Chapter

Systems-Thinking Framework for Renewables-Powered World

Lin-Shu Wang and Peng Shi

Abstract

Humans has experienced energy transitions throughout its history and the current transition from fossil energy to renewable energy is the latest example. But this latest example is different: rather than resulting from scarcity, this energy transition results from the threat of global warming—which is generally attributed to the short-term increasing of carbon dioxide in the atmosphere but also to the long-term heat threat posed by a warming Sun, according to the Gaia theory. Perspective appreciation of the nature of this combination necessitates for us to take a systems-thinking about the Earth system as a whole rather than the standard narrative of technical solution to our problem (of how to convert a small part of the abundant solar energy [including wind energy] into useful energy). Only by framing the energy transition as a part of dealing with the existential threat of global warming as *heat threat*, we are capturing the right perspective. Rather than any shortfall of energy—increasing carbon dioxide, heat threat, and collapse of Earth's ecosystems are the real threats. Cognizant of these is the beginning for humans to seize solutions to deal with the threats before it is too late.

Keywords: renewable energy, energy transition, global warming, heat threat from a warming Sun, systems thinking, entropy growth potential, carbon dioxide as a surrogate-indicator of the collapse of Earth's disequilibrium-ness, electrification of space heating

1. Introduction

This chapter is a perspective chapter—on the topic of renewable energy-resources or renewables, and how do we think about renewable energy and a renewables-powered world? One way to think about renewable energy is that it is a *form* of energy such as solar or wind that, unlike fossil energy that takes millions of years for its renewal, is being renewed diurnally. It should be emphasized that energy is never consumed (thus never needs to be renewed), and only the form of an energy, once it is transformed into heat form, needs to be renewed. Therefore, the vast difference between the times required for renewing the two kinds of energy is significant in talking about fossil energy and renewable energy. Historically, other kinds of transition from one kind of energy form to another kind of energy form have happen [1]. Nonetheless, the current transition is different; characterizing this transition from fossil energy regime to renewable energy regime as *energy* transition is, this essay argues, misleading and totally inadequate.

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year, of which it is estimated that the annual potential of solar energy converted into useful forms was 1,575–49,837 EJ still several times larger than the total world energy consumption, which was 559.8 EJ in 2012. If the annual need of energy by the world is about 560 EJ, only 0.015% of the total solar energy received by the Earth, the standard narrative of framing the energy problem is that we are blessed with the gift of 3,850,000 EJ/yr. energy input from the Sun and the challenge is how to convert a fraction of that energy input into useful forms of energy. Once that is achieved, problem solved!

I shall argue that this is a wrong way to frame the issue. The article's premise is that the idea of transition from fossil fuel energy to renewables is not just the transition from one form of energy resources to another form of energy resources; looking at renewables as a form of inexhaustible energies, or more correctly as a form of energies that are being readily renewed, is not sufficient reason for justifying energy transition: Instead,

the transition is necessary for overcoming an existential threat to humans rather than for solving the eventual shortfall of fossil energy (which cannot be readily renewed);

the transition is a transition from the notion of "energy and its consumption" to the notion of "entropy-growth-potential (EGP) management";
that is, the transition is a transition from looking at our world in terms of "machines as machines powered by energy" to that in terms of "EGP-powered systems and their management."

As President Kennedy said (see **Figure 1**), "In a crisis, be aware of the danger—but recognize the opportunity," the **purpose** of the essay is to make the point that this current energy transition is different from all previous ones [1] and this unique crisis of carbon-emission induced global warming is a crisis too "precious" to waste for us not to formulating solutions to deal with the human existential-risk [2] that is threatened not just by fossil fuels shortfall. EGP management and systems-thinking are two elements that'll help us to seize the opportunities.

To make the case, this essay makes use of a combination of **methods** including:

1. philosophical argument including argument against the machine-worldview and critiques on the scientific method or methodism are given in Section 2;

2. examples of buildings as homeostatic systems are presented in Section 3;

Figure 1.
J.F. Kennedy once said, "The Chinese use two brush strokes to write the word 'crisis'. One brush stroke stands for danger; the other for opportunity. In a crisis, be aware of the danger—but recognize the opportunity."

3. critical assessment of thermodynamics theory, which in its current form is deeply flawed; as well as

4. the example of the Earth system, the discussion is made in the context of the 1972 Gaia theory.

2. From the machine worldview to the systems worldview

Whether we are consciously aware of it or not, we have been conditioned in modernity since the 17th century by a foundationalist worldview [3–6], sometime called the Newtonian worldview of a determinist physicalist clockwork-universe. The full-pledged expression of foundationalism happened only in the nineteenth century. One timeline is the introduction of Laplace's Demon: "In the introduction to his 1814 *Essai philosophique sur les probabilités*, Pierre-Simon Laplace extended an idea of Gottfried Leibniz which became famous as Laplace's Demon," [7] which is a full expression of determinism. The second is one pointed out by Papineau [8], see also [3] that only with the advent of the law of conservation of energy which finally ruled out any force other than physical forces, the notion of a causally-closed physicalist universe became widely accepted. While a determinist universe solely in terms of physical forces was first suggested by Descartes and Leibniz in the seventeenth century, Papineau pointed out that later in the century Newton actually allowed possibility of non-physical forces [8]. The standard practice of calling the determinist physicalist clockwork-universe the Newtonian worldview, therefore, is actually inconsistent with the historical fact.

