion).

A more well known problem with solid theoretical and empirical underpinnings (see Luxemburg [1913] 2003; Fischer-Kowalski & Haberl 2007) is that new energy systems have not displaced fossil fuels (York 2012; Murphy & Hall 2010:110). Instead they have typically being included as sources of energy on top of fossil fuels, and thus increased overall energy expenditures. With regards to some fuels, it is even disputed whether they require higher amounts of energy than they return to society. The production of ethanol from sugarcane or corn has been included in various contentious debates regarding this matter (see Pimentel 2008b). David Pimentel who is among the most well known scholars investigating agrofuels has also argued that a shift to renewable energy systems from fossil fuels will require more labour and more space that in turn inevitably "will compete with agriculture, forestry, and urbanization for land" (Pimentel 2008a:12). Another contention has been raised by energy expert Vaclav Smil who argues that a transition to all-renewables is not as fast a process as some would have us think (e.g Jacobson & Delucchi 2011; Delucchi & Jacobson 2011), but a process that likely "will unfold across decades, not years" (Smil 2008).

Lastly, the matter of *whom* these technological systems are for is a highly relevant and important issue both with regards to social and ecological health and justice. It is important to note that advanced renewable energy systems do not come cheaply. This simple observation explains why 80 percent of all renewable energy derived from solar power technologies is produced "in five of the world's richest nations (Germany, Italy, Japan, USA and Spain)" (Hornborg 2011:21). It also helps to explain why the largest renewable energy projects, utilising technologies solar photovoltaics, are pushed to implementation in the cloudiest places on Earth (Smil 2000:14). While the benefits of the technology in question are attributed to the global wealthy, the detriments are typically displaced to the global poor where dumpsites and labour come readily available and cheap (Hornborg 2011:21). It is, in other words, not anyone's land or labour that is/would be appropriated in a future that derives its energy from renewable energy systems. Global environmental injustices such as these have been theorised to not simply be a result of global capitalism but a vital necessity for the existence and continuation of capital accumulation (Hornborg 2001, 2011, 2013).

In short, it becomes increasingly unclear whether technologically sophisticated renewable energy systems are as auspicious as they seem. Taken as a whole the critique presented above seem somehow to point at an increasing social-ecological instability that is derived from complexity (Tainter 1988), i.e. increasingly more sophisticated ways to capture energy for societal use/throughput. But what validates this complexity? Why does it seem like the only alternative? My intention throughout this study is not to further the idea of fossil fuels or a nuclear utopia in line with certain ecomodernists (Breakthrough Institute 2015), but to make room for discussing precisely *why* these technologies seem, in some sense, to be the only solution at hand. I believe they are not.

1.3 Research questions

This study is guided by the following three questions:

1. *How does a traditional agriculture powered by muscle work (humans and draft animals) differ from a modern day agriculture powered by agrofuels in terms of energy efficiency?*
2. *Based on the result of the first question, how does (i) a tractor driven by agrofuels and (ii) muscle work of humans and draft animals differ as agricultural prime movers with regards to sustainability and environmental justice?*
3. *Based on the answers to the first two questions, are there any reasons to doubt the feasibility of a future society sustained purely by the energy from renewable energy systems, such as solar photovoltaics?*

1.4 Purpose

The main purpose of this study is to scrutinise to what extent renewable energy systems are efficient and sustainable, and maybe more importantly, why we think they are efficient and sustainable. I believe that it is only by critically reflecting upon the core beliefs of Western culture that any real change in the now largely unhealthy human relation to other beings can really take hold. Technology, to which so much faith is given, is central for understanding the relation between modern societies and the environment of which they are part. By taking the concept of techno-fetishism as a point of departure I assume that much technology is imbued with an unfounded affection that forms specific taken-for-granted assumptions regarding its nature, and that these assumptions can say something about the larger cultural context in which they appear (see Hornborg 2001).

Another, yet equally important, purpose for this study is to forward the understanding of local based solutions, primarily for the so-called ‘global North’ or world economic ‘core’. It is, in what Wallerstein (2004) calls the “core” of the world economy that I believe change is most due. This is where the neo-colonial project of development is conducted and where the destructive notions of affluence and Cartesian separation of mind and body largely is upheld (Ferguson 1990; Sahlins 1997; Plumwood 2005). Indeed, the so-called ‘global South’ have almost always been better off without external (colonial) influence (see e.g. Wolf 2010; Bryant & Bailey 2005; Shiva 1991). This is not to dismiss local efforts and marginalised groups in the world ‘periphery’. On the contrary, by drawing on non-violent inspiration (as opposed to resources) from other place-based efforts the core regions of the world may mitigate some of the harm that perpetuates the ecological crisis.

One specific aspect running throughout this study is the sense of an intrinsic ‘efficiency’ in all living beings. This notion is very closely related to the notion that all species are interconnected. Interconnectedness as such is a surprisingly ‘mainstream’ ecological ‘fact’ whose further implication for humans[10], and the ecology of humans, have not nearly received the same scientific or cultural status (see e.g. Miller & Spoolman 2012). It is therefore, lastly, the purpose of this study to also further the understanding of what it means when we say that humans too are part of nature, specifically with regards to technology, muscle work and efficiency.

1.5 Structure

After the introduction (section 1) follows a section (2) outlining the methodology and research methods. In this section, after a brief note on methodology, the comparative method and the method for energy analysis are described, as well as how I chose my material and limits. In the following section (3) the theoretical framework, largely based upon the concept of techno-fetishism, ecologically unequal exchange and the ‘principle of Podolinsky’ is presented. In this section the core concepts of the study as well as some common phrases that needs explanation are also presented. In the fourth section (4) the two agricultural models are analysed and compared. The fifth section (5) brings together the theoretical framework and the empirical material in an analysis concerning the research questions. This is followed by a conclusion (section 6) that ties back to the research questions and reflects again on the larger issues posed in the introduction. A final section (7) presents the bibliography.

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[10] That humans too are connected and dependent upon other species and therefore *the same* as other species.

2 RESEARCH METHOD

This section is meant to provide the reader with an idea of how I chose to answer the questions previously raised. After a brief note on methodology follows a sub-section (2.2) explaining how I make use of the comparative methods and the case study method as well as the outline of the overarching research design. This is followed by a sub-section (2.3) explaining what material I chose and why, and later an additional sub-section (2.4) describing the EROI method for energy analysis. Lastly, sub-section 2.5 reflects on some of the limits of this approach and study.

2.1 A note on methodology

In this study I adopt a critical realist position. Critical realism, as developed by Roy Bhaskar (2008, 2011), first and foremost insists on a separation of ontology and epistemology. This means that any description of the social, be it a discourse or an event, is confined within (or emerging from) a certain way of knowing it, i.e. a certain epistemology. From this perspective, “empirical regularities” cannot occur outside of a certain closed context. Instead of empirical truths, it is the structures and mechanisms that produce and reproduce social events that are of interest (Bhaskar 2008:15-20). For this study this means that it is not only the energy calculations that are of importance, but also what social-ecological relations and structures the calculations can be said to represent when compared with each other. The problems and opportunities that arise with this comparative viewpoint, and the way that I have addressed them, as well as the general outline of the study will be discussed in the following sub-sections.

2.2 Comparative methods and the case study method

The comparative research method requires the comparison of at least two or more cases, and is therefore closely related to the case study method (Lijphart 1971:691-693; Seawright & Gerring 2008; George & Bennet 2005). The typical comparative approach seeks to find cases for comparison that are as similar as possible, or rather, cases that “resemble each other in all respects but one” (George & Bennet 2005:151). This type of “controlled comparison” is based on the principle that there is only to be one independent variable explaining the dependent variable. Such an ideal comparison of cases is not common, and some have even argued that they cannot exist (George & Bennet 2005:152-153). That said, the cases for this study have been chosen largely because they are as similar as can be.

In this study the analysis will mainly be revolving around differences in the energy flow and also (to a limited extent) embodied land of two agricultural systems (two cases). These cases are situated in two different contexts and thus have a number of different independent variables that can explain the presumed varying flows of energy. Here, the role of theory becomes important for the comparison. In this study, theory will be used to explain the connection between energy efficiency and different independent variables, such as social or ecological structures (see George and Bennet 2005:235-237). Theory will also help to explain the presumed contrast between the cases. In other words, concepts and structures will be derived from the theoretical framework to create a conceptual toolbox on which the analysis will be based (Figure 1). In combination with this, I will in this study; "[f]ocus the comparative analysis on the 'key' variables" and employ a technique of "scanning" (Lijphart 1971:690-691). Through this technique all (what I consider to be) major independent variables will be considered, but the final discussion will be focusing on the variables that seem to hold the largest significance for the research questions of the study.

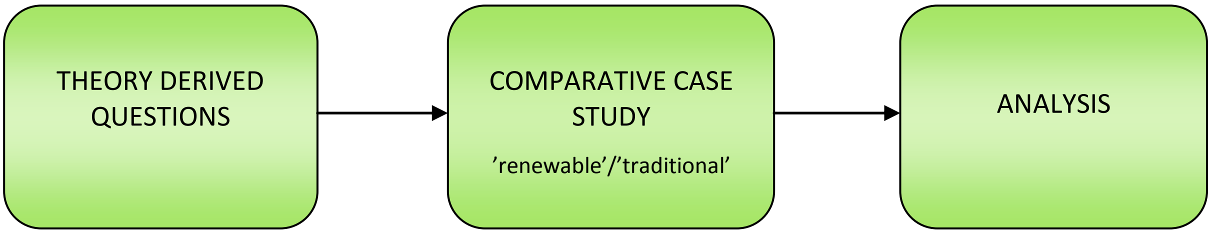

Figure 1. The overarching research design of this study.

In any comparative approach that draws on a small number of cases the problem of "over-determination" (over-generalisation) and "sampling bias" usually appears (Moses & Knutsen 2012:111-116). These are potential problems also for this study. There are two generic solutions to the first problem; (1) increase the number of cases or (2) reduce the number of independent variables. In this study I will do both. I will reduce variables, or rather, "use theories more vigorously to help in choosing only the most likely (important) variables" (Moses & Knutsen 2012:113). I will also include other prime movers as sources for in-case comparison (and therefore increase the number of cases) that will help contextualise the role of the renewable fuel and the muscle work. These measures, I believe, will also reduce potential sampling bias that threatens generalisability (see Moses & Knutsen 2012:113-114).

In addition, I will in a sub-section of the discussion specifically analyse the generalisability of my results. Mostly, however, I am interested in the contrast between two cases, and the mechanisms and structures that this contrast can be theorised to emerge from.

2.3 Note on demarcation and material selection

This study is based upon quantitative secondary data measuring energy and land requirements. Finding data on energy flows and embodied land is surprisingly hard considering its analytical value. Due to the limited amount of data available—not only for the contemporary case but even more so for the traditional case—I base my material upon the energy and labour analysis of a traditional U.S. wheat cultivation typical around 1800-1820 originally calculated by Leo Rogin (1931), but presented in a compiled and revised form by Vaclav Smil (1994:90). This not only means that I will use this source as data, but also that these calculations will determine the rough boundaries of my material, i.e., they will guide how the two agricultural systems are to be defined. Rogin not only calculates agricultural practices between 1800 and 1820, but bases his research on data from later agricultural practices in order to access the consequences of the proliferated use of farm machinery in 19th century New England, U.S. The analysis for this study is, conversely, interested in what Rogin describe as the "hand method", i.e., the agricultural practice that was dominant precisely prior to farm mechanisation and industrialisation that took place in New England after 1820. Consequently this is an agricultural practice in which technology is not utilised. [11] This demarcation is intentional since it defines what I in this study call traditional agriculture (see Smil 1994).

