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Article

Frameworks for Understanding and Promoting Solar Energy Technology Development

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Abstract: In this paper, the contrasting theories of metabolic rift and ecological modernization theory (EMT) are applied to the same empirical phenomenon. Metabolic rift argues that the natural metabolic relationship between humans and nature has been fractured through modernization, industrialization and urbanization. EMT, in contrast, argues that societies in an advanced state of industrialization adopt ecologically benign production technologies and political policies, suggesting that modern societies could be on course to alleviate the ecological damage caused by capitalism. These two theories are fundamentally different in their assumptions about modern economies and technologies, yet both can be used as a theoretical lens to examine the phenomenon of solar energy technology adoption. Furthermore, both theories shed light on the increasing adoption of solar energy technologies in both "developing" and "developed" regions and the potential social conditions for promoting renewable energy technology adoption.

Keywords: metabolic rift; ecological modernization theory; solar energy technology; renewable energy policy

1. Introduction

Both the theory of metabolic rift and ecological modernization theory (EMT) can be used to understand the empirical phenomenon of increasing adoption of solar energy technology. The theory of metabolic rift and the more recent EMT have contrasting foundations, frameworks, and implications. While both consider the human-environment relationship, they theoretically ground modernization and environmental degradation in contrasting ways. However, both can be used to examine the adoption of solar energy technology in both "developed" and "developing" societies throughout the modern world. This paper applies both theories to solar energy technology adoption and explores what the theories offer for understanding potential policies and practices that promote renewable energy technology adoption.

This study will begin with an examination of contemporary solar energy technology adoption. This will be followed by a review of both the theory of metabolic rift and EMT. Then the empirical and theoretical come together by examining the ways in which these divergent theories can be applied to solar energy technology adoption. Also, a meso-level of application will be discussed. Both theories provide unique and important insights into the structure and consequences of modern society that shape the economics and politics of renewable energy technology adoption, yet each offers only partial provided by its assumptions and foundational beginnings. While the theory of metabolic rift (and modern extensions of the basic theoretical premises from this classical foundation) is arguably more fitting for the decisions of individuals or small communities, and EMT more applicable to nation-states, both theories offer theoretical grounds for understanding the adoption of solar technologies by individuals, communities, and businesses and offer insight for potential policy tools to promote renewable energy technology adoption at multiple scales and in diverse national contexts. This paper concludes with a discussion and consideration of this meso-level of theoretical analysis for understanding renewable energy technology adoption in both "developing" and "developed" regions.

2. Solar Energy Technology Adoption

Solar energy technology has offered a feasible alternative to fossil fuel use in the heating and electricity sectors for decades. In 1979, President Jimmy Carter gave his well-known "Crisis of Confidence" speech, in which he set a goal of twenty percent of the nation's energy coming from solar energy by the year 2000. Scholars of the time reported significant increases in the perceived potential of solar energy and an overwhelmingly positive attitude among American consumers regarding the future of solar energy [1–4].

For example, a review of 190 surveys conducted between 1973 and 1979—156 of national samples and 33 of local or regional samples—results suggested an overwhelming optimistic view of the future of solar energy technology. Survey respondents indicated extremely favorable attitudes toward solar energy technology for both potential and actual usage. A survey conducted in April 1979 found that a 32% of Americans, more than in any other category, thought that solar energy would supply most (over 25%) of the nation's electrical energy needs in 20+ years. Further, in both 1977 and 1979, 65% of Americans surveyed agreed that solar energy was "realistically possible to use for replacing foreign oil during the next five years" (survey question wording). Solar energy was rated second only to coal as a feasible alternative to foreign oil [2]. Clearly, solar energy technology has not supplanted American dependence on foreign oil or eliminated the use of coal as a primary source of electricity. In 1986, President Ronald Reagan had the solar panels that Jimmy Carter had installed on the White House removed, and US political support for solar energy technology adoption remained largely silenced until around 2010 when President Barack Obama ordered that new ones be installed. However, the solar technology market has been growing at an incredibly rapid rate for the past several years. Even former US President George W. Bush, who is not known for his promotion of sustainable environmental policy, once said, "Solar technology is commercial. This technology right here is going to help us change the way we live in our homes" [5]. Solar energy technology adoption is expanding throughout the global, with supportive policies in Germany and across Europe and soaring production in China, Canada, and other parts of the world. Solar energy technology adoption is an important real-world phenomenon, a technology becoming increasingly sought after, as it increasingly becomes an economically viable alternative to fossil fuel based generation. The amount of solar radiation available on earth could technically supply global energy demands [6,7]; the only limitation is storage of this intermittent resource, a technological limitation that has not received adequate research attention, arguably for political reasons [8,9]. However, storage capacity is currently adequate for residential or small-scale applications of solar electric technology and is rapidly enhancing for larger-scale solar production facilities as well [10–13].

Furthermore, a shift in our source of energy is social, dependent upon and affecting social and economic relationships. Energy consumption in many ways defines the social and economic realities of the modern world. Energy consumption is shaped and driven by modern economies of production. The global increase in solar energy technology adoption is also important because it suggests a potential change in societal perceptions of using finite natural resources to provide for human energy needs. These are the perceptions explored by the theories discussed herein; ones sees renewable energy technology adoption as a function of ecological rationality resulting for modernization, while the other views solar technology a means of healing a rift in the human-nature metabolism. Both may be at least partially true, and these two sociological theories can help shed light on the increased adoption of solar technology worldwide, highlighting potential motivations for adoption and identifying potential policy mechanisms to promote renewable energy technology adoption at different scales and contexts.