In any case, profligate acceleration of energy consumption also began in the nineteenth century. This made it possible to start the Second Industrial Revolution in which fuel-burning powered machines were the backbone of all industrial activities. So, it began a worldview in which a clockwork-universe dovetailed with viewing at such a universe made of all those fuel-burning powered machines: not only the whole universe is a machine, the universe is made of all those individual machines. For this reason, we shall call the "Newtonian" worldview a machine worldview.

In 1712, Thomas Newcomen invented atmospheric steam engine, the first practical fuel-burning engine which demonstrated that heat can be a source of power. The atmospheric engines were applied on site of coal mines, where the cost of coal was not an issue, for pumping water from mines. Their efficiency, i.e., the coals required for their operation, was not good enough for applications of atmospheric engines away from sites of mine. Those applications became possible when James Watt, in partnership with Matthew Boulton, made a critical improvement of atmospheric engines by separating the condensation process of steam from the main cylinder to another cylinder designated for condensing steam: instead of the main cylinder undergoing alternate heating and cooling (for the purpose of lowering the pressure in the cylinder thus the difference of atmospheric pressure and the resulting cylinder pressure is the force that produces power), the main cylinder is the heated cylinder while the separate condensing cylinder is the cooled one; whereby the lowering pressure in the main cylinder is obtained by opening the valve connecting the two cylinders. Thermodynamically speaking, the elimination of alternate heating and cooling reduces irreversibility, a key thermodynamic concept, in the operation. The great reduction in coal consumption made it possible for the Boulton-Watt atmospheric steam engines to be used as stationary powerplants away from coal mines. In 1776, Boulton said to Boswell, who was visiting him, "*I sell here, Sir, what all the world desires to have—power.*"

This historic technology advance initiated the First Machine Age with factories with power source not only free from the constraints of water and wind but also of magnitude unimaginably higher than animal, water and wind powers. For the first time in history power can be obtained reliably, independent of the capricious nature of water and wind. Power is where engine is, stationary ones or movable ones. Engine power augmented muscle power wherever engines and atmospheric engines are located—*separating* the power (that could drive factory machines) from the capricious nature. That was the beginning of the Second Industrial Revolution.

The Second Industrial Revolution would not be a complete revolution without another transformative technology, electricity. Most people give credit to Benjamin Franklin for discovering electricity. The invention of the electrochemical battery by Alessandro Volta in 1799 made possible the production of persistent electric currents. Hans Christian Orsted, and Andre-Marie Ampere separately, investigated electromagnetic interaction and described how electric currents through electromagnetic interaction could give rise to mechanical force and motion. It was Michael Faraday who discovered electromagnetic induction and demonstrated the phenomenon in the opposite direction, how motion through electromagnetic induction could give rise to electric currents. Thus, the production of power and motion could be used to generate electric currents, which could be transported over large distance with the invention of high voltage AC currents—separating the power from the engines. Central electricity powerplants now could power electric motors driving operations of factories, making possible for further *flexibility in siting* factories, which can be sited wherever within the reach of grid of a centralized powerplant.

All these machines, mechanical ones and electric ones, are fed with input of fuel-energy or electric energy and have specified output of work, or delivered heat energy, or delivered cold energy (i.e., heat removal), or value-added products. With defined input and output, and well-established relation between input and output, performance of the machines is defined in terms of efficiency; in the case of delivered heat-removal, "efficiency" is in the form of "coefficient of performance."

In the early 20th century, efficiency movement, a movement that sought to identify and eliminate waste, became the obsession of continuously improving operation in all areas of the economy and society [9]. The second law of thermodynamics and the concept of reversibility (and irreversibility as the cause of loss in efficiency) were the theoretical cornerstone of that movement. Augmenting human and animal muscle power [10] and improving in augmentation through continuous efficiency gain has been the reason for the singular transformation of the last three hundred years since the Enlightenment.

There is one category, however, that has so far escaped the reach of the Enlightenment and the success of science undergirded by the foundationalist worldview, the category of systems and complex systems. For example, a building is a complex system, the study of which has been greatly enhanced by computer simulation tool, such as DOE's *EnergyPlus*. But this new category is different in more fundamental way than just being more complex: they are systems instead of machines.

3. Buildings as examples of homeostatic thermal-systems

Astrophysicist Emden published in *Nature* [11] a short article in the form of puzzle or riddle:

> *Why do we have winter heating?*
> *The layman will answer: "To make the room warmer."*

> *The student of thermodynamics will perhaps so express it: "To import the lacking (inner, thermal) energy."*
> *If so, then the layman's answer is right, the scientist's is wrong…*

Emden correctly perceived no intrinsic relation between the "lacking energy" and making the room "warmer." Yet, the issue of energy for building applications is universally addressed in terms of energy efficiency. The truth is that, absent of an input-and-output relation, energy efficiency is meaningless.

ASME (American Society of Mechanical Engineers) noted in a 2013 study report,

Whereas the United States has made significant progress in increasing efficiency and reducing energy use in the transportation and industrial sectors of the economy, both building sector energy use and building system energy use have shown only modest reductions, well below what building owners and government policy leaders have hoped for. Automobiles, aircraft systems, and locomotion systems have all shown efficiency improvements twice that of building systems… (ASME Integrated / Sustainable Building Equipment and Systems (ISBES) Open Research Forum (ORF-1) April 24, 2013 Washington, DC).

Neither the movement based on efficiency improvement nor the green-building movement has produced the result that have been the intense pursuit of the first two decades of the 21st century. There are two possible interpretations of this 2013-report conclusion of lacking of progress in building sector: (1) there is some fundamental misunderstanding of what a building is and, as a result of that, we fail to find effective building solutions; (2) building energy efficiency is the wrong metric as progress indicator so that talking about lacking of efficiency improvement is a red herring (see below for an alternative performance-metric).