While the case of traditional agricultural cultivation is based on data from actual agricultural systems, the agriculture driven by renewable fuels is a hypothetical case. This means that it is not based upon the data of one or several specific systems, but a compiled case from the average practices common in the production of winter wheat, and in the utilisation of biodiesel. Real cases will likely deviate from the energy analysis here due to several reasons, e.g., due to different uses of fertilisers, soil composition or fuel blends, and I do recognise this limit. The forming of hypothetical cases to reflect the average agricultural practice is, however, not uncommon (see e.g. Pimentel 2006).The latter case is, in addition, built from a

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[11] Technology is throughout this study distinguished from tools. My understanding of this distinction is that in contrast to technologies, tools do not necessitate specific social relations of unequal exchange (Hornborg 2001). Tools are in this sense available locally for anyone (democratic) if one knows how to make them, and therefore almost exclusively made from local material (Mumford 1963).

somewhat broad spectrum of sources ranging from official sources to studies on life-cycle-analysis. Some of the most influential sources from both cases are lined out and described here briefly:

The Introduction of Farm Machinery by Leo Rogin[12]

This study by Leo Rogin, a North American economist and economic historian, is an attempt to provide an empirical basis for understanding the productivity of labour, or more precisely, how the introduction of machinery affected labour requirements in North American wheat cultivations in the 19th century. The basis for the study is a comparison between two cultivation methods, one from the beginning of the 19th century (1790-1820) and one from the end of the 19th century. The data used is originating from *The Thirteenth Annual Report of the Commissioner of Labour on Hand and Machine Labor* of the U.S. Department of Labor in 1898 (see Rogin 1931:ix).

United States Department of Agriculture (USDA)

USDA is a federal executive department responsible for the development and management of U.S. agriculture, forestry and food. This department offer several databases with statistics and information ranging from matters of food nutrition to environmental policy. In my study I have primarily retrieved data from *The Economic Research Service* (ers.usda.gov).

The works of David Pimentel

From being a consultant of the USDA (in the 1970s) David Pimentel is today a professor at the Department of Entomology, Systematics, and Ecology at Cornell University. Since the 1970s Pimentel has been one of the more prominent scholars investigating the energetic and environmental concerns regarding modern agriculture, and agrofuels in particular. From the works of Pimentel I have derived figures that specifically require the compilation of several factors and data units, for example energy embodied in machinery.

Energy in Farm Production

This book edited by Richard Fluck is the sixth and final volume of an “international energy reference book series” by editor-in-chief B.A. Stout. The purpose of this book series is to

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[12] The full title is: *The Introduction of Farm Machinery in Relation to the Productivity of Labor in Agriculture of the United States during the Nineteenth Century.*

> bring together in a concise form the basic principle and the most relevant data concerning both the efficient use of energy in agriculture and the food industry and alternative energy sources for agriculture (Fluck 1992:vi).

This specific volume centres, among other things, around the energy requirements of agricultural inputs, and have therefore proven very useful for this study.

2.4 Energy analysis: energy return on energy investment

The primary tool to be used to prepare a comparative ground for the cases of this study is the calculation model *energy return on (energy) investment* (EROI). The pioneer of this model of energy analysis was Sergei Podolinsky, a Ukrainian physician and Narodnik[13] activist whose work will be considered in depth in section 3. Podolinsky did not explicitly call his calculations by the name of energy return on investment, or EROI. Instead the first to explicitly use this calculation model by its current name was Charles Hall in his "dissertation analysis of the energetics of migrating fish" in the 1970s, along with research by Cutler Cleveland, Robert Costanza and Robert Kaufmann (Murphy & Hall 2010:103). Apart from early significance in works of researchers such as Howard Odum and Roy Rappaport, the method has had little attention according to Hall (2011:1774).

So what does EROI calculate? In essence, EROI calculates the amount of energy that is returned to human society in relation to how much energy it requires to acquire that energy. It is, in essence, a calculation of sustainability in energy terms. For example: if it requires a higher amount of energy, say 2 barrels of oil, to access a specific energy source that only returns 1 barrel of oil, the phenomena and/or fuel in question needs to be fed with energy from elsewhere in order to sustain. An EROI ratio of 1:1 (expressed as 'one to one') means that the fuel in question can only provide energy to cover the initial energy "costs". This is unsustainable because the energy source in question then cannot provide for the requirements of human society (agriculture for food, education, arts etc.). EROI is, one can say, a method for calculating the ratio of surplus energy. Surplus energy, argues Charles Hall, is so vital for the continuation of all living species under "selective pressure" that it can be regarded as a natural law; "the law of minimum EROI" (Hall et al. 2009:30). This law reads as follows:

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[13] The Narodniks were a predominantly Russian, socialist peasant movement most active during the 1860s and 1870s who advocate that it was the role of the peasants (farmers) to overthrow the monarchy.

> Every plant and every animal must conform to this iron 'law' of evolutionary energetics: if you are to survive you must produce or capture more energy than you use to obtain it, if you are to reproduce you must have a large surplus beyond metabolic needs, and if your species are to prosper over evolutionary time you must have a very large surplus for the average individual to compensate for the large losses that occur to the majority of the population. In other words every surviving individual and species needs to do things that gain more energy than they cost (Hall et al. 2009:29).

From this quote it becomes more clear how EROI is linked to the concept of a sustainable society, i.e., there must be some type of a net energy surplus, for every plant, for every animal and for every society. The minimum EROI required for a sustained liveable society, however, has been estimated to be 3:1, which is higher than the break-even point at 1:1 (Hall et al. 2009). A higher EROI ratio than 3:1 generally means that a larger portion of energy can be distributed to other sectors than the energy sector/or to energy transforming (production) activities. Thus, a higher EROI is also typically being thought to correlate with a higher well-being[14] (Lambert et al. 2014).

The method of calculation as such is very simple, but the “devil is in the details” (Hall et al. 2009:26). The primary difficulty with the method is to decide the boundaries of the system that should be subjected to the energy analysis (see Figure 2). More accurately, the boundaries of the denominator, or the “energy input”, are the most difficult to determine. Since energy is in constant flow, a complete calculation of EROI would begin with the energy radiated from the sun followed through the system in question and end with the dispersion of energy into outer space. It is therefore necessary to determine some type of boundaries for analytical purposes (unless we want to calculate the EROI of the Earth). Hall, among others, have proposed different levels of “openness” with regards to the denominator and to the EROI calculations of different energy sources (see Murphy & Hall 2010:103-106). The boundaries of the energy analysis have in this study to be considered carefully in relation to the theoretical framework, meaning above all, that energy embodiments of inputs will be considered.

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[14] Though one must also consider the societal distribution of the energy and the benefits that energy surplus entail.

$$\text{EROI} = \frac{\text{Energy returned to society}}{\text{Energy required to get that energy}}$$

Figure 2. The equation used to calculate "energy return on energy investment" (inspired by Hall et al. 2009:26).

Through the analysis of energy dissipated and embodied in the products of the agricultural systems, the step to also consider embodied land and embodied labour is not far. It will be possible, without any extra data to determine e.g. the energy embodied per hectare of wheat, or the embodied labour of the traditional system. The renewable system—because it is more complex—will however require additional data on both embodied land and labour.

Lastly, all the data gathered in this study will be presented in tables. This is a simple technique that makes the quantitative aspects of the energy analysis much easier to overview. It is also a technique that has been widely used among those who study energy flows (see e.g. Pimentel 2006; Hall et al. 2010; Pimentel & Patzek 2005; Rappaport [1968]1984:44-52).

2.5 Limits

There are some limits to this study. First, there are specific concerns which the outlined research model does not include. Biodiversity, cultural diversity, land quality, water management and governance are just a few phenomena that the energy analysis does not explicitly consider. The energy analysis as a tool is not developed to the point where it is typical to include the long-term energy losses of declining biodiversity in an ecosystem or for the "fertilizer needed to restore soil fertility for the significant soil erosion" occasioned by agriculture, although "such arguments are likely to be much more important in the future" (Hall et al. 2009:27). In line with this, I found, there is also room to improve upon understandings of how embodied land relates to energy efficiency. These are all important limitations. Some, but not all, of these limitations will be discussed or mentioned as important and related issues in the final discussion. Second, the fact that I in this study attempt to investigate agrofuels—as opposed to some other renewable energy source—can be considered limiting in that it may be what Lijphart (1971:692-93) calls a "deviant case", which tend to "deviate from established generalizations". This, however, is debatable as we shall see in the discussion. In addition, it is primarily the *contrast* between agrofuels and its traditional equivalent (muscle work) that is of interest for this study. Other studies following the same method could, for instance, compare solar photovoltaics with photosynthesis, modern water power with watermills or modern wind power with sails, and perhaps reach similar conclusions.

3 THEORY

This section presents some of the primary concepts and theoretical foundations for this study. The first sub-section is concerned with the idea of techno-fetishism (3.1); the second with world system theory and ecologically unequal exchange (3.2); and the third with the principles of the human body and energy in agriculture as developed by Sergei Podolinsky (3.3). These three make out the overarching theoretical framework for this study. Sub-section four (3.4) is intended to provide an overview of the concepts to be used in the discussion, and sub-section five (3.5) is intended to provide definitions of words and phrases that are used throughout the study.

3.1 Techno-fetishism

To understand the concept of techno-fetishism it could be useful to first look at its origins. It is believed that the phrase fetishism (*feitiço,* in Portuguese) was first used in fifteenth century Portugal as a word to describe the practice of magic and that it later was applied by the Portuguese to the worshiping of objects among "people whom they encountered along the west coast of Africa" (Hornborg 2001:132). The phrase was picked up in the 1760s by Charles DeBrosses, and later adopted in the works of Karl Marx who primarily used the phrase to describe how “commodities appear as autonomous sources of value rather than embodiments of the labor of human persons” (Hornborg 2001:133). This insight, writes Hornborg, “was one of Marx's most remarkable achievements”, pertaining in particular to the way Marx turned the earlier condescendingly laden phrase of fetishism as a mirror to reflect the everyday life in industrial society, and thereby providing the first “anthropologically informed, cultural critique ... to Western power structures” (Hornborg 2001:134). Marx thus used the phrase commodity fetishism, or money fetishism, to describe the cultural illusion that commodities and money seemingly generate value in and of themselves. More important for this study, however, is the concept of machine or technological fetishism (henceforth referred to as techno-fetishism) as developed by Alf Hornborg (2001, 2010, 2011).

According to Hornborg, modern societies are caught in a collective illusion that mystifies the understanding of what technology really is. Here, one of the central ideas is that technology is not primarily the product of ingenuity or design, as is commonly held, but rather the product of specific social relations. Ingenuity and design are both necessary, but “definitely not ... *sufficient*”, for the development of modern technology (Hornborg 2015a:16, my translation). More than the product of ingenuity, technology is instead the product of unequal exchange in the world system. Unequal exchange is at once the *precondition* for and the *outcome* of modern technology, and it is maintained by continually being "represented as reciprocal" through the cultural notion of market price (Hornborg 2001:44). This is a crucial point, because it means that technology is not to be seen as an “index of productivity”, but rather as “an index of accumulation” (Hornborg 2001:151; Hornborg 2011:3). In other words, we must see technology not as efficiency, but as appropriation. Appropriation of time and space from elsewhere is not a side effect of the machine, but a necessary social condition for its existence; machines *are* unequal exchange.

It is believed that an important precondition for the proliferation of the industrial revolution in the 1850s Britain was precisely the unequal exchange of space (land) and time (labour). Britain could through certain exchange rates (market prices) displace the environmental and social loads required in the production of the raw materials for the early garment industry to the slave plantations in North America. This has been proposed by Hornborg (2007) who has calculated that through importing raw cotton (among other materials and products) from North America and exporting manufactured textiles, Britain could liberate “over 6 million hectares ... that would have been required to generate the equivalent amount of revenue from woolen manufactures” (Hornborg 2007:268). The outcome of this unequal exchange was capital accumulation, and with it, the expansion of the technological infrastructure in the form of factories and wage labour that made way for further capital accumulation. The technology (in this case factory machines) employed in this recursive dynamic of capital accumulation cannot be separated from the process, the symbolism and the material flows imbued in the wider context of the capital accumulation it at once sprang from and recreated. Here it would be good to quote Hornborg in length in order to understand techno-fetishism in this larger context of capital accumulation.