3. Metabolism and the Theory of Metabolic Rift

Marx's theory of metabolic rift "serves as an approach for conceptualizing relationships, but it also provides the basis for processing the empirical reality of the nature-society relationship" [14]. "Metabolism," in the sense used by ecologists and environmental sociologists, is the "relationship of exchange within and between nature and humans" [14]. Metabolism most fundamentally expresses the notion of "material exchange" [15]. The use of the word metabolism in the biological sciences, according to Frederick Engels, refers to "the organic exchange of matter," and explains that "life is the mode of existence of protein bodies, the essential element of which consists in *continual metabolic interchange with the natural environment outside them*" [15]. In the use of metabolism, Karl Marx referred both "to the actual metabolic interaction between nature and society through human labor (the usual context in which the term was used in his work), and in a wider sense (particularly in the *Grundrisse*) to describe the complex, dynamic, interdependent set of needs and relations brought into being and constantly reproduced in alienated form under capitalism, and the question of human freedom it raised—all of which could be seen as being connected to the way in which the human metabolism with nature was expressed through the concrete organization of human labor. The concept of metabolism thus took on both a specific ecological meaning and a wider social meaning" [15].

The theory of metabolic rift, originally developed by Karl Marx, is based on this concept of metabolism. It illuminates the ways in which the energy exchange between nature and humans has been disrupted [14–16]. Marx argued that industrial capitalism creates conditions that inevitably cause an irreparable rift in the human-nature metabolism, a metabolism based on natural processes in the non-human world [16].

Marx was particularly interested in the rift in human-nature metabolism, caused by a capitalist economic system of exchange, which results in the pollution of air, water, and land, and discussed this rift particularly in relation to soil, soil quality, and large-scale capitalist agriculture [17–19]. Marx recognized the importance of a balanced energy exchange between human societies and nature, and acknowledged the disruption of this exchange resulting from industrialization. This theoretical construct has come to be known the theory of metabolic rift.

The mechanization of agricultural production necessary for large-scale production was entirely new in Marx's era. Marx argued that mechanized, large-scale agriculture created the emergence of a metabolic rift as essential soil nutrients were not replenished. Thus, humans were taking more from nature than they were returning to nature, creating a rift in the human-nature metabolism of energy and nutrient flows [20,21].

According to some, this rift in the metabolic relation of nutrient flows began with the very onset of capitalism, as "capitalism marked not only a decisive shift in the arenas of politics, economy, and society, but a fundamental reorganization of world ecology, characterized by a metabolic rift" [22]. Others contend that the rift first occurred because of urbanization, which occurred on a massive scale with the onset of capitalism [16].

Yet others argue more specifically that this rift occurred when human societies transcended the "solar income budget constraint" to which all of the earth must comply, and promote what has been called "steady-state economics" [23]. Every living thing—every plant, animal, and ecosystem—lives within the constraints of the energy provided by the sun. That is, every form of life except humans. Humans have surpassed this restraint through the utilization of nonrenewable sources of energy, thus interrupting the metabolic balance between the natural and the human realm. While Marx discusses metabolic rift in relation to agriculture, and other discuss the rift in relation to urbanization [19], both may be missing a key element that occurred before either of these phenomena were possible. This is consistent with the findings of other Marxist scholars [20].

Thermodynamics teaches that "the ultimate usable stuff of the universe is low-entropy matter-energy" [23]. There are two forms of low-entropy materials for use on planet earth: terrestrial stock and solar flow. Terrestrial stock can be categorized as renewable and nonrenewable. These categorizations are, in some part, based on use. For example, oil will never be utilized to the degree that it can be re-categorized as a renewable resource, at least not on a human time scale. Forests, on the other hand, could be considered a renewable or nonrenewable resource, depending on the extent of their exploitation. Both terrestrial stock and solar flow are limited. However, terrestrial stock is limited absolutely, while solar flow is practically infinite in total supply but limited in rate and pattern of arrival to earth. This concept of low-entropy forms of matter and its relation to human life on earth is derived from the logic of the second law of thermodynamics: all states of matter and energy cannot be created nor destroyed, yet they can be transformed. The premise of steady-state economics, and the underlying critique offered by the concept of metabolic rift, suggests that human societies can and ought to live within the energy balances provided by natural resources and on a sustainable time scale. The human ability to transcend the constraints of living by solar energy through our use and exploitation of nonrenewable energy sources (*i.e.*, trees, fossil fuels, *etc.*) fundamentally sets humanity apart from the entirety of the natural world, thus initiating a metabolic rift in the realm of energy use. The ability to exploit nonrenewable energy sources (which coincidently were and are past solar resources stored in another form) is what fundamentally sets humans apart from the rest of the plant and animal world. This was a requisite occurrence before large-scale agriculture or urbanization could occur. Further, the more use humans make of solar flow, the less they will be forced to rely on terrestrial stock (assuming total energy usage remains constant). This is not only in congruence with the logic of sustainability; it also serves as a potential means of addressing the metabolic rift.