Both interpretations are correct. The best way to decode the Emden riddle begins with the recognition that a building is not a machine and it is not designed to have a product output. Instead, a building is a system, the "design goal" of which is in keeping the state of its existence within homeostatic ranges, in particulate within a temperature range. "The scientist" and "the student of thermodynamics" are wrong because they have been trained in viewing every system as machine instead of real system—and the performance metric of every machine is in terms of efficiency.

Architects appreciate partially the point in this way: building conditioning should not be based on machine-based solutions failing to see a building as a system as a whole. Addressing the building conditioning problem, "Albert, Righter and Tittmann" characterized the solutions of the three centuries this way as shown in **Figure 2**. ART depicted a 19th century building offering minimal thermal comfort. In the 20th century, the building conditioning was handled by machines of the First Machine Age resulting in, as ART depicted, a messy, incoherent set of devices. The point is that the machine-based solutions were conceived without a plan for maintaining a building as a system as a whole. This practice continues today. In the third depiction, ART suggested the building being maintained by renewable energies managed with mechanical assistance—basically it suggested an architecture-based solution that are known as green building solutions by USGBC. While the eventual success of transitioning from mechanical-engineering solutions to green-building solutions remains an open question, **Figure 2** correctly suggests that architectural societies and engineering (ASHRAE) societies need, in partnership, to look at buildings as systems, not machines.

Furthermore, the full implication of thinking in terms of systems must go beyond individual systems to think about both individual systems and how the individual systems, in the context of building systems, interact with each other and with "power-grid/powerplants-that-power-the-grid." Systems thinking is very much ecological thinking.

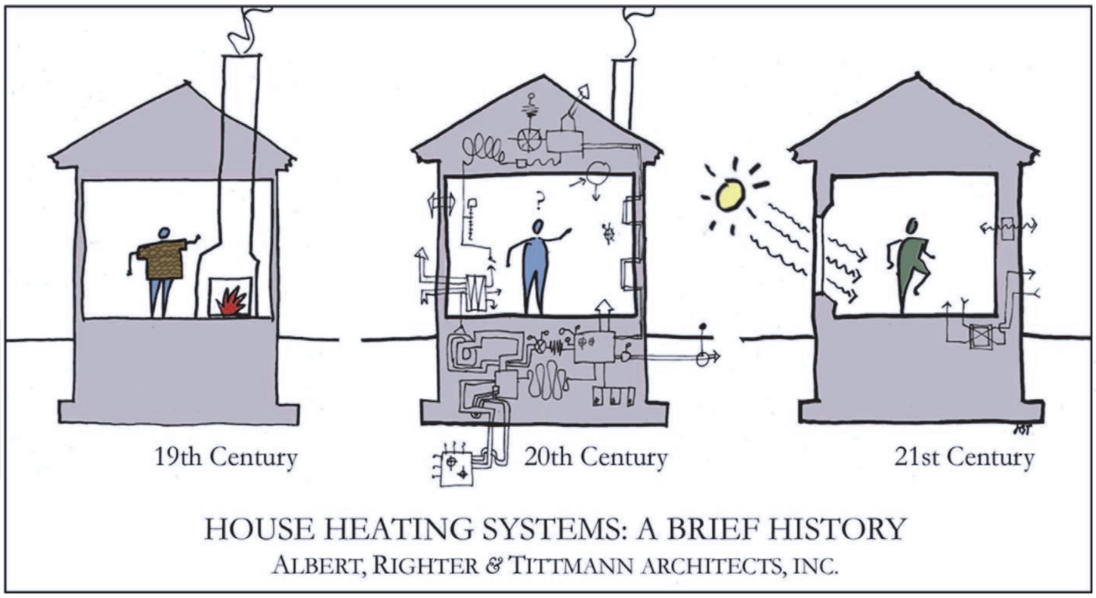

Figure 2.
Evolution of building heating systems over three centuries: From architectural solutions to mechanical-engineering solution to machine-assisted green solutions.

Electrical power is an energy carrier that can be powered by renewables. In recent years, wind power and solar electric power have become cost-wise competitive with traditional powers, and there is a consensus that electrification-of-everything is the best approach to achieve ultralow-carbon emission goal or zero-carbon emission goal—which is the ultimate objective of the current energy transition project.

Instead of being distracted with "increasing efficiency and reducing energy use in … building sector," we have the perfect performance-metric for building, *carbon emission.* A recent study of the application of such metric unveils a very interesting finding.

A typical electric grid is powered by a mix of generators: baseload powerplants of nuclear, coal, and hydro; natural gas electric-generators; wind farms and solar farms; fossil-fuel peak-stations. The carbon emission related to electricity generation/consumption is strongly dependent on the actual mixture of the generators with various types of fuel sources. The study, a doctoral thesis [12], is based on the 2019 (hourly) time series data of electricity generation/consumption by source fuel type (NY ISO [13]) for determining hourly *carbon intensity*,

$$carbonemission = carbonintensity \times electricityconsumption \tag{1}$$

Because of high variation in the instantaneous mixture of generators, both hourly carbon emission, which depends on hourly fuel consumption, and hourly carbon intensity are highly variable.