> The modern phenomenon that I refer to as machine fetishism tends to represent ... structures of exchange as external to the technologies 'themselves.' I argue that this is an illusion.

> 'Prices,' 'wages,' 'interest': all these categories are symbolic constructs that are essential elements in the material operation of modern, industrial technology. No less than the ritual shell sacrifices or beer parties of the Inca emperor, they represent culture-specific, symbolic strategies for making claims on other people's resources. As such, they are inextricably interfused with the material aspects of the accumulative processes that they orchestrate. No less than Inca ritual, the vocabulary of our economic institutions and the concomitant structures of exchange are *an integral part of the technology* [...] To propose that we are no less bedazzled by the machine than the Inca peasant was by his emperor certainly defies common sense. After all, the machines *do* work, don't they? Yes, but in the eyes of the participants, so did Inca ritual. In neither case is there a doubt that these social arrangements were or are efficacious; the question is *how* they work (Hornborg 2011:152).

To reveal techno-fetishism is therefore ostensibly similar to understand systems as in system's thinking where “the properties of the parts are not intrinsic properties, but can be understood only within the context of the larger whole” (Capra 1997:37). “Ultimately ... there are no parts at all” (Ibid.), or as in this case; “there is... no technology as such” (Hornborg 2015a:9, my translation), only patterns in a “web of relationships” (Capra 1997:37). To assume that material forms (e.g. technologies) can be separated from the social relations (e.g. unequal exchange) that created them is delusive (Hornborg 2015a:14). As such, the concept of techno-fetishism can be seen as a tool to scrutinise some core cultural, economic and biophysical premises of the modern world system as interconnected conceptions of capital accumulation and relations of power. That techno-fetishism is ultimately a matter of culture and semiotics (signs) becomes more clear also in the above-mentioned quote. It is, in essence, the *beliefs* projected on technology and technological progress that forms the conditions for its existence, and thus the conditions for the unequal exchange it necessitates. That we[15] cannot see this fundamental aspect of what technology really *is* reflects a deeply pervading techno-fetishism at the heart of the ecological crisis.

3.2 World systems theory and ecologically unequal exchange

Studies on social metabolism (material flows in and between societies) have shown that unequal exchange can be seen as a reality that not only shaped inequalities in past societies and cultures, but also stratifies wealth in the contemporary world economy (Fischer-Kowalski & Haberl 2007; Weisz 2007). An understanding of techno-fetishism is often combined with this analytical framework of social metabolism and world systems theory in seeking to

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[15] The dominant modern culture.

understand the role of technology in different world regions. To understand the world economy from this outlook is in principle to understand it as a “zero-sum game” by which the capital accumulation in one part of the world entails the capital deficit in another part of the world (Hornborg 2009). This view has its roots in the dependency school of the 1950-70s that in essence understood the development of one world region to be dependent on the underdevelopment of another, and vice versa (Frank 1966). Today, the legacy of this school and line of critical thinking lives on primarily in Immanuel Wallerstein's world systems theory, but also in the work of Stephen Bunker in his insights on the role of “extractive” and “productive” economies (Wallerstein 2004; Bunker 2007). It is in the work of Wallerstein, however, that we find the three phrases core, periphery and semi-periphery to represent different world-segments of capital accumulation. Core and periphery are the two phrases that represent the segment of the world economy *to* which capital flows (core), and the segment of the world economy *from* which capital flows (periphery). Wallerstein, seeing the ambiguity of this distinction, introduced the notion of a semi-periphery that was then understood to embody qualities indicative of both the core and the periphery. The adoption of a world systems perspective is in part a protest against the classical analytical division of the world into nation states. It is also, and maybe more importantly, a theory employed to analyse the world system as a capitalist world economy based and upheld by inequalities and an international division of labour (Wallerstein 2004).

Within this wider understanding of global inequalities we find a range of scholars researching environmental justice and the unequal distribution of social-environmental loads in the global arena (see Martinez-Alier 2001; Foster et al. 2010; Hornborg 2011). One central concept for the understanding of environmental in/justice is the concept of *ecologically unequal exchange*. This concept is based on the central premise that the neoclassical economic perception of exchange is flawed in that it does not take into account the exchange of biophysical flows of energy. It is somewhat disputed precisely what the ‘ecologically’ means in the concept of ecologically unequal exchange . One still persisting issue with regards to this definition is whether to understand it in terms of values at all or simply to be content with understanding the flows of biophysical terms of energy, land or labour. The primary proponent of the latter position is Hornborg (2014a, 2014b) who opposes both the eco-Marxist’s and neo-Physiocrat's readily defined understanding of value, i.e., the labour theory of value and the energy theory of value (Foster & Holleman 2014; Foster et al. 2010:61-64; Costanza 2004). Instead, he argues, we should understand value as culturally mediated in lines with the understanding of certain anthropologists like Marshall Sahlins (1997), in order to not confuse the analytical levels of cultural perception and biophysical flows of energy[16]. This is a necessary precondition for relating cultural projections of value and biophysical elements to each other (Hornborg 2014a:80-83). The "ecologically" in ecologically unequal exchange according to this position is thus simply the flows of biophysical matter and energy, calculated either in emergy[17], embodied land or embodied labour. The concept of ecologically unequal exchange then refers in turn to the notion that biophysical matter and energy (not value) is distributed unequally in the world economy. It is this position and understanding of ecologically unequal exchange that will be adopted in this study.

3.3 Podolinsky's principle

The contributions of Sergei Podolinsky represent an often overlooked piece in the history of human ecology. Until the explicit mention and discussion of his contributions in Martinez-Alier's *Ecological Economics* the insights of Podolinsky were more or less forgotten over a course of nearly a hundred years. Even today, nearly thirty years since Martinez-Alier published his book, the main principle of Podolinsky remains largely unexplored.

The origins of what Martinez-Alier calls Podolinsky's principle can be found in Podolinsky's work *Socialism and the unity of physical forces* ([1881]2004). This text was simultaneously sent to Friedrich Engels and published in a range of languages between 1880 and 1883. In it, Podolinsky believed he had found a reconciliation between the Physiocrats[18] and Marx's theory of labour that could provide a foundation for the understanding of human work and energy in different modes of production (Martinez-Alier 1987:51). Engels' reply, however, proved to be less than favourable. In sum, the principle that Podolinsky put forward stated that the energy accumulated as a result of human labour would always have to be more or equal to the energy efficiency of the human body. In Martinez-Alier's (1987:70) words the principle stated that "the energy productivity of human work must be equal to or greater than the efficiency of human beings as heat engines". The perhaps more immediately relevant of

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[16] This is not to say that different cultural perceptions of value does not affect flows of energy. Rather, it is to say that definitions of value is not something that can, nor should, be imposed on people (be normative). Ultimately, no definition will be representative of the myriad of values imbued in each society, culture or person. On the cultural level Leslie White is one among the most well known authors to research the different flows of energy in different cultures, or to understand "[c]ulture as a thermodynamic system" (White 2006:139). White did, however, have a rigid linear evolutionary outlook on cultures and judged them as "high" or "low" depending on the "amount of energy harnessed per capita per year" (White 2006:143).

[17] Explained in sub-section 3.5.

[18] A French school of philosophers and economists who believed land to be the source of all wealth.

Podolinsky's insights for this study however is *how* he understood the human body to be a “perfect machine” capable of accumulating energy on Earth. To understand this we need to look closer at the arguments made by Podolinsky.

He began his assessment by asking how energy radiated from the Sun could accumulate on Earth, and how to best employ the labour of humans in order to increase the force (energy) available for societies. To understand this, there was a need to understand how human labour and energy were related. If “human labour” in line with Marx’s theory of labour "accumulates in its products a greater quantity of energy than that which was expended in the production of the labor power of the workers” then “[w]hy and how is this accumulation brought about?” (Podolinsky [1881]2004:61). Being aware of both the first and the second law of thermodynamics, he realised that no labour could, strictly speaking, ‘produce’ energy, and that everything tended to heat equilibrium. As such, labour had to be seen as the transformation of energy. He realised that “[a]ll physical *and biological* phenomena were expressions of the transformation of ... energy” (Martinez-Alier 1987:47, emphasis added). Plants in particular were to be seen as a key in understanding how solar heat was captured on Earth “without raising its temperature” (Podolinsky [1881]2004:64). He wrote that “plants in general and cultivation in particular are the most feared enemies of the dispersion of energy into interstellar space” (Podolinsky ([1881]2004:64). The last quote contains the interesting notion that humans, through "cultivation in particular" could increase the accumulation of energy (or biomass) on Earth. This was the second central notion that led to the abovementioned principle. Podolinsky demonstrated this by calculating and comparing the energy accumulation of natural pastures untouched by humans to sown pastures and wheat cultivation directed by human labour. He found that sown pastures yielded 40 calories per calorie of labour, and that wheat cultivation yielded 22 per calorie of labour, which meant that human labour could indeed increase the accumulation of energy on the surface of the Earth. In sum, Podolinsky concluded, human work could contribute to the accumulation of energy on land at least tenfold ([1881]2004:67).

To answer how this was possible, Podolinsky employed the metaphor of the human body as a machine, or a heat engine. The human heat engine could on a rough average transform into labour one-tenth (1/10) of the energy through its metabolism. This was a higher “economic coefficient” (as he called it) than that of the steam engine. More importantly, however, human labour could simultaneously increase the accumulation of biomass on Earth. In that capacity the human heat engine could feed its own boiler, or in other terms, transform the energy required for its work *through* its own work. This was, as Podolinsky proposed, a case of a "perfect machine" in the sense of Sadi Carnot, who fifty years earlier had discovered that no machine could perpetually feed its own boiler, and that such an ideal case would simply be impossible. This led him to conclude that "the human machine is a perfect machine, whereas an inanimate machine never achieves the conditions of perfection that Sadi Carnot requires" ([1881]2004:70). This also led Podolinsky to the abovementioned principle that meant that the energy productivity of human work must be equal to or higher than the energy efficiency of the average human body. If the productivity of human labour dropped below the metabolic requirements of the average human, then deprivation would occur. It was primarily in agricultural work that human labour acted as a perfect machine, but also to a degree in artisan labour that produced clothes and tools needed to hinder the dispersion of energy. Podolinsky was also keen to point out that "the only kind that really increases the quantity of energy that is available to humans, is the work done with the muscles" ([1881]2004:67). The burning of coal was a lesser option as a means to work because it dispersed vast amounts of heat into space.

The understanding of the human body as a perfect machine was simply one aspect of the broader question that Podolinsky posed in his work, namely how to best organise human societies so that the ability to increase the energy on the surface of the Earth would be best utilised. Here, Podolinsky followed Marx historical materialism suggesting first that "primitive man" simply dispersed energy into interstellar space through nourishing on fruit, roots and animals (Podolinsky [1881]2004:71). In turn, a mode of production based on slave labour required high energy expenses in its need of "multitude of guards", and "standing armies". Capitalism had taken advantage of the division of labour, but was according to Podolinsky, in a fashion, parasiting on the ability of the human body to accumulate energy. On its own, he wrote, capitalism "would produce *absolutely nothing*" (Podolinsky [1881]2004:71). Finally, socialism was the mode of production capable of satisfying "all the needs of humanity" (Podolinsky [1881]2004:71). Podolinsky's insights were received by Engels. Engels, however, wrote to Marx in principle saying that Podolinsky had simply reinvented the wheel, because all he had been able to demonstrate was the "old economic fact that all industrial producers have to live from the products of agriculture" and that there was "hardly any gain" in translating this notion into physical terms (Engels [1882]1968a). In an earlier letter to Marx concerning Podolinsky, Engels had also written that "it is absolutely impossible to try and express economic relations in physical magnitudes" (Engels [1882]1968b). Martinez-Alier contends that this response on behalf of Engels was a "missed chance" for a Marxist understanding of agricultural energetics and a labour theory that included accounts on energy flows (Martinez-Alier 1987:45-54, 2011). More generally, this has led to questions whether Marx and Engels really understood the law of entropy. Engels' replies have, however, been vigorously defended primarily by Foster and Burkett (2004; Burkett & Foster 2008) who similar to Engels view the contributions of Podolinsky to be laden with "energy reductionism" and inadequate as an attempt to unite Marx's theory of surplus value with understandings of economic and historical energy analysis. Recently, however, Foster and Holleman's (2014) have attempted to reconcile H.T Odum's concept of emergy with Marx understanding of 'use value'. Thus, as Hornborg observes, there seems to be an inconsistency in some eco-Marxist's position towards Podolinsky, who in fact was the intellectual predecessor of Odum (Hornborg 2015b).