Mechanized agriculture, the onset of capitalism, the shift to urbanization, and the initial use of fossil fuels beyond replacement rates all occurred within a relatively short time period. While it is difficult, perhaps impossible, to pinpoint exactly the cause of metabolic rift was, there are arguments in favor of the latter point. Capitalism, per se, does not necessitate a rift in the human-nature metabolic relation (a radical point, perhaps, but one supported by the implications of EMT, to be discussed shortly). Urbanization and mechanized agriculture would not have been possible without exceeding the solar budget allotted to humans through the exploitation of past solar output (*i.e.*, fossil fuels). Thus, the argument presented in this paper will conceptualize the surpassing of humanity's solar energy budget constraint as the initial onset of the metabolic rift.

The metabolic rift, then, can be understood as a rift in two interrelated earth metabolisms. First, the energy metabolism or "solar income budget constraint" was surpassed by the adoption of nonrenewable fuel sources. Humans, no longer dependent solely on energy provided by the sun, created a metabolic rift in human-nature energy relationships. This created a second metabolic rift in the human-nature carbon exchange; humans produce more carbon than the earth can metabolize through the use of nonrenewable energy sources, creating a rift in the carbon metabolism of the world.

Other scholars have recognized the potential to address the negative environmental consequences of a capitalist mode of production by reintegrating natural resources use into ecologically sound production [24–26]. Contemporary authors utilize the basic conceptual underpinnings of this classical argument regarding a rift in human-nature metabolisms to advance a variety of arguments regarding closed loop production models [27,28] and "cradle-to-cradle" design [29,30]. Another framing argues for a circular economy [31–33]. While these perspectives do not contain the radicalism of Marx's original arguments, they do provide similar views regarding the need to restore balance to the cycles of production and consumption integral to the human-nature relationship, and will be further explored below.

The theory of metabolic rift, and more contemporary articulations of the same basic conceptual premises, thus suggests that one way of improving the human-nature metabolism is to return to our reliance on solar energy, which would realign humanity with every other species and ecosystem on earth. The adoption of solar energy technologies in both "developed" and "developing" regions can be understood and promoted by utilizing the theory of metabolic rift. For "developed" nations, policies that encourage solar energy technology at the commercial and utility scale are arguably addressing a fundamental rift in the relationship between humans and nature, as expressed in the concept of an energy metabolism. For individual homeowners choosing to adopt solar energy technology, a desire to address and rectify this rift may be a motivating factor [34–38]. "Developing" nations have an opportunity to adopt solar energy technologies in order to limit the extent to which they rely on a fundamental rift in human-nature metabolisms, rifts caused by relying on energy sources that surpass the solar energy balance and by exceeding the possible carbon metabolism, in order to promote economic and social development. Nations that do not yet have an expansive electric utility grid can avoid developing a technological infrastructure that is increasingly becoming obsolete through the adoption of distributed, renewable energy sources.

4. Ecological Modernization Theory

Other sociological theorists conceptualize the use of solar energy technology in a very different manner. Although environmental values are often framed as related to values of pre-modernity, especially because of the influential forms of environmentalism that emerged in modern cultural contexts during the 1960s and 1970s, ecological modernization theory (EMT) argues that advanced states of industrialization result in the potential for environmental values to be adopted into production practices and policy stances. EMT became increasingly popular in the 1990s, when modern industrial nations initiated "action, environment-induced, transformations of the institutional order of society" [39].

According to EMT, this institutional action is not merely window dressing but is evidence that ecological modernization can and will occur within the institutional structure of advanced industrial societies [39–41]. Ecological modernization theorists contend by extension that the use of solar energy technology is yet another step in the process of modernization in capitalist production processes, geared towards ecological sustainability for the sake of both profit and industrial longevity.

EMT offers theoretical conceptualization of the relationship between industrialization and environmental protection. EMT allows for an analysis of "the necessary development of central institutions in modern societies to solve the fundamental problems of the ecological crisis" [41]. According to EMT, achieving certain levels of advanced industrialization influences institutional capacity for considering ecological consequences and addressing ecological concerns. EMT contends that at a certain level of modernization, industrial growth and success will *require* an ecological rationality. Industry will thus consider ecological impact as a major component of any cost-benefit analysis, will minimize environmental externalities, and will increase the efficiency of production to the maximum possible level, all because it will be rational to do so [40].

EMT identifies three specific realms of modern society and the relationship between these realms necessary to achieve ecological modernization. According to EMT, both the sociosphere (the social system) and the biosphere (the systems of the natural world) are, in modern society, related to and subjugated by the technosphere (the industrial system of production). An eco-social restructuring of the technosphere, through the process of super-industrialization, is what creates ecological modernization. Ecological modernization, characterized by super-industrialization, allows for industrial, social, and ecological considerations to be weighted equally without jeopardizing the longevity and success of the existing capitalist structure [42,43].

EMT provides a practical theoretical framework for policy development; the theory can be used "as a political program to direct an environmental policy" [41], including specific industrial measures and political options for countering environmental problems. This practical side of EMT is evident in the recent political and institutional developments in Western European countries such as the Germany. Furthermore, the application of EMT to practically address environmental problems through advanced industrialization and policy driven outcomes is perfectly applicable to the worldwide increase solar energy technology adoption, which is arguably most pronounced in what EMT could categorize as advanced nations.