Unlike the hourly generation/consumption by source data, the hourly fuel consumption data is not available from NY ISO. The only related fuel consumption data for electricity generation comes from US EIA electricity monthly database. From this database, the fuel consumption and resulting electricity generation data are available in monthly resolution in New York in 2019. Therefore, the efficiencies of various types of generators can be calculated. The monthly generation efficiencies from natural gas, petroleum liquid, and coal generators are up-sampled as constants and serve as denominator of the hourly electricity generation by source data to calculate the hourly consumption of the three fossil fuels. Then total carbon emissions from these fossil fuel consumptions can be calculated in hourly resolution with the EPA Greenhouse Gas Inventories.

Once the hourly carbon emissions data associated with electricity generation is obtained, the *time-varying carbon intensity* of electricity is calculated by dividing that with the hourly electricity generation/consumption data. One may wonder if the ultimate objective is to lower total carbon emission why one goes through the loop of dividing carbon emission data with electricity consumption data—for the purpose of multiplying the resulting carbon intensity with electricity consumption, again, to get carbon emission estimate. The answer is that carbon intensity is a function of existing grid based on current pattern of grid-wide electricity usage, whereas consideration of change in individual electricity consumption may be made for evaluating impact of such change on carbon emission. Such consideration may be made under the assumed carbon intensity, which will not change in short term. In short, with an assumed unchanging ***carbonintensity*** (e.g., in gray in **Figure 3**), estimate of ***carbonemission*** of different demand of electric usage (in yellow in **Figure 3**) can be made.

$$\text{estimateofcarbonemission} = \sum_{Year} carbonintensity \times changedelectricityconsumption \tag{2}$$

Calculated result of carbon intensity based on existing pattern of grid-wide electricity usage in the study [12] is reproduced here in **Figure 3**. Superimposed with carbon intensity in the figure is the simulated electricity consumption makeup of an individual building with air-conditioning as well as electrified space heating and domestic water heating shown in yellow (referred to as eHP). Note the high winter peaks of eHP as a result of winter space heating, whereas the standard common practice of a combination of air-conditioning and fossil fuel fired space heating and domestic hot-water heating has peaks, much lower ones, in summer only. So, when we multiply the carbon intensity with electricity consumption (electric demand), it is a very different electric demand makeup (from that determining the existing carbon intensity) resulting in very different carbon emission estimate.

The estimate of annual carbon emission is shown as **Figure 4**.

As a result of the peaks of carbon intensity (based on current grid with its operation outside the summer season being underused) and electricity demand of eHP are out of phase with each other, a 70% reduction in carbon emission (reduction from 7087 to 2214) is projected even with the current grid. Even with limited

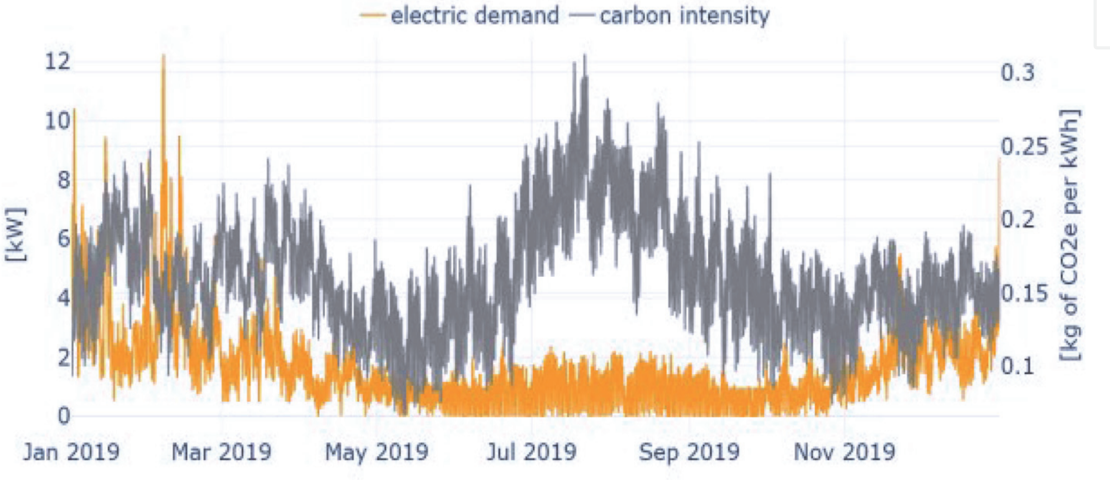

Figure 3.
Carbon intensity of existing pattern of grid-wide electricity usage and simulated electric demand of eHP (electrified space cooling & heating and DHW heating).

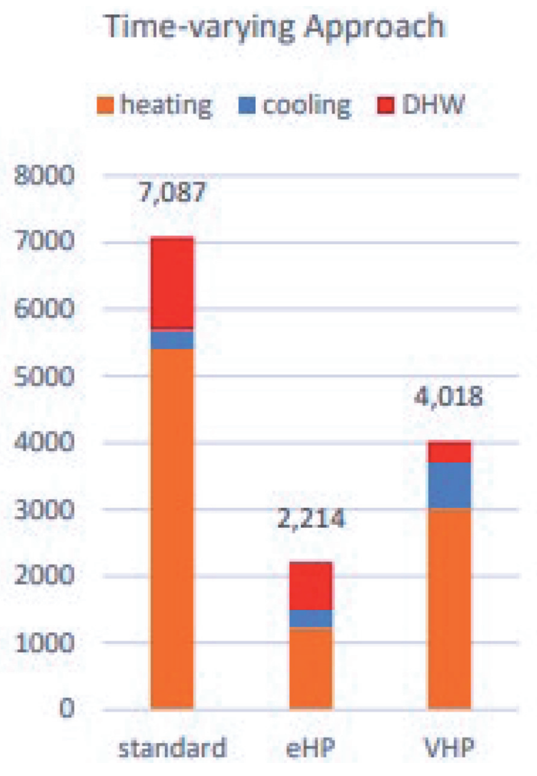

Figure 4.
Estimate of annual carbon emission of eHP in comparison with that of standard building conditioning.

penetration of renewables in our current grid, an instant drastic reduction in carbon emission can be achieved when each individual building goes to be fully electrified.