Translated into contemporary vocabulary we can summarise by restating that Podolinsky was the first to do calculations on the EROI of agriculture and established the basis for understanding the energy metabolism of societies and different modes of production (Martinez-Alier 2011). On a final note it should also be mentioned that Martinez-Alier (2011) has demonstrated and discussed how the principles of Podolinsky can be found again today in the terminology of Via Campesina. This, in particular, is very interesting since it suggests that the now largely forgotten ideas drawn by Podolinsky more than a hundred years ago seem to be both evident and vital for small-scale farmers and activists today.

3.4 Conceptual tools for analysis

Techno-fetishism

The mystification of what technology is, i.e., social relations of exchange.

Ecologically unequal exchange

The process by which the unequal distribution of biophysical resource such as energy and embodied land are creating an unequal distribution of environmental loads and benefits in the capitalist world economy.

Energy return on investment (EROI)

This concept/method is explained in sub-section 2.2.

The first law of thermodynamics (the law of Conservation of energy)
No energy can be created or destroyed, only transformed to other forms of energy.

The second law of thermodynamics (the law of Entropy)
Everything tends towards heat equilibrium, or entropy (less order), in isolated systems. This means among other things that (1) energy transformed is always transformed to energy of lower quality capable of less work, and that (2) in every energy conversion there is a loss of energy (dissipation).

3.5 Words and phrases

Prime mover
In the words of Vaclav Smil, prime movers "are energy converters able to produce kinetic (mechanical) energy in forms suitable for human uses" (Smil 2010a:6). Throughout time there have been both animate prime movers such as muscle work, and inanimate prime movers such as wind sails, water wheels, steam turbines and diesel generators. The most dominant prime movers in the contemporary world-economy are diesel engines and gas turbines (Smil 2010b), but the prime movers dominant in different cultures vary throughout time and space.

Exergy
Exergy is understood as the portion of an amount of energy capable of work. In every instance of work (energy conversion), one portion of the total energy is dissipated (anergy). The remaining energy capable of work is so-called high quality energy, or exergy, representing the portion of the total energy (input) capable of work.

Emergy
Emergy, or embodied energy/energy memory, is understood as "the available energy of one kind previously used up directly and indirectly to make a product or service" (see Odum 2007:68-69). Emergy is thus, broadly speaking, a measure of the energy dissipated in the making, production or emerging of a specific product, service or phenomenon.

4 EMPIRICAL FOUNDATION: ENERGY ANALYSIS

Here, the EROI of the two agricultural models will be presented after a description of their respective context. These presentations will be followed by a sub-section in which I discuss the contrasting EROIs and shortly reflect on the total yield in relation to land embodiments.

4.1 Energy analysis: traditional agriculture

The first case to be presented is a traditional agricultural cultivation common in New England during the 1800-1820s, in which “two oxen and one to four [humans] powered all the tasks”[19] (Smil 1994:90). This specific period and practice is situated precisely prior to the widespread agricultural mechanisation in the U.S., which according to Rogin (1931:21-31) began just after the 1820s with the rapid diffusion of the standardised cast-iron plow (see also, Smil 1994:70-71). This is an important point in time because it demarcates the final stages of traditional agricultural practices as they occurred before industrialisation in this specific region. The cultivation analysed is that of wheat production, or more precisely, the cultivation of winter wheat (as opposed to spring wheat or durum wheat). It is characterised by a strong reliance on the body of humans and draft animals in every step of the cultivation process. This, also called the “hand method”, was the characteristic of this cultivation model which meant that humans stood for the larger energy inputs when it came to lighter agricultural tasks such as sowing, measuring and binding, but also in medium- or light (but protracted) tasks such as harvesting by hand with sickle, threshing with a flail, and winnowing (Rogin 1931). The usage of draft animals was, it seems, mostly used in heavier duties such as plowing and harrowing; tasks that manipulated the soil more drastically. The typical New England cultivation practice was done with two oxen, as stated, yet Rogin's account also includes drafting by horses in certain regions (see Rogin 1931:234-235). Given the wide range of farm sizes at the time I have here considered the average farm to be 200 acres, which roughly equals 81 hectares (see Rogin 1931; Quaintance 1904:46-47[845-846]). Farms around a thousand acres or more were typically not subsistence farms at the time, but plantations primarily growing cotton, tobacco or other cash-crops.

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[19] It is uncertain through the records studied by Rogin whether slave labour was present in any of the cultivations. Rogin acknowledges this and argues that we should assume that there is no slave labour represented in the figures (1931:132). This ambiguity is troublesome, and ought to be kept in mind throughout this study. Still, it does not affect the energy analysis as such.

To keep draft animals was costly, both economically and energetically. Oxen required comparatively less land and energy than working horses because they did not require the same high-nutritional feed. Oxen were, however, also less productive (Smil 1994:67-68,86,91), something that becomes evident in Rogin's calculations (1931:234-235). Although high in energy costs, draft animals—just like tools, food and craftsmanship—were commonly shared in the local farming community. Through a body of literature debating the transition to industrial capitalism in rural north-eastern U.S. (see e.g. Woodruff & Clark 1992; Kulikoff 1989), it becomes clear that reciprocity was common and even had "great cultural significance" in the early 19th century (Kulikoff 1989:129). Although this period and region was not void of market exchanges and international trade, "exchange relations were embedded in a household structure that distinguished between local and long distance trade" and, as opposed to international trade, "local transactions ... were governed by mutuality and reciprocity" (Woodruff & Clark 1992:170). Hand-in-hand with a higher level of reciprocity came also a higher degree of self-sufficiency. Tools such as plows and harrows were often manufactured by the farmers themselves with local raw material (predominantly wood) and it was not uncommon to share implements (Ibid.).

Traditional agriculture in general consists, as it is described here, to a high degree of cyclical use and reuse of local resources. This was, as we have seen, the case with regards to tools but it is an equally applicable principle to traditional means of providing nutrients to the crops and the feeding of human and non-human animals alike. This has important implications for what inputs to include in this specific system (Table 1.). First, Smil (1994:54) writes that "rain, dust, weathering, and recycling of crop residues replenished withdrawals of phosphorous, potassium, and micronutrients" but that nitrogen was a bigger problem. Often, traditional agriculture "replaced nitrogen by plowing in straw or plant stalks, recycling animal and human excreta, and cultivating leguminous crops" (Smil 1994:54). There were, in other words, no energy required other than that of human and draft-animal work in recycling nutrients for the crop. Likewise, human and draft animal work were the only necessary energy inputs both for tool manufacture and domestic work. Also, considering that most farming tools were wooden or made from other plant material—with the exception of the sickle blade and occasional pieces of metal used to repair the wooden plow (Rogin 1931:231; Smil 1994:30-35,90)—the emergy embodied in metal implements have not been included in the energy analysis. While the humans typically ate that which was harvested, the draft animals ate wild (not sowed) plants during the grazing season and hay or grain during the winter period.

Table 1

Energy input in wheat production per hectare in the United States 1800-1820, driven by one to four humans and two draft animals

Input	Quantity	Energy	Emergy	Energy total
Human work	162 hours[a]	130 MJ[b]	41,8 MJ[cde]	171,8 MJ
Oxen work	64 hours[a]	333 MJ[f]	29 MJ[gh]	362 MJ
Total:		463 MJ	70,8 MJ	533,8 MJ

Sources and comments

[a] Originally calculated by Rogin (1931), but derived in compiled form from Smil (1994:90).

[b] Calculated from Smil (1994:85-86) who estimates the "net food energy cost of an average hour of labor in traditional agriculture" to be 800 kJ.

[c] Tool manufacture and repair, 15 MJ: Estimated by calculating dollars required for manufacturing and repair per farm and year from the American agricultural census' of 1800, 1810, and 1820 compiled in Towne & Rasmussen (1960:269,272), and then calculating the average of these taken together . This equals $3,5per farm and year. These expenses were used to calculate the average labour time necessary (on part of the carpenter and blacksmith).The average earnings a day for a blacksmith was $1,64, and for a carpenter $1,5, during 1815-1860 (Long 1960; Lebergott 1960:457). This equals 2,3 days of work, or roughly 18-25 hours of labour, depending on work load.

[d] Basic human metabolic requirements, 17,5 MJ: Assuming that the work load is distributed between 2,5 persons (Smil 1994:90) and that an average winter wheat harvest season spans over 7 months, this energy requirement was calculated from Smil's (1994:86) estimation of average human basal metabolic requirements, divided by the average amount of hectares per farm at the time.

[e] Everyday chores for subsistence, 9.3 MJ: Assuming that 3 hours per person are devoted to light tasks not involving agricultural work (for a discussion on the modern equivalent on this see Fluck 1992:31-36). Calculated by considering that light agricultural tasks required 20 KJ per minute (Smil 1994:86).

[f] Calculated from Lawrence (1985).

[g] Basic oxen metabolic needs, 21 MJ: An average of 1,5 kg of feed was estimated from Lawrence (1985). Considering that animals on the farm were “frequently” grazing on pastures, this should be taken as a generous average (see (Rogin 1931:231, in footnote 342).

[h] Equipement and implements for animal draft, 8 MJ: Calculation is based on wood, leather, steel and iron requirements in the maintenance of one working horse in Sweden, 1927 (Ryderg & Jansén 2002).

The yield generated through this particular cultivation were 20 bushels on an average, as indicated by Smil (1994:90). This equals 1350 kilograms of wheat grain. Yields could, however, in some regions be as large as 25 bushels (Rogin 1931:234-235). This amounts to roughly a quarter or a fifth of the wheat yields obtained in modern agricultures. Although significantly lower than modern yields, 1350 kilogram is a generous amount in relation to the energy demands of the yield. This total wheat grain yield adds up to 18750 MJ produced from 533,8 MJ expended. With a harvest of 1350 kg of wheat grain, one kilogram of wheat grain therefore took approximately 0,4 MJ to produce. The energy invested in relation to the energy returned (EROI) of the traditional system was therefore 35:1 (see table 2).

Table 2

Energy output and EROI of wheat production per hectare in the United States 1800-1820, driven by humans and draft animals

Output	**Quantity**	**Energy**
Wheat grain	1350 kg[a]	18750 MJ[a]
Total:		18750 MJ
	EROI	18750/533,8 = 35:1

Sources and comments

[a] (Smil 1994:90).

4.2 Energy analysis: modern agriculture driven by biodiesel

The second case for this study is a modern cultivation of wheat production that utilises agrofuels[20], or more precisely, biodiesel as tractor fuel. In contrast to ethanol, biodiesel is the most commonly used liquid agrofuel in tractors and for agricultural purposes. Whereas ethanol is made from sugar, from either sugarcane or corn, biodiesel is made through combining vegetable oils or animal fat with alcohol. A wide range of vegetable oils or fats can be used but the most commons are derived from either soybeans or sunflowers. In the cultivation process outlined below I have used data based on biodiesel from soy. For comparative reasons winter wheat will also here be the analytical focus of the energy analysis. Winter wheat of the 'hard red' varieties in particular are the most cultivated in the U.S. today (USDA 2014a) and the energy analysis have therefore been based on data from these varieties, when it was available.