According to EMT, nations that reach a state of modern industrialization can and will develop industrial policies that promote environmental responsibility. EMT (and related theories such as the Environmental Kuznets Curve, another articulation of post-materialist theory) has been profusely challenged for its failure to actually predict current policy structures [44–49]. Yet the theory does offer insight into how to promote renewable energy technology adoption. According to this theoretical framework, nations must be able to advance to a modern level of industrialization before it will be in their best interest to adopt environmental responsibility as a key pillar of industrial policy.

5. Understanding Solar Energy Technology Adoption across the Globe

The theory of metabolic rift proposes that there is a long-standing rift in the human-nature metabolism. As argued here, this rift occurred with human exploitation of nonrenewable resources, a prerequisite to urbanization, industrialization, and mechanized agriculture, creating a rift in the solar energy balance metabolism and the carbon metabolic balance. Humans are the only species on earth to exploit nonrenewable energy sources that surpass the constraints of our solar income budget.

Marx considered the demise of capitalism be the only means of healing the rift, because he believed that industrial capitalism necessitates being out of balance with nature. However, since the concept of the rift is based on the concept of metabolism, healing the human-nature metabolic relationship is another way of addressing the rift. Solar energy technology offers one way to eliminate the metabolic rift and restoring a balance in human-nature metabolic relations.

Solar energy technology allows for the harnessing of the renewable and practically infinite energy of the sun to provide for human energy needs. Solar technology has the potential to heal the rift in the human-nature metabolic energy and carbon balances. By using the energy provided by the sun, humans would be realigned with the energy flow of the earth as a metabolic system and could live within the solar energy budget.

Solar electric technology adoption is developing rapidly, as costs continue to plummet and the technology continues to improve. One limitation to harvesting the abundant resources available from solar radiation for meeting global electricity demand is the storage of this intermittent resource, although battery storage technologies also continue to advance. Furthermore, the storage capacity necessary for small-scale solar electric systems is already available [10,11].

The theory of metabolic rift is an appropriate lens for understanding individuals and communities that adopt solar energy technologies. Living “off-grid,” using renewable energy technologies without connection infrastructures that provide services using fossil fuels and resulting in carbon pollution, may be motivated by an individual desire to restore the rift in the human-nature metabolism. A key component of this application is intention; individuals or groups can adopt solar energy technology as an intentional means of addressing the imbalanced human-environment relationship.

The theory lends itself most clearly to considering individual or small group decisions, although nation-states may fit within this conceptual lens as well. Nations may choose to pursue renewable energy technology adoption as a means of avoiding or limiting the metabolic rift. Especially in developing nations that do not yet have the large scale infrastructures for providing fossil-fuel based energy services, this theoretical framework can offer guidance for an alternative, environmentally beneficial form of energy development.

While solar energy technology does indeed provide a potential means of addressing the metabolic rift, the production processes necessary to produce solar energy technologies provides a point of contention. The production of solar energy technology requires the use of fossil fuels and rare earth minerals that arguably contribute to the metabolic rift. In addition, the growth of net metering—where users of solar technology also get energy from traditional utility companies—allows for the use of solar energy technology while still living beyond a solar energy budget. The role of fossil fuels in the production of solar technology and as a supplement to solar technology use suggests that solar energy technology may not necessarily heal the metabolic rift.

Furthermore, as capitalism tends to demand ever increasing production and consumption, the solar energy technology market would have to be ever expanding to accommodate the needs and wants of human societies while staying within a solar budget. While the use of solar energy technology is increasing, the overall per capita use of energy is also increasing. Unless solar energy is able to meet all human energy demand, it cannot heal the rift in energy and carbon metabolic exchange. The logic of capitalism works against the potential for solar energy technology to mend the rift in human-nature metabolic relationships. The application of EMT lacks these weaknesses.

EMT places an emphasis on the production process and suggests that production will become more ecologically benign in societies reaching an advanced state of industrialization. Thus, EMT takes into account the production input necessary for solar technology. It is also able to explain the increased adoption of solar energy systems, particularly at a national scale and in advanced industrialized economies.

EMT suggests it is rational for modern societies to consider ecological factors when designing policy and regulatory frameworks. This, presumably, includes the adoption of new technologies that are more energy efficient and ecologically sound. Thus, according to EMT, societies will progress to a state of economic development wherein solar energy technology adoption is both feasible and rational. This process is arguably currently occurring in nations such as Germany.

As discussed above, EMT is not only a theory, but also a political program for creating social change. The theory takes into account the political climate and policy decisions that encourage ecological rationality in decision making related to industry and technology. According to EMT, solar energy technology can be promoted through intentional policy frameworks meant to promote ecologically responsible forms of production and industrial development.

There is a potential weakness in the application of EMT to solar technology adoption in that it cannot address phenomenon on a global scale. However, EMT acknowledges its own inappropriateness for considering societies that have not reached an adequate level of industrialization. As globalization becomes increasingly important in both theoretical consideration and real life consequences, the inability of a theory to consider social behavior on a global level or the global impact of social reality may be considered a significant weakness. Also, because EMT is premised on a certain level of industrialization occurring before ecologically sound industrial practices are adopted, it cannot account for the increasing adoption of solar technology in non-industrialized or under-industrialized states.