This is an example of the great potential of systems approach.

Another characteristic that differentiates systems approach from "Newtonian" machine approach is while the machine worldview is a static worldview, the systems worldview sees the world as a dynamic, changing, world. The finding of **Figures 3** and **4** make a compelling case for immediate deployment of electrification of space heating and domestic hot water heating—as6long as the extent of such deployment does not change "pattern of grid-wide electricity usage" in any significant way, i.e., the carbon intensity shown in **Figure 3** holds.

When market-deployments of electrification of heating reach significant market penetration, it'll change pattern of grid-wide electricity usage into one that manifests high winter peak demand. That is a problem which has to be solved—without which the progress of electrification of everything including heating will be halting to full stop resulting from a carbon intensity very different from the one shown in **Figure 3**. Both the cost advantage and the carbon emission advantage will vanish. Usage of energy storages both of electricity storages and thermal energy storage (TES) will be *crucial parts* of the solutions, investigation of the latter kind, TES, has been carried out in the study [12].

The building sector is a good example of systems approaches. Buildings, when they are considered as parts of grid system, are example of ecosystems. However, as ecosystems they are different from "ecological systems that are made of organisms" in a fundamental nature: unlike organisms that are active participants of the ecological systems having geophysical/geophysiological impacts on the non-living part of the systems (especially, see the Gaia discussion in Section 5), human inhabitants are passive components of building without defining building in a physical or ecological sense. While it has been suggested that standard theories of thermodynamics fail to treat the world in terms of systems thus fail to equip students of thermodynamics to have a solid grasp on the study of buildings, their shortcoming in dealing with ecological systems is much more serious. A case can be made that they totally miss the central question and its related core issues. A brief report on how this can be remediated is given in the next section.

4. The first law and the second law of thermodynamics

Theory of thermodynamics is constructed on the two laws of thermodynamics, the first law and the second law. Generally, students of thermodynamics consider that the first law is well understood but that the second law is the one that is difficult to comprehend. One obvious problem is that there are two versions of the second law: the original version formulated by Thomson (later, lord Kelvin) that of the universal degradation of mechanical energy [14], which'll be called, in short, *the energy principle*; the later version formulated by the Berlin School of thermodynamics by Clausius and Planck, which'll be called the entropy principle. The entropy principle has been universally acknowledged to be the true second law of thermodynamics.

There are multiple problems here. First is that though the entropy principle is accepted to be the true second law most students consider the meaning of the entropy principle to be encapsulated by the universal degradation of high-grade forms of energy, i.e., the energy principle. If the two principles are merely synonyms, that situation is acceptable. The problem worsens, therefore, because they are not. That demonstration can be made by showing that while the entropy principle is a universal principle, the energy principle is *not* a universal principle. Such a conclusion was reached by Planck [15]:

> *The real meaning of the second law has frequently been looked for in a "dissipation of energy." This view, proceeding, as it does, from the irreversible phenomena of conduction and radiation of heat, presents only one side of the question. There are irreversible processes in which the final and initial states show exactly the same form of energy, e.g., the diffusion of two perfect gases or further dilution of a dilute solution. Such processes are accompanied by no perceptible transference of heat, nor by external work, nor by any noticeable transformation of energy. They occur only for the reason that they lead to an appreciable increase of the entropy ([5], pp. 103–104).*

Details of Planck's argument has been worked out in a recent book, *A Treatise of Heat and Energy* [16], which concludes that mechanical energy degrades spontaneously not universally.

A good question would be why Planck's conclusion, which is of supreme importance, has not been more widely disseminated. *A Treatise* seeks to explain this situation by arguing that the entropy principle formulated by the Berlin School was a selection principle: the 19th century Berlin School was under the sway of the foundationalist mechanical-philosophy and the only kind of selection permitted by the entropy principle as a selection principle in accordance with the mechanical philosophy is selection based on physical necessity or efficient causation. As a result of the metaphysics of necessity as physical necessity alone, the inevitability of entropy growth infers the corollary of inevitable accumulation of heat, i.e., the energy principle.

In short, under the sway of the mechanical-philosophy, Clausius and Planck were not able to formulate a second law that Planck clearly realized, later on, should cast away the energy principle.

Before a new formulation of the second law for achieving that purpose is discussed, let us look at the first law: it turns out that we have misconception about the first law as well. Misconception about the two laws is intrinsically intersected: The first law was based on the mechanical equivalent of heat, i.e., the equivalence principle. The equivalence principle is the idea that all forms of energy during transformation from one form to another are conserved, i.e., all energy-forms are universally connected. But connection does not mean (necessarily) causation. That misstep was taken by Thomson and Clausius when they independently formulated the first and the second laws by giving causal power (the power that should be the purview of the second law) to the first law—making it too powerful depriving the second law of its rightful purview. The result of that misstep is a second law as a selection principle instead of a selection and causal principle.

This point was made in A Treatise. A more detailed discussion can be found in a new paper [17]. Back to the issue on the second law: a short account of a new formulation of the second law as it is related to the Carnot cycle is shown here.