The input sheet (Table 3) of this cultivation process shows that this it is heavily reliant on machinery as opposed to muscle work, i.e., humans or draft animals[21]. The largest direct energy input for this cultivation is the fuels used in the machinery, i.e., the biodiesel for tractation. Biodiesel is for the most part domestically produced in the U.S., though roughly 14

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[20] It could be important to note that while biomass accounts for 10 percent of the world energy supply, liquid agrofuels stands only for a small percentage of that figure (0,0019 percent of world supply). Animal dung, charcoal and firewood are still by far the most commonly used renewable agrofuels throughout the world (FAO 2008). Along with hydropower accounting for 2 percent, and "other renewables" accounting for 1 percent, these fuels make out the world supply of renewable energy. Despite these figures, liquid agrofuel production has been expected to increase (OECD/FAO 2013). In 2007, the largest producers of biodiesel were Malaysia and Indonesia where biodiesel is primarily produced from palm oil, followed by U.S. and Brazil where biodiesel is primarily produced from soybeans (FAO 2008).

[21] Embodied labour in the manufacturing, transportations and packaging of the goods used in this cultivation process is most likely considerably higher than the near eight hours indicated in the input sheet (though this is perhaps an analysis for another study).

percent was imported during 2014 according to the latest monthly review from the U.S. Energy Information Administration (EIA 2015a:152). The U.S. has from 2007 been considered a net exporter of biodiesel, though this trend shifted during 2013 and 2014. Main exporters to the U.S. are now Argentina, Malaysia and Indonesia, with Argentina being the most significant exporter due to tax incentives and lower export fees (USDA 2014b; NREL 2013). [22] Brazil, otherwise known as the major exporter of ethanol agrofuel has near zero biodiesel export, yet the domestic production and consumption remains large. In both Argentina and Brazil the production of biodiesel has been reported to contribute to "adverse social and environmental impacts" (Tomei & Upham 2009; Hermele 2009:93).

Pure biodiesel (B100) disperses less energy in combustion than both conventional diesel and biodiesel blended with diesel (B20), and is therefore seemingly auspicious as an energy input (see Table 3). This leads us, however, to the non-negligible observation that embodied energies shift the outlook of the energy analysis completely. This not only allows for the analysis of indirect energy costs indicative of fertilisers, non-domestic seeds and pesticides, but also to consider the embodied energies of the fuels in question. With this broadening of perspective we see that pure biodiesel is in fact not preferable to blended biodiesel or even conventional diesel if we consider the energy requirements necessary for their production, transportation and packaging (purely from an energetic point of view).The reason for this high emergy is because biodiesel requires many steps of processing before it can be considered biodiesel at all. Data on the emergy required for biodiesel are derived from Sheehan et al. (1998) who have done a meticulous study on the energy requirements in biodiesel production. Their analysis begins with the cultivation of soy and follows the complete process (transportation-crushing-transportation-conversion-transportation) of the fuel production. In every step of the process more fossil fuels, electricity and non-renewable material is used and thus increasing the emergy of the final product. Likewise the energy required for machinery manufacturing and repair, as well as the embodiment of electrical devises and the liming needed in the cultivation all point to important emergy values that follow a similar production process.

Especially significant with regards to emergy is the artificially produced nitrogen fertiliser, which is also known as "one of the most energy costly inputs in crop production" (Pimentel &

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[22] The largest portion of exports from Argentina, Malaysia and Indonesia goes to nations within the EU, where consumption is highest.

Patzek 2005:71). It is, however, above all through the ability to artificially produce nitrogen fertiliser—in what is known as the Haber-Bosch process—that contemporary agricultural practices have been able to expect very high yields. Smil's calculation that "roughly 40% … of the world's dietary protein supply in the mid-1990s originated in the Haber–Bosch synthesis of ammonia" helps to illustrate the significance the Haber-Bosch process (Smil 2000:158). It also illustrates the importance of nitrogen for generic plant growth. The production of ammonia for nitrogen fertiliser is "extremely energy intensive" and frequently utilises natural gas both as source of fuel and chemical component, as well as coal (Kelischek 2011). Thus, despite its importance for modern livelihood, the production process has a range of negative consequences. These not only include the use and burning of natural gas and coal, but also contributes to problems related to the cultivation process such as

> worsened tilth, easier erodibility, lowered water-holding capacity, and weakened ability to support diverse soil biota and to buffer acid deposition (Smil 2000:205)

as well as

> high concentrations of nitrogen being leached into the groundwater, … stimulation of algal growth, hypoxia in regions in our oceans, acid rain, as well as a major contributor of green house gas emissions (specifically NOx and CO2) (Kelischek 2011:35).

Today the U.S. imports 82 percent of all nitrogen based fertilisers from a range of different countries (Kelischek 2011). In a very similar fashion to the production of fertilisers, the production of machinery, seeds, and pesticides results in high emergy values. Liming, a process by which soil acidification is regulated, also shows very high emergy values. Similar to nitrogen "[l]ime production is extremely energy intensive" (Crump 2000:II-15).

Lastly it is appropriate to mention a word about the lifestyle of the humans working with the cultivation. Andrew Nikiforuk in his thought provoking book *The Energy of Slaves* shows precisely how the emergy values of human work, here derived from Fluck (1992), can be so high. By consuming energy equivalent of "23,6 barrels of oil a year" Nikiforuk writes that the average North American live as if having "89 virtual slaves" at his/her disposal (2012:64-65). As such, it is primarily the consumption of food and commodities that in their production requires large amounts of energy that contributes to this high figure. The emergy values of the transportation and electricity for the cultivation could be indicative of this fact (oil consumption and lifestyle) as well, but should largely be taken as figures for heating and hauling necessary for the farm operations (Piringer & Steinberg 2006).

Table 3

Energy input for wheat production per hectare in the United States, using an agrofuel driven tractor.

Input	Quantity	Energy	Emergy	Energy total
Human work	7,8 hr[a]	6 MJ[b]	1522 MJ[c]	1528 MJ
Machinery	50 kg[c]	-	3349 MJ[d]	3349 MJ
Biodiesel (B100)	78,9 l[e]	2780 MJ[f]	4616 MJ[g]	7396 MJ
(Biodiesel (B20)	78,9 l[e]	2979 MJ[f]	2825 MJ[g]	5804 MJ)
(Diesel	78,9 l[e]	3029 MJ[f]	2477 MJ[g]	5506 MJ)
Nitrogen	78,5 kg[h]	-	4553 MJ[k]	4553 MJ
Phosphate	39 kg[i]	-	612 MJ[l]	612 MJ
Potash (potassium)	38 kg[j]	-	243 MJ[l]	243 MJ
Lime	1000 kg[m]	-	2900 MJ[n]	2900 MJ
Non-domestic seeds	94 kg[o]	-	1184 MJ[p]	1184 MJ
Herbicides	4 kg[q]	-	1388 MJ[p]	1388 MJ
Insecticides	0,05 kg[c]	-	16 MJ[p]	16 MJ
Fungicides	0,004 kg[c]	-	1 MJ[p]	1 MJ
Electricity	37,07 kWh[r]	133 MJ	311 MJ[p]	444 MJ
Transportation and custom operations	-	813MJ[cr]	-	813 MJ
Total:		3732 MJ	20695MJ	24427 MJ

Sources and comments

[a] (Pimentel 2006:7,14; Piringer & Steinberg 2006).

[b] Calculation based on (Smil 1994:85-90).

[c] (Pimentel 2006:14).

[d] Measuring emergy in machinery is tricky. The most common method is to make calculations based on the weight of the machinery (see Fluck 1992:117-22). From knowing the weight it is possible to make estimations with regards to manufacturing, transportations and repair. Rough emergy estimates for different raw materials are also possible by knowing their weight (Ibid. 119). Since lighter materials (such as rubber) can have significantly higher emergy values than heavier materials (such as iron) it is common to measure specific tractor parts such as tires in separation (Ibid.). Given this elaborate calculation process I have here chosen to adopt the emergy value of machinery from Pimentel (2006).

[e] (Pelletier et al. 2014:978).

[f] (Li et al. 2006).

[g] Calculated average from Pimentel & Patzek (2005) and Sheehan et al. (1998), assuming a fuel density of 0,88 for biodiesel (B100) and 0,85 for conventional diesel.

[h] Estimated average 2000-2009 (USDA 2013a).

[i] Estimated average 2000-2009 (USDA 2013b).

[j] Estimated average 2000-2009 (USDA 2013c).

[k] Calculated from Schnepf (2004:34).

[l] Phosphate requires on an average 15,69 MJ/Kg, but it should be noted that this figure varies from 11-19 MJ/Kg depending on processing strategy (Fluck 1992:183). Potash requires 6,2 MJ/Kg (Ibid).

[m] Liming vary from 400-1600 kg per hectare depending on soil acidity (Mamo et al. 2003; Hart et al. 2011:7).

[n] (Crump 2000).

[o] (Ali 2002:14).

[p] (Fluck 1992).

[q] (USDA 2009).

[r] (Piringer & Steinberg 2006).

The yield generated through this type of modern wheat cultivation averages to roughly 89 bushels per hectare if counting the average yield of the 'hard red winter wheat' varieties between 2011 and 2015 (USDA 2015). This translates to roughly 6016 kilogram of wheat grains per hectare. From these figures we can calculate that it takes 4 MJ to produce 1 kilogram of wheat grain through this cultivation process. Total output of wheat grain equals approximately 83556 MJ which in contrast with the input gives an EROI ratio of 3,4:1.

Table 4

Energy output and EROI for wheat production per hectare in the United States, using an agrofuel driven tractor.

Output	**Quantity**	**Energy**
Wheat grain	6016 kg[a]	83556 MJ[b]
Total:		83556 MJ
	EROI	83556/24427 = 3,4:1

Sources and comments

[a] Hard red winter wheat (USDA 2015).
[b] Calculation based on (Smil 1994:85-90).

4.3 Results and a note on land embodiment

One of the contrasts that immediately becomes evident between the two cases is that there is a lot 'going on' in the modern cultivation driven by renewable energy in comparison to the traditional cultivation driven by human and draft animal work. Although somewhat naïve, this remark seems to hint at the warnings given by Joseph Tainter in the late 1980s that complexity can lead to lower returns and onto a path of societal collapse (1988). To argue that a collapse is indicated by this cultivation alone would be quite drastic. Reflected in the data, however, is precisely the figure of a low energy return that in Tainter's view is correlated with complexity and long term unsustainability. Conversely, the traditional system seems very simple but provides a higher EROI ratio.

This brings us to the second important observation for this study, namely the contrast in EROI. What does this contrast mean? As mentioned before (sub-section 2.4) the more infrastructure and effort must be designated to the production of energy, the lower is the

EROI. This pattern of diminishing EROI does not follow a linear pattern, but forms a graph known as "the net energy cliff" (Figure 3). The net energy cliff resembles an exponentially decreasing curve as EROI gets closer to 1:1 which means that "decreasing EROI from100 to 80 has much less of an impact than decreasing EROI from 5 to 1" (Hall & Murphy 2010:107). The difference between the EROI of 35:1 and of 3,4:1can therefore be seen as considerable. This becomes clear also when considering that one kilogram of wheat grain requires the dispersion of 0,4 MJ in the traditional agriculture, whereas 4 MJ is dispersed in the production of the same amount of wheat grain in the agriculture fuelled by biodiesel. In other words, the traditional agriculture here analysed is ten times more energy efficient than the modern agriculture based on renewable fuels. This can be seen when looking at the cases as wholes, but it also becomes evident in some of their respective parts. To produce one hectare of wheat using muscle work of humans and oxen required 526,5 MJ, but to work the same field with a tractor driven by biodiesel (B100) requires 12074 MJ. In this instance it is near 23 times more energy efficient to turn to muscle work than to mechanical work based on agrofuels. Because a considerable proportion (60 to 80 percent) of the high yield in the latter case is largely due to the intensive use of fertiliser, then this comparison can indeed be seen as fair (see Smil 2000).