6. Using Theory to Explore Motivations, Policies, and Potentials

While highlighting potential weaknesses in their application, the discussion above demonstrates the application of both the theory of metabolic rift and EMT to the growth of the solar technology market. Both theories are based on a particular foundational lens, which shapes the assumptions and possibility of applications utilizing the theoretical framework. These two very different theories share one fundamental aspect that may help explain their ability to address the same empirical reality although they are based on such contrasting perspectives—both have at their core an effort to explore and explain the relationship between the social and the natural realms of reality. Yet both provide, at best, a partial picture of the human-environment relationship, particularly when it comes to understanding and looking for theoretical guidance to promote solar energy technology adoption in the context of both "developed" and "developing" nations.

These two theories converge at a meso-level of analysis, in a middle ground that includes businesses or community decisions. Both metabolic rift and EMT can explain the adoption of solar energy technology by businesses or small communities. This meso-level of analysis is important for the potential policy recommendations it provides.

Marx's conceptualization of metabolic rift is inextricably related to his critique of capitalism. Marx criticized capitalism as an alienating force, and his discussion of the *problems* of capitalism is the lens through which Marx understood the nature of ecology and the metabolic rift. Marx considered the demise of capitalism to be the solution. He argued that communism could eradicate the alienation created by capitalism through "the perfected unity in essence of man with nature, the true resurrection of nature, the realized naturalism of man and the realized humanism of nature" [50]. The theory of metabolic rift, especially as utilized by contemporary scholars, addresses the enormous problems caused by capitalism and its consequences for the human-nature metabolic relationship. The primary focus on problems, rather than solutions, is a part of the theoretical foundation of metabolic rift.

EMT, in contrast, is focused on solutions [44]. In this way, it is starkly different from the theory of metabolic rift, which focuses almost exclusively on a particular problem. EMT argues that advanced states of industrialization rationally and inevitably leads to ecological considerations being implemented into industrial and political practices. According to EMT, there is within every society both ecological rationality and economic rationality; traditionally, the latter dominates. However, the former is gaining credence and consideration in societies that have reached an advanced level of industrialization. This ecological rationality is dedicated to finding rational solutions to the negative environmental consequences of production processes.

The focus on solutions, particularly in relation to environmental degradation, suggests a reliance on ecological reform in the economic sphere. For example, pollution credits or caps as well as efficiency standards demonstrate some types of solutions that are currently being adopted. Solar technology adoption is another potential solution.

Although the theory of metabolic rift and EMT are both able to explain the worldwide increase in solar technology use, their appropriate use as a theoretical framework for describing this empirical reality varies based on the unit of analysis in consideration. The extent to which solar technology is currently being adopted varies across nations and global regions, and these two theories hold different explanatory weights when considering different scales of context.

For example, it is difficult to explain solar energy technology adoption on a national scale using the theory of metabolic rift. Widespread adoption of solar technology throughout a nation does not necessarily mean that the rift is being mended. Other elements of the national energy agenda, such as mechanized agriculture (Marx's original application of metabolic rift), or unsustainable water consumption, or an over-reliance on personal automobiles powered by fossil fuels, all contribute to a rift in the total sum of human-nature metabolic relations. Attempting to apply metabolic rift to explain the increased adoption of solar technology throughout a nation simply does not seem to fit.

However, the theory of metabolic rift is extremely appropriate as a theoretical framework for examining solar technology adoption using a small unit of analysis, such as case studies of individual homeowners or businesses. In these instances, using metabolic rift as a theoretical foundation could help explain motivations for adoption as individuals come to recognize the rift in the human-nature metabolism. Understanding the process through which small groups come to identify and attempt to mend the rift is an appropriate application of this theoretical framework, while attempting to study a larger unit of analysis such as a nation potentially would not.

On the other hand, the application of EMT to conceptualize adoption of solar technology within one nation is perfectly appropriate. Consider, for example, the case of Germany. As a modern nation in advanced states of industrialization, Germany is industrially, politically, and socially suited for policies that promote solar energy technology utilization. However, small groups such as communities, cooperatives, and small businesses do not require a specific level of industrialization before being capable of solar technology adoption. Small group decisions are much more culturally, personally, and psychologically based, relying on the values and norms in place within that group. EMT does not offer insight for understanding renewable energy technology adoption at this smaller scale.

On the other end of the spectrum, solar technology adoption on a global level must also be considered, and EMT is also an inappropriate theoretical frame for understanding the global increase in solar energy technology. Japan has the second highest levels of installation of solar panels per year; non-governmental organization (NGOs) and businesses are using solar panels throughout Africa and the Middle East. In Turkey, solar energy use is developing rapidly [51]. Solar energy technology prices are dropping quickly, and distributed renewable energy sources are an ideal choice for sustainability in the context of poorer and developing nations [52,53].

The theory of metabolic rift may be more appropriate for understanding solar energy technology adoption throughout the globe, especially if considering not the actual mending of the metabolic rift but the potential to do so. The adoption of solar technology has the potential to mend the rift in human-nature energy and carbon metabolisms. On a global scale, both "developed" and "developing" regions can pursue solar energy technology adoption as a potential way to repair the metabolic rift and restore the human-nature solar income budget to a balanced level.