The Carnot cycle can be interpreted differently from how it has been taken according to the conventional perspective: Instead of it as "an energy conversion of heat energy at T_A to mechanical energy," we consider the cycle as "the reversible event, in reference to a corresponding spontaneous event, of heat transfer from a T_A hot body to a T_B cold heat-reservoir." We thus begin, with the same setup enabling the Carnot cycle, by considering two "book-end" events,

1. The spontaneous event of the heat transfer process, the reference event, and

2. The reversible work production event of the Carnot cycle.

The book-end events define a *Poincare range* [15, 16]. Consider, first, entropy growth in the spontaneous event, in which the same amount of heat energy Q_A exiting the T_A heat body enters the T_B cold heat-reservoir. Therefore, the entropy growth in the universe is:

$$(\Delta_G S)_{univ} = \frac{-Q_A}{T_A} + \frac{Q_A}{T_B} \tag{3}$$

Whereas in the reversible event, a smaller amount of heat energy, Q_B, enters the T_B cold heat-reservoir resulting in zero entropy growth, in accordance with the entropy principle,

$$0 = \frac{-Q_A}{T_A} + \frac{Q_B}{T_B} \tag{4}$$

The heat energies exchanged with the T_B heat-reservoir during the two events are Q_A and $Q_A \bullet \frac{T_B}{T_A}$, respectively, as summarized in **Table 1**.

Rather than as a fraction of Q_A in accordance with the conventional perspective, note, in this new perspective, that the mechanical energy, (W_{rev}), is *preciously* the

Heat discharged to the T_B heat-reservoir	Event
	the spontaneous event
$Q_B = Q_A \bullet \frac{T_B}{T_A}$	the reversible event (According to a standard Carnot heat engine treatment)

Table 1.
Difference in heat discharged to heat-reservoir for the two book-end events.

difference between the amounts of heat energy added to the T_B heat-reservoir for the two events, given by:

$$W_{rev} = Q_A - Q_A \bullet \frac{T_B}{T_A} \tag{5}$$

Which is found to be the product of the universe's entropy growth in the spontaneous event according to (3), $(\Delta_G S)_{univ}$, and the temperature of the cold heat-reservoir, T_B,

$$W_{rev} = Q_A - Q_A \bullet \frac{T_B}{T_A} = T_B \bullet \left(\frac{-Q_A}{T_A} + \frac{Q_A}{T_B} \right) = T_B \bullet (\Delta_G S)_{univ} \tag{6}$$

Accordingly, we call the universe's entropy growth in the spontaneous event, $(\Delta_G S)_{univ}$, the "*entropy growth potential*" (EGP), $(\Delta_P S)_{univ}$ (for the reason articulated in the paragraph below):

$$(\Delta_G S)_{univ} = (\Delta_P S)_{univ} \tag{7}$$

Eq. (6), then, becomes,

$$W_{rev} = T_B \bullet (\Delta_P S)_{univ} \tag{8}$$

The logic of calling $(\Delta_G S)_{univ}$ "EGP" in (7) and (8) is that EGP is a *common property* (the term Poincare used in [16, 18]) of both events, as well as of all possible events in the Poincare range. This common property is the driver for enabling the *extraction* of a given amount of heat energy from the T_B heat-reservoir and converting it to mechanical energy of the same amount; in each case the amount for a specific event, though subject to the same "common property," is different; the maximum amount of extracted heat for a Poincare range is given by (8).

The same kind of demonstration on the idea of a common property has been made for systems in general, especially for isolated composite systems, in A Treatise and in References [17, 19]. We have, therefore, as a new part of the second law, *entropy growth potential principle*, in a general statement [19]:

> *for a given non-equilibrium system, the spontaneous event of the system approaching equilibrium state and the corresponding reversible event defined by the same initial and final states define its Poincare range; any event in the range shares the same common property of EGP, while the specific entropy growth is different dependent on the individual event in accordance with its individual causal necessity.*

Note that, for the existence of a system's EGP in association with change between the initial state and the final states of the system, physics does not require system energy change (though it often is associated with system energy change). Energy is NOT a necessary substrate for the existence of EGP. In contrast, physics (the second law) does require the system in its initial-state existence at non-equilibrium state. A good safe distance from equilibrium state is the defining condition for a system, any system, to be the driving force for making the world go around—the precise metric of which is its entropy growth potential, EGP.

In sum, the conventional formulation of the first law is too powerful depriving the second law, as a selection principle, of its rightful purview. We have reformulated the first law [17] by taking away the causal power of energy—and reformulated the second law [16, 19] as a selection principle (the inevitable growth of entropy) and causal principle (entropy growth potential principle).

5. Homeostasis in ecological systems, and the need to keep the Earth system cool

The conventional thermodynamics was formulated in the 19th century under the orthodoxy of the foundationalist mechanical-philosophy, in which the world is a machine made of machines. The theory is unable to deal with systems, especially ecological systems made of biological organisms.

Because the conventional theory is based on metaphysics of physical necessity, in dealing with complex systems with emergent orders a common theory of complex systems is known as maximum entropy production principle (MEPP). MEPP accounts for the emergence of local orders of individual complex systems by individual complex systems' ability to export entropy produced (grown) internally/locally to their surroundings. In the context of the Earth and ecological systems on Earth, such conclusion would predict an Earth ecosystem with greater and greater entropy corresponding with higher and higher global disorder.