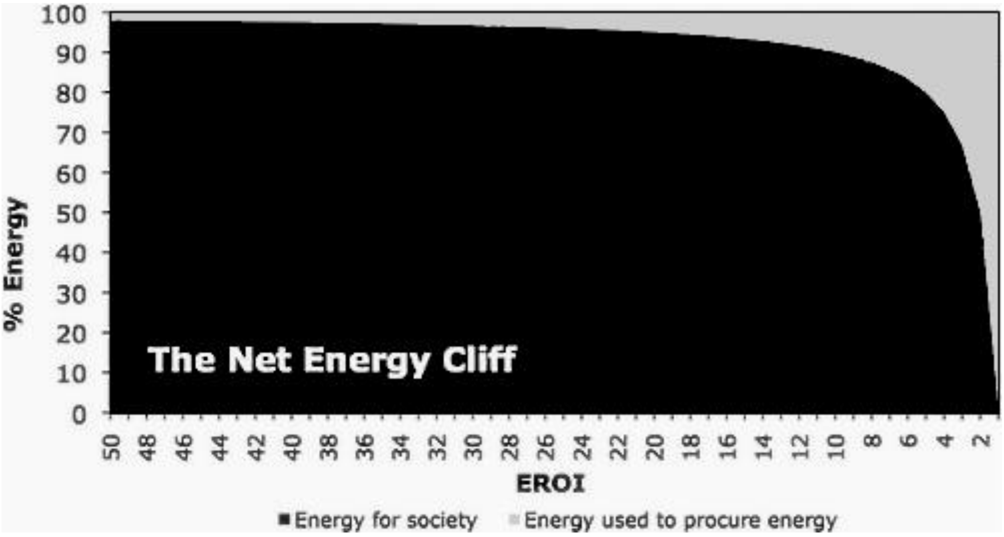

Figure 3. "The net energy cliff", inspired and reworked from Murphy & Hall (2010:108, Figure 3).

It must also be mentioned that energy efficiency, or the different EROI ratios, is here a calculation of the relation between output and input. It does not, in other words, take into consideration the productivity of the two cases as per total yield. The figures on productivity of the two cases are 1350 kilogram contra 6016 kilogram of wheat grain, and as such the cultivation based on renewable energy provides near four and a half times the yield of the traditional agriculture based on muscle work. This is a considerable difference. Yet when considering that the production of the inputs in the agriculture based on biodiesel requires in and of themselves land from elsewhere, then this figure is no longer fully representative of 'yield per hectare'. For example, one liter of biodiesel requires roughly 5 kilograms of soybean (Pimentel & Patzak 2005: 8). This means that the 78,9 liters of biodiesel required for this wheat production requires in turn the land to produce nearly 400 kilograms of soybeans in addition to the hectare calculated. This equals roughly 0,15 hectares of additional land. The yield per hectare is thus reduced to roughly 5231 kilograms of wheat grain simply by considering the embodied land of *one portion* of an input.

In estimating how much land is requires to produce the energy of the different inputs, i.e. m^2/MJ, we can turn to the calculations on ecological footprints. In essence, ecological footprints measure "the amount of biologically productive land and sea area" which something requires "to produce the resources it consumes and absorb the carbon dioxide emissions" in relation to land available (Footprintnetwork.org). In following Stöglehner's (2003) calculation method of ecological footprints which measure m^2/MJ we can make a rough estimate of the land required for some of the inputs (Table 5). We see then that at least 8,6 hectares would be needed for producing 6016 kilogram of wheat grain, which is equal to 700 kilogram per hectare. Calculating land embodiments based on land requirements for the reproduction of fossil fuels is admittedly an inaccurate business but it gives us a hint of how we can understand the issue of land requirements in relation to total yield. For now it will have to suffice to assume that the productivity illustrated in the second energy analysis (Table 3) cannot be fully representative of yield per hectare.

Table 5.

The amount of productive land and sea area required for the reproduction of different fuel inputs used in wheat production.

Input	**Emergy**[a]	**Energy type**	**Footprint**[b]
Nitrogen	4553 MJ	Natural gas	4,7 ha
Human work	1522 MJ	Fossil fuels	1,8 ha
Transportation etc.	813 MJ	Fossil fuels	1 ha
Electricity	311 MJ	Water power (76,2%)	0,1 ha
Total:			7,6 ha

Sources

[a] All emergy values are based on Table 3.

[b] All footprints are calculated with indices from Stöglehner (2003).

In conclusion we can briefly summarise the results here presented. The most important result of this section is the EROI ratios of the two agricultural models. These are:

- EROI of the traditional agriculture based on muscle work is 35:1
- EROI of the modern day agriculture based on biodiesel is 3,4:1

To understand that these in contrast represents a significant difference in energy efficiency is an important result that will be discussed in the following section. Finally, it is important to note that there is an uncertainty with regards to total yield per hectare of the agriculture driven by biodiesel.

5 ANALYSIS

In this section we will first dwell deeper into what the cases above are examples of, with the help of the theoretical concepts. Accordingly, the first sub-section (5.1) deals with how we can understand what technology and bodies are respectively. This lays the ground for the following two sections that deal with how we can understand muscle work (sub-section 5.2) and agrofuels (sub-section 5.3) as contrasting 'prime movers' for agriculture in terms of sustainability and environmental justice. In the final sub-section (5.4) three key concerns with regards to renewable energy systems at large are identified and discussed. The last discussion also ends with suggestions on further research.

5.1 What is technology; what is the body?

In order to address the research questions posed in the introduction it is important to first define what is meant by agrofuels and muscle work, i.e. what are these two phenomena that I attempt to juxtapose? Already we have seen how agrofuels and muscle work differ with regards to energy efficiency in food production, but we have yet to properly define them and thus understand more accurately the essential differences that led to these contrasting results. One assumption that will guide the following analysis is that if muscle work necessitates a body then liquid agrofuels are necessitate technology and/or machinery. In other words, there cannot be muscle work without a body and no liquid agrofuel without technology and/or machinery. Hence, agrofuel and muscle work represents technology and bodies respectively. This leads further to suggest that there are important distinctions between bodies and technologies that could help explain the results presented.

Throughout this study I have stressed that technology and thus agrofuels as we understand them cannot be understood in isolation. This means that biodiesel is not simply combined and processed alcohol, vegetable oil and/or animal fat (see Demirbas 2009:2239). This defines its content, surely, but it says little—if anything—about its actual existence. As illustrated in the energy analysis, biodiesel is accompanied by several other inputs such as machinery, human work, fertiliser and pesticide in its duty to deliver mechanical work. Therefore when speaking about biodiesel and the work it makes possible we must simultaneously speak about all of the other inputs as well. This is so simply because an agriculture driven by biodiesel could not exist as it appears in the energy analysis without them[23]. Other than a physical liquid driving mechanical work it *is* the relations that makes it possible and the relations that it reinforces. It is in its capacity as technology a node in the larger world economy (Hornborg 2001, 2015a).

In a similar fashion I believe we can analyse the body in the traditional agriculture presented. The body, or muscle work, as our main point of interest would then also be a node within a larger system of exchange. This is a different view of the body as opposed to mainstream biology where DNA, or the genome, is taken as a code that informs the behaviour and constitution of the bodily cells. In this view it is the genome that determine the form of the body, not unlike how some think that biodiesel determine the form machinery. Tim Ingold (2000) has convincingly argued that this view of the body is fundamentally flawed. He argues for instance that

> in reality, DNA never exists on its own, except when artificially isolated in the laboratory. It exists within cells, which are the parts of organisms, themselves situated within wider environments (Ingold 2000:382).

Rather than an "agent" or blueprint that determines the form of the body, DNA is more a "reactant" to the wider environmental context in which the body is situated (Ibid.). Although muscle work necessitates the composition of muscular tissue shaped by smaller components

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[23] We can, for instance, safely assume that without high inputs of nitrogen the specific agriculture in question would not be cost effective and therefore not exist. The yield would be much too low to account for the costs of the whole range of input necessary.

such as cells and strings of DNA, it is even more so the specific environment (including social relations) and context that forms its specific anatomy (Ingold 2000). Thus, the body, or muscle work as it exists in the past section’s calculus *is*—just like technology—the relations that makes it possible and the relations that it reinforces. It is not immediately evident, however, what this is precisely. The results in EROI (35:1) seems to suggest that what is both made possible and reinforced through muscle work is in fact exergy, or, high quality energy in the form of food. Here the ideas suggested by Podolinsky seems to imply that muscle work as it exists in the traditional agriculture (presented as “hand method”) has the potential to feed itself by making way for photosynthesis and the accumulation of biomass (Podolinsky [1881]2004). The accumulation of biomass, then, may very well be that which the body here both makes possible and reinforces, and in extent, that which it is.

Similar to technology in the sense of Hornborg (2001) muscle work must also here be seen as the result of exchange. In a traditional agriculture that largely lacks monetary exchange or significant social exchange outside the immediate ecosystem (region), it is above all the ecological, or energetic, exchange between the Sun, the plants, humans, oxen and other species that perpetuates the system and the form of the body. When speaking of bodies this is not always so. Throughout history, bodies have worked and slaved (literally) for the continuation of civilisations and unequal social relations; be it on the wheat fields of the Roman empire, the slave plantations and mines in North and South America or the assembly factories in contemporary China (Hornborg et al. 2007; Chan & Pun 2010). The body could therefore also be seen as a social relation perpetuating unequal relations. It seems that the body is, apart from very energy efficient, also extremely versatile in this sense. One can say that there are numerous definitions of the body, based on different social and ecological contexts, which agrees with what we may interpret as either history or evolution (Ingold 2000). These different contexts have very important implications for both sustainability and environmental justice that we will later turn to. Here it will have to suffice to conclude that both work based on agrofuels (technology) and work based on muscle power (the body) are relations of exchange that form and perpetuate something larger than themselves. They are each parts of a system.

5.2 Biodiesel in the accumulation of capital: sustainability and environmental justice

In the beginning of the twentieth century, Rudolf Diesel, the inventor of the diesel engine, wrote the following in an introductory chapter of the book *Diesel Engines for Land and Marine Work* by Alfred Philip Chalkley:

> When it is remembered that, as previously mentioned, the Diesel motor can also run on vegetable oils, it is not difficult to see that this fact opens out a new prospect for the prosperity and industry of the colonies, a fact which is of greater importance to England than to any other country owing to the large number of its possessions. On this point and as quickly as possible the problem should be tackled; the Diesel motor can be driven by the colonies' own products, and thus in a great degree can aid in the development of the agriculture in the country in which it operates (Chalkley 1912:7).

From the vision of Diesel we learn at least two things. First, we learn, that the notion of a mechanical agriculture driven by organic energy is not a new idea at all. It seems, for instance, that Diesel at the time of writing had both tested and successfully run one of his engines on vegetable oil from peanuts (Chalkley 1912:4). Second, we learn that biodiesel was—just like today—suggested as a solution meant to lift the periphery out of the state of 'underdevelopment' and 'poverty' (see e.g. Shepley 2009). Although over a hundred years have passed since Diesel formulated these words, the same vision is echoing almost word-by-word among current advocates of agrofuels. As opposed to contemporary agrofuel proponents, however, we can see in the terminology of Diesel quite clearly how the vision of biodiesel relates to colonialism. Here, in the following paragraphs, I will attempt to deal with some of the more problematic implications of this century-old vision as it appears in the world economy today, specifically in terms of sustainability and environmental justice.