At a meso-level of analysis, considering communities and businesses as a social entity more economically complex than the individual but more value-driven than the nation-state, both of these theories have explanatory power. Whether a multinational corporation or a small village community, certain levels of economic stability may be required before alternative energy technologies will be feasible. Yet, for both businesses and communities, a value orientation may drive motivation, and a desire to address the rift in human-nature metabolic relationships may motivate the choice to adopt solar energy technologies.

There is empirical support for this meso-level of application in the body of work dedicated to understanding what is called industrial ecology. Both a field of study and a body of production and design practices, industrial ecology focuses on balancing human-nature balances in energy, consumption, and waste [54–56]. Considering the specific application of solar electric technology adoption, industrial ecology can provide a framework for policy design and technology promotion focused on the benefits of utilizing a renewable resource to meet human energy demands.

This meso-level, focusing on businesses and communities rather than individuals or nation states as the locus of policy design and the potential for change, may contribute to creating a more sustainable energy future [57]. The overlap in application of these two theories to the adoption of solar technology by businesses and communities throughout the world raises important policy implications. If the adoption of solar technology by businesses is appropriately conceptualized as either an ecologically rational result of industrialization or an intentional attempt to restore healthy human-nature metabolic interactions, then perhaps this is the realm in which solar technology adoption can have the biggest impact.

Policies that promote the adoption of solar energy technology for businesses and communities may be the most successful means of promoting renewable energy technology. The convergence of these two theories in this meso-level of analysis, as a unit larger than individual communities but smaller than nation-states, provides a middle ground at which policy may be successfully targeted. If the aim is to promote renewable energy resources use in both "developed" and "developing" nations, it is important to find conceptual and empirical synergies that can contribute to successful policy development.

7. Conclusions

Underlying this study is an acknowledgement of the importance of solar energy technology adoption and the imperative of harnessing the power of the sun for sustainable human energy consumption. As a result of mechanized agriculture, which is only possible because of the carbon metabolic rift, we do not eat potatoes made from the sun; we eat potatoes made from oil [23]. Dependence on nonrenewable energy resources has significantly decreased the efficiency of both energy production and consumption [23]. Furthermore, reliance on nonrenewable energy sources, primarily fossil fuels, is resulting in devastating consequences for both human and non-human species.

There is, however, a potential solution to unsustainable energy extraction and utilization. "It is well known that solar energy is the source of life on earth" [51]. Further, "The solar source of low entropy is more abundant than the terrestrial source. If all the world's fossil fuels were burned, they would produce only the equivalent of a few weeks of sunlight. The sun is expected to last for another 5 or 6 billion years. In addition to being nondepletable, the sun is also a nonpolluting source of energy. It would seem prudent, therefore, to make our technology run on solar low entropy to the greatest possible extent …. The biosphere runs on solar energy, and man has lived on solar energy the vast majority of his history" [23].

Scientists know that "solar radiation arriving on earth is the most fundamental renewable energy source in nature. It powers the biosystem, the ocean and atmospheric current system and affects the global climate" [51]. Solar energy is a practically infinite, feasible and historically utilized energy source. As renewable energy technologies provide a key source for future energy development, solar energy technologies are among the most important alternative energy sources.

Battery technologies for storing the electrical resources produced by harnessing intermittent solar radiation are one technological hurdle to full remedy of the rift in human-nature energy metabolisms through complete reliance on electricity produced by solar energy. Battery storage technology research and development has arguably been limited for reasons related to political economy [8,9]. However, battery storage technologies currently available may be sufficient for meeting energy needs at the meso-level of communities and organizations [10,11,13]. This may be the case especially if other closed loop and "cradle-to-cradle" schemes are utilized to increase efficiencies and establish a balance between human needs and the resources available from the natural world [12,29,55]. Both the theory of metabolic rift and EMT suggest holistic thinking in terms of how human societies rely upon and relate to the natural environment, encouraging a total reconfiguration of the human-nature relationship.

Energy choices dictate the organization of life, work, transport, our economies, and our social hierarchies; "energy is the lifeblood of any societal process, and it impacts directly on the economic growth of all nations on this planet" [58]. Energy choices affect the entirety of social institutions and social structure, as well as the natural environment. It is well documented that current energy choices have a negative environmental impact. Yet it is important to remember that "the environmental crisis is thus, above all, a crisis of society" [59]. The very idea of sustainable development, and its potential through renewable energy technology adoption in both "developed" and "developing" national contexts, requires critical attention to the historically unprecedented rates of resource consumption and existing conflicts regarding consumption and economic inequality among consumers both within and across nations [57,60–62].

The attempt to reflexively integrate two seemingly contrasting theories in application to solar technology adoption results in a potential policy recommendation. As both theories are able to conceptualize solar technology adoption at the meso-level scale of businesses and communities, there is reason to recommend policy measures aimed at promoting solar energy technology in this realm. In both the "developed" and the "developing" world, solar energy technology is an economically feasible means of pursuing ecologically rational development that restores the rifts in the energy and carbon metabolisms caused by the materials, processes, and industrial forms of organization used by human societies. These two conceptual frameworks can contribute to the creation of policies focused on promoting resilient communities and efficient industries that restore the balance between human energy needs and the energy budget constraints of the natural world.

Conflicts of Interest

The author declares no conflict of interest.