A living organism becomes a dead organism by definition if its existence approaches a state of thermodynamic equilibrium or it exists in an environment that is approaching thermodynamic equilibrium. Because of that, a living organism as well as any complex system consisting of living organisms can only exist at states safely away from equilibrium. Aside from a metric-set of homeostatic ranges (for instance, temperature range), "far from equilibrium existence" (its metric is the entropy difference between entropy of the existing system and entropy of the system when it would approach thermodynamic equilibrium) is another defining characteristic of the *homeostatic state* of an organism. That is,

> ***homeostatic state*** = *metric-set of homeostatic ranges*, and *entropy difference of the system from system-at-reference-equilibrium-state.*

It is the latter defining characteristic that disqualifies MEPP, though it may be valid for complex physical systems such as climatic systems, for explaining the emergence of biological orders [19]. MEPP is a theory that is in full compliance with metaphysics of physical necessity. Ref. [17] puts forwards that by admitting causal necessity, the inference that the inevitability of entropy growth leads to the inevitable accumulation of heat, which is accepted and embraced by MEPP, is broken. Correspondingly, Ref. [19] puts forwards the thesis that emergence of biological and ecological orders requires admitting causal necessity as well. That is, the abandonment of mechanical-philosophy with its physical necessity stricture.

An example of this kind of consideration is the body of work on Gaia by James Lovelock, who applied far-from-equilibrium consideration to complex system consisting of living organisms. When he was a consultant at the Jet Propulsion Laboratory in Pasadena, CA, he was given the assignment of how to detect whether a planet harbors life. Lovelock began with the hypothesis that a planet as a complex system consisting of life—like a single organism—must be far from equilibrium or at radically disequilibrium state. Therefore, its atmospheric chemical composition must exhibit high concentrations of reactive gases, such as Earth's atmosphere which contains high concentration of oxygen and methane. Whereas, the static Martian atmosphere composing of almost entirely of non-reactive carbon dioxide is indicative of it being absent of life. Lovelock then took the next step by hypothesizing the "renewing" of these reactive gases to be a self-regulating mechanism of a planetary ecosystem. Lovelock together with microbiologist Lynn Margulis went further claiming the Earth to be in effect a superorganism, called Gaia (Lovelock, [20], Lovelock and Margulis, [21, 22]; Margulis and Lovelock, [23]). This version of Gaia, of a "living" complex system consisting of living organisms just like a single living organism, had received strong push back, when it was originally proposed, by biologists especially evolutionary biologists as unworkable in theory (Dawkins, [24]; Doolittle, [25]).

However, the idea of Gaia that all living things collectively define and maintain the conditions conducive for life through a filtering "selection" mechanism has since begun to receive acceptance [26] including Doolittle himself (see below). What is at issue is not the disequilibrium state of the Earth and that some kind of self-regulating mechanism for maintaining the state homeostatically (the former is a matter of physics and the latter is an observational fact of the Earth system), but how a "superorganism" acquires such a mechanism. Doolittle, in his reassessment of Gaia, put the matter this way (very different from his view of four decades earlier) as:

> *The Gaia hypothesis in a strong and frequently criticized form assumes that global homeostatic mechanisms have evolved by natural selection favoring the maintenance of conditions suitable for life. Traditional neoDarwinists hold this to be impossible in theory. But the hypothesis does make sense if one treats the clade that comprises the biological component of Gaia as an individual and allows differential persistence – as well as differential reproduction – to be an outcome of evolution by natural selection. Recent developments in theoretical and experimental evolutionary biology may justify both maneuvers [27].*

This new assessment on Gaia is a momentous step, which confirms the rejection of mechanical-philosophy—additionally, it makes the metaphysical presupposition that the world is made up of *natural kinds* such as atoms, molecules, and chemical elements, and *individuals* such as organisms, species. Clades, and Gaia. Whereas the former is characterized in terms of physical necessity, the latter in terms of physical necessity and causal necessity. The concept of natural selection was the revolutionary step taken by Darwin to finesse the teleological issue within the orthodoxy of mechanical-philosophy in biology. That was revolutionary and subversive. With the new momentous step, natural selection, which seemed to be a poster-boy of mechanical-philosophy, now undergoes its subversive transformation overthrowing the mechanical philosophy to include "survival of reproduction competitiveness" as well as "persistence as a result of global homeostatic mechanisms" [27].

One of Earth's homeostatic mechanisms is the mechanism to keep the Earth cool, according to Lovelock, in face of Sun's increasing solar radiative heat output. It is necessary to keep the Earth cool because:

> *It is vital for our survival that the sea is kept cool … Whenever the surface temperature of the ocean rises above 15°C, the ocean becomes a desert far more bereft of life than the Sahara. This is because at temperature above about 15°C the nutrients in the ocean surface are rapidly eaten and the dead bodies and detritus sink to the regions below. There is plenty of food in the lower waters, but it cannot rise to the surface because the cooler lower ocean water is denser than water at the surface … This is important because … Earth is a water planet with nearly three-quarters of its surface covered by oceans. Life on land depends on the supply of certain essential elements such as sulfur, selenium, iodine and others. Just now these are supplied by ocean surface life as gases like dimethyl sulfide and methyl iodide. The loss of this surface life due to the heating of these waters would be catastrophic [28].*

Rising ocean surface temperature will lead to catastrophic decline of both ocean surface life and land life.