It becomes evident in the results of the energy analysis that the sum of the energy dispersed raises serious doubts concerning the 'renewability' of the agriculture driven by biodiesel. An EROI of 3,4:1 is not only remarkably lower than 35:1, but dangerously close to 3:1 which defines the "law of minimum EROI" (Hall et al. 2009). With hardly any net surplus energy gain this agriculture is therefore not suitable as an energy source. If EROI is, as Podolinsky suggested, a metric for measuring the "foundation for the reproduction of … social system[s]" (Martinez-Alier 2007:227), then we can safely assume that an agriculture driven by biodiesel, as presented here, does not contribute to the reproduction of society. In remembering the "net energy cliff" (Figure 3) we can see that roughly 40 percent of total energy available for society would have to be reinvested in the system if this agricultural practice was to provide the fuel for further mechanical work. This is theoretically possible but there is yet no empirical case to illustrate how such a society would function. If we consider that the EROI of different modes of subsistence throughout history have been around 20-40:1 it is indeed quite hard to imagine a society based on 3,4:1 (Smil 1994: 21,27,76; Rappaport [1968]1984:49-52; Harris 1993:215-16). This agricultural practice could, on the other hand, exist as a societal sector that is fed with energy from elsewhere provided that there are other energy sectors to support it. This is essentially how it seems to function today from the results of the energy analysis, as it is largely upheld by manufacturing and transportation utilising fossil fuels. As such, we can conclude that the presented agriculture based on biodiesel is in fact not driven by the organic energy from the Sun, but driven by the fossilised energy stocks from the crust of the Earth. The ability of the plants to capture energy from the sun through photosynthesis is here, energetically speaking, almost negligible.

The vision of Diesel and his contemporary peers, i.e., that mechanical work can be driven by organic energy, remains therefore a vision. Hence it also becomes progressively more clear that the question that should be asked is not whether an agriculture based on biodiesel is sustainable, but how it could ever have been considered sustainable to begin with. If this agricultural practice may produce less yield per hectare than a traditional agriculture in 1800-1820 New England, utilises large quantities of fossil fuels and shows signs of extremely low energy returns, then what on Earth is it for?

In following the theories of techno-fetishism and ecologically unequal exchange as presented in the theoretical framework, technologies can be seen as strategies for capital accumulation through the means of ecologically unequal exchange (Hornborg 2001, 2011). The question we should be asking, then, is whether biodiesel is a mechanism for capital accumulation.

Biodiesel as a mechanism for capital accumulation through ecologically unequal exchange would not be alien to the results of the energy analysis because, as we have seen, the agriculture in question requires high input of emergy, i.e. energy dispersed elsewhere. The vital question with regards to ecologically unequal exchange is in what parts of the world system the energy in question has been dispersed. From a tentative account of this we can see that many of the most energy demanding inputs for the agriculture driven by biodiesel are typically imported to the U.S. and therefore dispersed outside its own borders (Table 6).

Although biodiesel as the most energy demanding input tends to be domestically produced, both the fertiliser, the lime and the crude oil used for electricity generation and transportation are all predominantly imported. This mix of domestic and imported inputs is not surprising considering that nations rarely (if ever) either only export or import energy demanding goods. The U.S., for instance, is considered to be simultaneously the world's biggest importer of nitrogen fertiliser and the largest exporter of "key agricultural products" (Hermele 2009: 170; USDA 2013d)[24]. In the case of an agriculture driven by biodiesel we can also see how this import is distributed in the world economy. We see that Canada is the biggest exporter for the inputs of this cultivation. This is not surprising given the fact that Canada is geographically close to the U.S. while simultaneously being sparsely populated "with large land areas and abundant land-based resources" (Ibid. 156). Though, as part of the global core, Canada is sometimes considered an exception in analysing global ecologically unequal exchange along with e.g. Australia, Norway and Sweden. Hence, it is not odd to see Canada accompanied by a mix of what we might call peripheral and semi-peripheral regions in the origins of the energy inputs. These together confirm that an agriculture driven by biodiesel might indeed be a mechanism for capital accumulation based on ecologically unequal exchange. Agrofuels, or in this case biodiesel, can thus be understood as a means to appropriate exergy from elsewhere (see e.g. Hornborg 2001:67-68).

Table 6.

Domestic and international production of certain energy inputs used in U.S. agriculture

Input	Domestically produced (percent)	Internationally produced (percent)	Main exporting nations to the U.S.
Biodiesel	86 %[a]	14 %[a]	Argentina, Malaysia and Indonesia[b]
Fertiliser	18 %[c]	82 %[c]	Trinidad and Canada[d]
Oil	31 %[e]	69 %[e]	Canada, Saudi Arabia, Mexico, Venezuela and Iraq[e]
Lime	21 %[f]	79 %[f]	Canada and Mexico[f]

Sources

[a] (EIA 2015a:152).
[b] (USDA 2014b; NREL 2013).
[c] (Kelischek 2011).

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[24] All in all, however, the U.S. qualifies as one of the biggest net importers of biophysical goods in the world (Hermele 2009:157).

[d] (TFI 2015).
[e] (EIA 2015b).
[f] (EPA 2000).

From a very similar perspective, although with a focus on the production of agrofuels at large, the promotion of agrofuels has been pointed out as a "colonial route" for making claim on other people's land and resources (Hermele 2009). This suggestion seems to be supported by political ecologists who conclude that agrofuels, as they are introduced in the 'global South', encourages the marginalisation of the poor and the benefits of the rich (Dauvergne & Neville 2010; McMichael 2009). It is, in other words, a way through which to perpetuate unequal exchange not only globally, but also locally. Important concerns with regards to how nature, wealth and gender is conceptualised in agrofuel efforts have also been raised in regional settings, implying that this social relation is introduced and reproduced by certain cultural notions of reality (Rometsch 2012). The many protests and cries against how agrofuels compromise food security, compete with food production and traditional ways of living and relating to the land confirms also how agrofuels are perpetuating colonial relations of power (Matondi et al. 2011; Pimentel et al. 2009).

It is not by accident, therefore, that the phrasing of Rudolf Diesel—when writing how it is of "greater importance to *England*" that its colonies should adopt biodiesel—seems to coincide with how colonial relations are reproduced by the same "development" involving agrofuels today (Chalkley 1912:7, emphasis added). It helps to confirm, together with the energy analysis, that agrofuels are not primarily a means to further mechanical work driven by organic energy, but rather a means to maintain vital infrastructure and beliefs that stratifies the world economy at the expense of local societies and environments in peripheral regions. The energy analysis reveals that agrofuels is an energetic luxury that entails the dispersion of other people's exergy (resources). Simultaneously, as we have seen, it is a strategy to build a cultural and physical infrastructure in peripheral regions that in turn may embrace the same logic. In short, it is a means to expand markets and increase entropy (Georgescu-Roegen 1993). Hornborg (2014a), having proposed that "increased technological efficiency may be largely illusory, due to an inadequate consideration of all parameters" and that technological development "may represent an increasingly unequal redistribution of resources among different sectors of world society" anticipates the generic results of this sub-section.

We have so far seen how vast inefficiencies in an agricultural model based on biodiesel raises serious concerns about sustainability and environmental justice in a world economic context. Next we will turn to see how muscle work stands as a contrasting strategy for food production in the past and the present.

5.3 Muscle work in the accumulation of biomass: sustainability and environmental justice

One conclusion already drawn from the energy analysis above is that muscle work can effectively be based on the organic flows of energy alone. This is admittedly an ancient and to some extent an evident conclusion, but it is nevertheless an important conclusion for the discussion to come. Indeed, the observant reader would have noted that biodiesel as a means for work did not meet this very fundamental criterion. If, as Podolinsky ([1881]2004) wrote, "the satisfaction of all our needs … represents a quantity of work almost ten times greater than the human muscular labor" then the product of human work must contribute to at least ten units of surplus energy by making way for photosynthesis. We see in the energy analysis of the traditional agriculture that such a requirement is surpassed as one unit of work contributes to no less than thirty-five units of surplus energy, which is equivalent to the EROI of "historic oil and gas fields" (Murphy & Hall 2010:108). These figures are primarily made possible in the human partnership with the work of oxen, the photosynthesis of the plants and other living organisms (including other humans). It is, in a sense, the result of an ecological relationship between species in which each feeds from the other's waste and the ecosystem as a whole therefore "remains without waste" (Capra 1992:291). This allows for an agriculture based on muscle work that not only contributes to its own survival, but also has the potential to accumulate biomass in the ecosystem over time. A system that offers biomass to the topsoil or the flora and fauna by every natural cycle is no doubt a very successful system. The most well-known empirical example of this is that of the 'Terras pretas' in the Amazon, the remnants of an ancient cultivation practice in the form of dark and highly nutritious soils. These "anthropogenic soils with enhanced fertility" occupy vast areas in the Brazilian Amazon, and stand as a firm example of how human cultivation practices can in fact accumulate biomass on Earth (Glaser et al. 2001:37). Today, thousands of years later, the Terra preta of the Amazon still provide the basis for human subsistence. Humans can, in other words, not only live from—but also enhance—land by means of their existence.

From this we understand that a successful agricultural practice based on muscle work would with relative ease be able to sustain societies, provided that no social relations of unequal exchange contribute to the dispersion of energy and materials. Although it has been a very successful strategy in the accumulation of biomass for centuries, however, agriculture without unequal exchange has perhaps been more of an exception than a rule throughout history (see Smil 1994). Slavery and serfdom are both examples *par excellence* of how the potential of muscle work to accumulate biomass in agriculture has been exploited. The traditional agriculture presented seems at an initial glance to be blessed from such power relations contributing to unequal exchange. A closer look, however, reveals that the cultivation can in itself be seen as exploitative in at least two ways; first as it follows the footsteps of earlier European settlers by basing its subsistence upon occupied land, and second as it builds upon the biomass presumably accumulated by the Native Americans. William Cronon (2003) has convincingly shown how the practice of settlers progressively degraded the rich abundance of the New England environment between 1620 and 1900. His central argument is that this biophysical change primarily followed the European "colonialists' more exclusive sense of property and their involvement in a capitalist economy" (Cronon 2003: xvi). As we have seen, the traditional agriculture presented in the previous section was not involved very much in the capitalist economy, and it is therefore questionable to what extent this agriculture and its energy metabolism is reflecting the arguments of Cronon. However, according to Cronon (2003:21-23),

> [s]ettlers had first to survive and prosper before they could sell commodities across the sea, and that meant understanding the land they lived in. By the time they did this, however, the land was already changing in response to that new understanding, creating a landscape different from the one that had been there before.

Indeed, as indicated by both Smil (1994) and Rogin (1931), the traditional method of cultivation was soon followed by surge of industrialisation and commodification. It may therefore have been under the influence of an external economy accompanied by a specific way of conceptualising the environment (nature) that the sustainable means of subsistence was displaced, or, in the lines with Cronon, an underlying mindset that was allowed to flourish. This, as we have seen, is not dissimilar to how agrofuels influence parts of the global South today. This shows in part why global social groups like Via Campesina—who renounce the commodification of food and environments—are so crucial. In creating a ground for resistance, Via Campesina makes way for an ecologically sound way of living that has the potential to not only bring food sovereignty[25], but also to restore damaged land. Small-scale agriculture based on muscle work can then be seen as a strategy to heal damage from colonialism, industrialisation and globalisation apart from a strategy for "cooling down the Earth" (Via Campesina 2009).

5.4 There … from muscle work to solar photovoltaics … and back again

As a preamble for the final part of the discussion we may begin by formulating the third research question again in the light of previous findings. Thus, we can ask: if a traditional agriculture is ten times more energy efficient than a contemporary agriculture driven by agrofuel, what reasons are there to doubt the possibility of a future society sustained purely with energy derived from renewable energy systems—such as solar photovoltaics?