References

1. Farhar, B.C.; Unseld, C.T.; Vories, R.; Crews, R. Public opinion about energy. *Annu. Rev. Energy* **1980**, *5*, 141–172.
2. Farhar-Pilgrim, B.; Unseld, C.T. *America's Solar Potential: A National Consumer Study*; Praeger Publishers: New York, NY, USA, 1982.
3. Shama, A. *Marketing Solar Energy Innovations*; Praeger Publishers: New York, NY, USA, 1981.
4. Shama, A. Speeding the diffusion of solar energy innovations. *Energy* **1982**, *7*, 705–715.

5. United States Solar Energy Industry Association (SEIA). *U.S. Solar Industry Year in Review: U.S. Solar Energy Industry Charging Ahead*; 2006 Annual Report; SEIA: Washington, DC, USA, 2006.
6. Jacobson, M.Z.; Delucchi, M.A. A path to sustainable energy by 2030. *Sci. Am.* **2009**, *301*, 58–65.
7. Jacobson, M.Z.; Delucchi, M.A. Providing all global energy with wind, water, and solar power, Part 1: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy* **2011**, *39*, 1154–1169.
8. Gonzalez, G.A. *Energy and Empire: The Politics of Nuclear and Solar Power in the United States*; State University of New York Press: Albany, NY, USA, 2012.
9. Reece, R. *The Sun Betrayed: A Report on the Corporate Seizure of U.S. Solar Energy Development*; South End Press: Boston, MA, USA, 1979.
10. Pearce, J.M. Photovoltaics: A path to sustainable futures. *Futures* **2002**, *34*, 663–674.
11. Pearce, J.M. Expanding photovoltaic penetration with residential distributed generation from hybrid solar photovoltaic and combined heat and power systems. *Energy* **2009**, *34*, 1947–1954.
12. Pearce, J.M. Industrial symbiosis of very large scale photovoltaic manufacturing. *Renew. Energy* **2008**, *33*, 1101–1108.
13. Wiginton, L.K.; Nguyen, H.T.; Pearce, J.M. Quantifying solar photovoltaic potential on a large scale for renewable energy regional policy. *Comput. Environ. Urban Syst.* **2010**, *34*, 345–357.
14. Clark, B.; York, R. Carbon metabolism: Global capitalism, climate change, and the biospheric rift. *Theory Soc.* **2005**, *34*, 391–428.
15. Foster, J.B. *Marx's Ecology: Materialism and Nature*; Monthly Review Press: New York, NY, USA, 2000.
16. Foster, J.B. Marx's theory of metabolic rift: Classical foundations for environmental sociology. *Am. J. Soc.* **1999**, *105*, 366–405.
17. Marx, K. *Grundrisse: Foundations of the Critique of Political Economy*; Random House: New York, NY, USA, 1973.
18. Burkett, P. Marx's vision of sustainable human development. *Mon. Rev. An Indep. Soc. Mag.* **2005**, *5*, 34–62.
19. Foster, J.B. The crisis of the earth: Marx's theory of ecological sustainability as a nature-imposed necessity for human production. *Org. Environ.* **1997**, *10*, 278–295.
20. Burkett, P.; Foster, J.B. Metabolism, energy, and entropy in Marx's critique of political economy. *Theory Soc.* **2006**, *35*, 109–156.
21. Marx, K. *Capital*; International Publishers: New York, NY, USA, 1967; Volume 3.
22. Moore, J.W. Environmental crisis and the metabolic rift in world-historical perspective. *Org. Environ.* **2000**, *13*, 123–157.
23. Daly, H.E. *Steady-State Economics: The Economics of Biophysical Equilibrium and Moral Growth*; W.H. Freeman and Company: San Francisco, CA, USA, 1977.
24. Lovins, A.B.; Lovins, L.H.; Hawken, P. A road map for natural capitalism. *Harv. Bus. Rev.* **1999**, *77*, 145–158.
25. Hawken, P.; Lovins, A. Lovins, L.H. *Natural Capitalism: Creating the Next Industrial Revolution*; Little, Brown and Company: Boston, MA, USA, 1999.
26. Washington, H. *Human Dependence on Nature: How to Help Solve the Environmental Crisis*; Routledge: New York, NY, USA, 2013.