How has Gaia, the Earth system, maintained its temperature within a homeostatic range: Lovelock suggests the following mechanism as a working hypothesis:

> *"In modern times, carbon dioxide is a mere trace gas in the atmosphere compared with its dominance on the other terrestrial planets or with the abundant gases of Earth, oxygen and nitrogen. Carbon dioxide is at a bare 340 parts per million by volume now. The early Earth when life began is likely to have 1000 times as much carbon dioxide… As the Sun warmed, two processes took place. The first was an increase in the rate of evaporation of water from the sea and, hence, rainfall; the second, an increase in the rate of the reaction of carbon dioxide with the rocks. Together, these processes would increase the rate of weathering of the rocks and so decrease the carbon dioxide. The net effect would be a negative feedback on the temperature rise as the solar output increased… [Lovelock then added a third process involving living organisms]… living organisms act like a giant pump. They continuously remove carbon dioxide from the air and conduct it deep into the soil where it can react with the rock particles and be removed [29].*
> *"… If confirmed, it suggests that cloud cover and low carbon dioxide operated in synchrony as part of a geo-physiological process to keep the Earth cool… [30].*
> *"From the very beginning of life on Earth, carbon dioxide has had a contradictory role. It is the food of photo-synthesizers and therefore of all life; the medium through which the energy of sunlight is transformed into living matter. At the same time, it has served as the blanket that kept the Earth warm when the Sun was cool. A blanket that, now that the Sun is hot, is becoming thin; yet one that must be worn, for it is also our sustenance as food. We have seen earlier how the biota everywhere on the land and sea are acting to pump carbon dioxide from the air so that the carbon dioxide which leaks into the atmosphere from volcanoes does not smother us. Without this never-ceasing pumping, the gas would rise in concentration within a million years to levels that would make the Earth a torrid place and unfit for almost all life here now. Carbon dioxide is like salt. We cannot live without it, but too much is a poison" [31].*

The details of the working hypothesis may yet to be worked out. But two takeaways are sufficiently clear and they are: (Surmise-1) the necessity to keep the Earth system cool in order to keep it within the temperature *homeostatic ranges*—while keeping in mind of other important *homeostatic ranges* of the *metric-set*; (Surmise-2) carbon dioxide is the critical element involved in the mechanisms of achieving the goal.

This brings us to the two metrics of ***homeostatic state***, i.e., underlying all the homeostatic ranges of Surmise-1 is the idea of keeping the Earth system safely from thermodynamic equilibrium—corresponding to Surmise-2, in which carbon dioxide is the proxy of *entropy difference of the system from system-at-reference-equilibrium-state*. This is why it is necessary to abandon the conventional thermodynamics, in which the idea would be a nonstarter, to embracing, instead, a new engineering-thermodynamics. Only with the second law as both a principle of inevitable entropy growth and a principle of entropy growth potential, it is possible to keep the Earth system safely from thermodynamic equilibrium.

One example of solutions for the goal is the electrification of space heating. The purpose of the essay is not to outline such kind of specific solutions but to use such a solution-example to advance the argument that such opportunities exist only if we frame the crisis and problem in systems-framework in terms of EGP management.

In this systems-thinking framework, we do have an existential threat. The threat is, however, not the threat of running out of fossil fuel or fossil energy. The standard narrative of such kind of thinking is that we have abundant solar energy and the solution to our problem is to find ways of converting a small part of solar energy (including wind energy) into useful energy. This is clearly the wrong way to look at the problem. If sunlight is our savior (which is) in this sense, a warming Sun should have been a welcoming development, in opposite to the idea of *heat threat* from a hot Sun [32].

Transition from fossil energy to renewables *is* a good idea, not because we welcome a warming Sun as a source of heat energy. But because the solar output received by Earth is a "form of entropy flow of very low value." Assuming the Earth system is in a state of energy balance, the Earth infrared radiative heat outflow equals the solar radiative heat inflow received by the Earth. The corresponding values of entropy flow received by the Earth from the Sun and of entropy out-flow from the Earth to out-space will be significantly very low and very high, respectively. That means that very large entropy growth potential exists in the difference of the two flows.

That means that large opportunities exist in the management of entropy growth potential. Some of those opportunities, such as electrification of heating, can be related to the control of carbon dioxide. That also means that while a warming Sun poses heat threat to the Earth, it also presents greater opportunities for EGP management.

6. Conclusion

Humans has experienced energy transitions throughout its history and the current transition from fossil energy to renewable energy is the latest example. But this latest example is different: this energy transition results from the threat of global warming—which is generally attributed to the short-term increasing of carbon dioxide in the atmosphere but also to the long-term heat threat posed by a warming Sun, according to the Gaia theory. Appreciation of the nature of this combination of proximate cause and ultimate cause necessitates for us to take a systems-thinking about the Earth system as a whole. Energy transition to renewable energy is certainly correct, especially reassuring since solar energy received by the Earth is 6,900 times of the energy needs of humans. The solution would be then how to convert a small part of which into useful forms for human consumption.

But justification of such a step in the narrow terms of energy is wrong. Humans face existential threat of global warming as *heat threat* from the Sun, not as energy threat of running out of fossil fuels. Solving Earth's heat threat necessitates us to take consideration of its proximate and ultimate causes with systems-thinking framework in terms of the management of EGP. Only by taking this perspective, we can address the root-issue of the heat threat—as well as seeing a warming Sun as both threat and opportunity. One of the opportunities is electrification of space heating, a paradigmatic example of systems solutions. Other possible solutions may be formulated by taking systems-thinking in terms of the management of EGP that may address some of humans' *Existential Risk and the Future of Humanity* [2].

Author details

Lin-Shu Wang* and Peng Shi
Stony Brook University, Stony Brook, NY, USA

*Address all correspondence to: lin-shu.wang@stonybrook.edu

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