The first point to raise doubts about the feasibility of a future society sustained purely with the energy derived from renewable energy systems is that mechanical work driven by agrofuels cannot reproduce itself without high influxes of fossil energy from elsewhere. This is an imperative that—as we have seen—contributes to a low EROI ratio and the need for external sources of exergy. If agrofuels requires machinery, fossil fuels and non-renewable material, then they cannot run by the organic flow of energy alone and therefore cannot exist for very long in a universe governed by the law of entropy (see Georgescu-Roegen 1993; Hornborg 2014a). A machine, in the words of Marx ([1867]1968:696) "consumes coal, oil etc. … just as the worker consumes food, to keep up its perpetual motion". Despite popular beliefs this seems to be the case also with agrofuels, and it may be true for renewable energy systems such as solar photovoltaic (PV) and wind power as well. For example, in a recent book by Prieto and Hall (2013) it was concluded that solar PV energy in Spain had an EROI as low as 2,45:1. This remarkably low EROI of PV power has since been supported by other studies (Palmer 2013; Weißbach et al. 2013).[26] In line with the previous discussion (see 5.3), Prieto and Hall also saw this EROI as a mark of fossil dependency. They wrote, for instance, that

> solar PV has appeared more as a 'fossil fuel extender' than an energy source able to self-breed its own sector while providing a significant net energy surplus to our modern global society (Prieto & Hall 2013:118).

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[25] The means for people to control both the production and distribution of their own food.

[26] But there is a degree of contention (for a discussion see Hall et al. 2014).

As such, it seems fair to assess that renewable energy systems are at least partially a means to burn more, rather than less, fossil fuels. The important point here is to note that it is not only agrofuels, but perhaps renewable energy systems at large, that seem to be unable to recreate the necessary conditions for their own existence. Such is the case with regards to energy, but maybe even more convincingly so with regards to non-renewable materials. Renewable energy systems, being built from non-renewable materials such as steel and silicon, will likely never be able to create the full conditions for their own existence because they are unable to provide energy for coke production (Smil 2009). Hence, if Nikiforuk (2012) is correct in arguing that we can understand combustion engines and fossil fuels as a substitution for the muscle work of slaves, we must conclude that this replacement will likely not be in place for very long. In the words of Georgescu-Roegen (1993:84) the fact that modern civilisation is based upon the "terrestrial stocks of low entropy" encapsulates at once "the main problem for the fate of the human species". It is doubtful whether renewable energy systems can tackle this problem. So what now? It is commonly asserted that with more innovation, research and development, problems such as these will be solved in the near future with the introduction of new technology. Technology is, however, the very problem. We must not forget that it was renewable energy systems that were supposed to tackle these problems to begin with, not perpetuate them. Thus, in line with Gowdy (1994), I would argue that it is when technological utopianism and progress is abandoned that real solutions can be discussed.

This leads us to the second point which is that it seems that only system based on the accumulation of biomass, as opposed to capital and technomass, can be sustainable. In creating companionships with other living beings—as opposed to technologies—humans have the possibility to establish and be part of long term sustainable energy systems almost anywhere. This, I believe, is not only useful in making assessments of the continuation of agrofuels, but equally useful when discussing solar PV power. It has been argued that solar PVs are more efficient than photosynthesis "on the basis of converting the most sunlight to usable energy" (Biello 2011). While this conclusion as such may be true, I would argue that it is only by measuring the amount of exergy captured in relation to the infrastructure that it sustains, that a valid comparison can be made. Plants, having been the energetic foundation for almost all civilisations in the past, must therefore be seen as remarkably more efficient. In addition, if Delin's conclusion that plants are "a hundred billion times better than our industrial technology when it comes to putting atoms into useful structures" is anywhere near the mark, then not only human bodies, but plants too, are what Podolinsky called “perfect machines” (Delin 1985:49-50, my translation; Podolinsky [1881]2004). By extention we might conclude that all living species are “perfect machines”, as they all contribute to their own reproduction, each in their own unique way. Autopoiesis (the ability to self-create) is at the heart of ecosystems and the web of life, and “in this”, Ingold writes, “they [animals] are the very *opposite* of machines” (Ingold 1994:9, emphasis added; Capra 1992). What Podolinsky saw as a “perfect machine” we can therefore, more accurately, understand as the opposite of a machine. Indeed, a perfect *machine* in the sense of Sadi Carnot is impossible and therefore not a machine at all. Hence, the most efficient solutions—to capture energy for heating, lighting, cooking, transport, building, etc.—can all be found in the complex relation with other living beings. The average human body necessitates an EROI of roughly 10:1, as Podolinsky made clear. The hidden side of this is that it simultaneously must mean that the body is also capable of reaching this requirement by its own accord, i.e. without technology, provided that the environmental and social conditions are harmonious with this end.

The third and final point, which underscores many of the arguments made throughout this study, is that the contrast in EROI between the two cases exemplifies a specific frame of mind. From this point of view it is not the contrast in EROI in itself that speaks the loudest, but the taken-for-granted assumptions and beliefs that lead to the assertion that new agricultural models are per definition better than traditional models. Here I have shown that new agricultural systems, on the contrary, seem to increase energy dispersion and thus also further environmental destruction. To quickly illustrate this we can simply look at the results of the energy analyses whereby muscle work disperses 533,8 MJ per hectare, conventional diesel 5506 MJ per hectare and biodiesel 7396 MJ (Table 3). Thus, with every historical change more energy is dispersed for *the same work done*. What cultural mindset, or what political economy, would lead to assume that agrofuels are then preferable to muscle work? For an explanation we might return to the concept of techno-fetishism developed by Hornborg (see sub-section 3.1). Here the explanation seems to be that agrofuels would seem auspicious because the relations of exchange that are necessary for their existence are perceived as external to themselves. Indicative of this is that global terms of trade and infrastructure that makes them accessible to the farmer will remain obfuscated (see Hornborg 2014b). This perception, in the words of Hornborg (2014b:11) is the result of “a tenacious illusion of Enlightenment” whereby “material forms” are separated from “the relations which generate them”, which lies at the very core of fetishism. We can see that techno-fetishism, apart from obfuscating the inefficiencies of biodiesel locally also obfuscates the actual efficiency of traditional agriculture, and by extension the complexity-in-simplification that it advocates. It inhibits, in a sense, the “reversal of the modernist distaste for small-holder farming, fishing and pastoralism” that is necessary for tackling current crises (McMichael 2008) and for establishing food sovereignty (Via Campesina 2009). As such, it enforces a cultural uniformity whereby all cultures and modes of subsistence are swept into the cycle of capital accumulation. Modern technology, more than anything, keeps modern humans simultaneously in a state of awe and numbness that is essential for an ontological coercion and a hierarchical society (Hornborg 2001, 2014b; Marcuse 1964). The promise of renewable energy systems is, in this sense, a mechanism for continued accumulation of capital allowed by a collective mystification of technology (see Hornborg 2001). The widespread failure to collectively reflect upon this can be seen as a sign of how deep the mystification goes, but even more so how fundamental this mystification is for the modern world economy to maintain its form.

If there is any truth to the notion that the law of entropy will inevitably bring the exhaustion of the material conditions for capital accumulation built on fossil fuels (Georgescu-Roegen 1993) it is doubtful whether time or effort should be invested in solutions that are based upon them. Sooner or later there needs to be some type of reconciliation (Ibid.). Living systems, in contrast to agrofuels and solar PV power, are able to reproduce themselves in spite of entropy. One can say that they are, in a way, dependent upon it (Schrödinger [1944]2000). The animal body is uniquely suited to live within this reality while the machine is not. From such a perspective we can suggest that renewable energy systems represent an attempt to transcend the law of entropy through the products of human ingenuity. However, evolution is the adaptation to environments, including the natural laws that shape them, not change or innovation *per se*. Failure to realise this is a necessary condition for the capitalist economy built upon the perpetual expansion of markets (Luxemburg [1913]2003), and to put faith in renewable energy systems may be a way to further this imperative, as I have shown.

Further research with regards to the sustainability of renewable energy systems could enhance this suggestion, but I believe that it is also important to look further into the differences that sets certain Marxists apart from Ecological Economists and Deep Ecologists with regards to the matter of renewable energy systems (a matter I unfortunately did not have room to address here). More generally I believe it is important to look further into the relation between culture (beliefs), political economy and energy. History may be a good theoretical field on which to base such studies, but important alternatives could also be e.g. how political dissent and/or healing strategies relates to energy and environmental justice in the lines with those brought up by Via Campesina (2009) and Martinez-Alier (2011). Further research could also attempt to build on the method of energy analysis as it was used in this study. It is my belief that calculations and analyses systematised similar to this study may be conducted to understand efficiency from a new perspective. Additional areas of comparison could be transportation (e.g. draft animals & cars), heating (e.g. firewood & electricity), lighting (e.g. bees wax candles & electricity), etc.. I would also like to encourage the development of this type of analysis with measurements other than energy/emergy, such as land and/or time embodiments. Lastly, I also believe that it is important to research and reflect upon how/if studies such as this one could be conducted in collaboration with peasant farmers and activists so as to build a multifaceted space for learning and resistance.

6 CONCLUSION

This study found that a traditional agriculture powered by the muscle work from humans and draft animals was ten times more energy efficient than a modern day agriculture powered by agrofuels. In the former, approximately 0,4 MJ of energy was dispersed in the production of one kilogram of wheat grain, whereas in the latter a whole 4 MJ of energy was dispersed for one kilogram of wheat grain. These results, based on EROI calculations from secondary data, indicated that there is a large and non-negligible difference in the way that these two agricultural models relate to energy dispersion and food production. The matter of productivity (total yield) was briefly discussed and it was concluded that further inquiries considering the embodiments of land would be necessary for an honest estimate of yield per hectare.

Based on these results, critique was raised against the belief that agrofuels can be based on organic energy. Contrary to this belief I argued that agrofuels are based on unequal exchange of energy dispersion, manifested by global trade in the world economy, and that this condition reinforces hegemonic power relations at the detriment of the world periphery and environments ‘elsewhere’. As indicated by the EROI of the traditional agriculture, humans and non-human animals have the ability to carry out work based on organic energy alone.

This ability, however, is susceptible to exploitation which means that social groups, such as Via Campesina that protects food sovereignty and the interest of small-scale farmers, are crucial in the realisation of the high EROI indicated.

From this background three major concerns were raised regarding the feasibility of a future society sustained purely by the energy from renewable energy systems, such as solar photovoltaics. These are:

- It is highly uncertain whether renewable energy systems can reproduce their own form.
- It seems that the ability to autonomously recreate can only be found in systems reproducing biomass, not technomass.
- The belief that drive the aspiration for a future society sustained purely by the energy from renewable energy systems is rooted in the assumption that humans and objects can exist apart from the relations that create them.

The purpose of this study was to scrutinise the efficiency and sustainability of renewable energy systems in light of an emerging body of critique. I hope to have demonstrated that this critique might indeed be valid. The doubts raised here seem to indicate that there may be an unfounded belief in renewable energy systems that is largely upheld by economic interests and a corresponding way of knowing the world. A wide range of social and ideological groups now stand behind renewable energy systems, and the modes of subsistence that have proven to work in the past are advocated only by a few. If there is any truth to the physicist’s conceptualisation of the laws of thermodynamics, then what we call the ‘past’ must be reconsidered. History needs to be reconsidered. From the results here presented it also seems that the notion of an inherently progressive and linear course of history is disputable, which becomes particularly noticeable when deconstructing the ‘modern project’ of development and mechanisation. A political-ecological conscious way of tending to soil and other living beings may contribute to a more democratic and productive way of feeding societies, and it may also provide a template from which to reconsider current beliefs in practice. In moving towards the simple notion that humans are not alone and isolated in the quest for survival on Earth, there might be healthy changes for the global North with positive repercussions worldwide. Meanwhile, however, the opposite may be endorsed by a wide range of social groups and ideologies. Future research could seek to engage in areas that allowed to challenge these ideologies and simultaneously further the understanding of humans *in* animate solutions.

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