27. Linton, J.D; Klassen, R.; Jayaraman, V. Sustainable supply chains: An introduction. *J. Op. Manag.* **2007**, *25*, 1075–1082.
28. Seuring, S.; Müller, M. From a literature review to a conceptual framework for sustainable supply chain management. *J. Clean. Prod.* **2008**, *16*, 1699–1710.
29. Braungart, M.; McDonough, W. *Cradle to Cradle: Remaking the Way We Make Things*; North Point Press: New York, NY, USA, 2002.
30. Braungart, M; McDonough, W.; Bollinger, A. Cradle-to-cradle design: Creating healthy emissions—A strategy for eco-effective product and system design. *J. Clean. Prod.* **2007**, *15*, 1337–1348.
31. Ellen MacArthur Foundation. *Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition*; Ellen MacArthur Foundation: Cowes, UK, 2012.
32. Preston, F. *A Global Redesign? Shaping the Circular Economy*; Chatham House: London, UK, 2012.
33. Ngyun, H.; Stuchtey, M.; Zils, M. Remaking the industrial economy. Available online: http://www.mckinsey.com/insights/manufacturing/remaking_the_industrial_economy (accessed on 9 February 2015).
34. Schelly, C. Transitioning to renewable sources of electricity: Motivations, policy, and potential. In *Controversies in Science and Technology*; Kleinman, D.L., Cloud-Hansen, K., Handelsman, J., Eds.; Oxford University Press: New York, NY, USA, 2014; Volume 4, pp. 62–72.
35. Schelly, C. Residential solar electricity adoption: What motivates, and what matters? A case study of early adopters. *Energy Res. Soc. Sci.* **2014**, *2*, 183–191.
36. Schelly, C. Implementing renewable energy portfolio standards: The good, the bad, and the ugly in a two state comparison. *Energy Policy* **2014**, *67*, 543–551.
37. Lorenzen, J.A. Green and smart: The co-construction of users and technology. *Res. Hum. Ecol.* **2012**, *19*, 25–36.
38. Owens, S.; Driffill, L. How to change attitudes and behaviours in the context of energy. *Energy Policy* **2008**, *36*, 4412–4418.
39. Mol, A.P.J. Ecological modernization: Industrial transformations and environmental reform. In *The International Handbook of Environmental Sociology*; Redclift, M., Woodgate, G., Eds.; Edward Elgar Press: Cheltenham, UK, 1997.
40. Mol, A.P.J. *The Refinement of Production: Ecological Modernization Theory and the Chemical Industry*; Van Arkel: Utrecht, The Netherlands, 1995.
41. Spaargaren, G.; Mol, A.P.J. Sociology, environment, and modernity: Ecological modernization as a theory of social change. *Soc. Nat. Res.* **1992**, *5*, 323–344.
42. Huber, J. *The Lost Innocence of Ecology: New Technologies and Superindustrial Development*; Fisher: Frankfurt am Main, Germany, 1982.
43. Huber, J. *The Rainbow Society: Ecology and Social Policy*; Fisher: Frankfurt am Main, Germany, 1985.
44. York, R.; Rosa, E.A. Key challenges to ecological modernization theory. *Org. Environ.* **2003**, *16*, 273–288.
45. York, R.; Rosa, E.A.; Dietz, T. Footprints on the earth: The environmental consequences of modernity. *Am. Soc. Rev.* **2003**, *68*, 279–300.

46. Buttel, F.H. Ecological modernization as social theory. *Geoforum* **2000**, *31*, 57–65.
47. Carolan, M.S. Ecological modernization: What about consumption? *Soc. Nat. Res.* **2004**, *17*, 247–260.
48. Mol, A.P.J.; Spaargaren, G. Ecological modernization theory in Debate: A review. *Env. Politics* **2000**, *9*, 17–49.
49. Harbaugh, W.T.; Levinson, A.; Wilson, D.M. Reexamining the empirical evidence for an environmental Kuznets curve. *Rev Econ. Stat.* **2002**, *84*, 541–551.
50. Marx, K. *Early Writings*; Vintage Press: New York, NY, USA, 1974.
51. Ulgen, K.; Hepbasli, A. Solar radiation models part 1: A review. *Energy Sources* **2004**, *26*, 507–520.
52. Branker, K.; Pathak, M.J.M.; Pearce, J.M. A review of solar photovoltaic levelized cost of electricity. *Renew. Sustain. Energy Rev.* **2011**, *15*, 4470–4482.
53. Pearce, J.M.; Blair, C.M.; Laciak, K.J.; Andrews, R.; Nosrat, A.; Zelenika-Zovko, I. 3-D printing of open source appropriate technologies for self-directed sustainable development. *J. Sustain. Dev.* **2010**, *3*, 17–29.
54. Ehrenfeld, J.; Gertler, N. Industrial ecology in practice: The evolution of interdependence at Kalundborg. *J. Ind. Ecol.* **1997**, *1*, 67–79.
55. Ehrenfeld, J. Industrial ecology: A framework for product and process design. *J. Clean. Prod.* **1997**, *5*, 87–95.
56. Ehrenfeld, J. Industrial ecology: A new field of only a metaphor? *J. Clean. Prod.* **2004**, *12*, 825–831.
57. Rees, W.E. Achieving sustainability: Reform of transformation? *J. Plan. Lit.* **1995**, *9*, 343–361.
58. Sklar, S. Institutional and financing changes that need to be implemented to bring solar and renewable energy into significant worldwide markets. *Sol. Energy* **1993**, *50*, 101–103.
59. Foster, J.B.; Jermier, J.M.; Shrivastava, P. Global environmental crisis and ecosocial reflection and inquiry. *Org. Environ.* **1997**, *10*, 5–11.
60. Kopnina, H. What is (responsible) consumption? Discussing environment and consumption with children from different socioeconomic backgrounds in The Netherlands. *Environmentalist* **2011**, *31*, 216–226.
61. Kopnina, H. An exploratory case study of Dutch children's attitudes toward consumption: Implications for environmental education. *J. Environ. Ed.* **2013**, *44*, 128–144.
62. O'Connor, J. Is sustainable capitalism possible. In *Is Capitalism Sustainable? Political Economy and the Politics of Ecology*; O'Connor, M., Ed.; Guilford Press: New York, NY, USA, 1994.