Seatific, Vol. 2, Issue. 1, pp. 27–43, June 2022

Seatific
https://seatific.yildiz.edu.tr
DOI: https://doi.org/10.14744/seatific.2022.0003

Research Article

The dynamics of human society evolution: An energetics approach

Ram Chandra Poudel*[1], Jon G. Mcgowan[2]

[1]*Sustainable Technology and the Built Environment, Appalachian State University, North Carolina, USA*
[2]*Department of Mechanical and Industrial Engineering, University of Massachusetts, Amherst, USA*

ARTICLE INFO

Article history
Received: 20 May 2022
Revised: June 25, 2022
Accepted: June 28, 2022

Keywords:
Capabilities; Capital; Energetics; Evolution; Social field theory

ABSTRACT

Human society is an open system that evolves by coupling with various known and unknown (energy) fluxes. How do these dynamics unfold precisely? Energetics may provide further insights. We expand on Navier-Stokes' approach to study non-equilibrium dynamics in a field that evolves over time. Based on social field theory, an induction of the classical field theories, we define social force, social energy, and the Hamiltonian of an individual in society. The equations for the evolution of an individual and society are sketched out based on the time-dependent Hamiltonian that includes power dynamics. We demonstrate in this paper that Lotka-Volterra-type equations can be derived from the Hamiltonian equation in the social field.

Cite this article as: Poudel RC, McGowan JG. The dynamics of human society evolution: An energetics approach. Seatific 2022;2:1:27–43.

1. INTRODUCTION

Human life is a complex system. Interpreting human life based on its physical properties alone is very difficult. For now we will postpone the genesis of life and focus here on human life after it emerges. Whether one reads Longfellow (Longfellow, 1892) or Tesla (Tesla, 1900) , they each point out that human life is a movement. What is the nature of this movement? Instead of making an eponymous hypothesis, we conjecture that the human system and its underlying movements are not much different from many other systems around us. Making some sense of a conscious human being may require a higher level of comprehension (Polanyi, 1959) along with some generalizations beyond classical field theories.

Classical field theories define the potential energy of an object within the field of another object that shares the same property, such as mass, charge, or (di)pole strength. A force is a gradient of potential energy. Many phenomena in nature can be interpreted in terms of four fundamental forces: the electromagnetic, gravitational, strong, and weak forces. Are the myriad phenomena in nature governed by just these four fundamental forces? Many assume such a notion to be true. Nonetheless, some scholars are in search of more general principles (Soodak & Iberall, 1978; Haken, 1987; Gladyshev, 2017; Schumacher, 1978) that may also be applicable to living beings. Mark Buchanan (Buchanan, 2007) suggested looking at the human patterns rather than people in order to study human systems and behavior. Robert Laughlin (Laughlin, 2005) has searched for organizational forces beyond the microscopic rules, a physical principle where the whole can be greater or less than the sum of its parts. Such an organizational force may be at play in a dipole-, electric-, or magnetic field. The orientation of

***Corresponding author.**
*E-mail address: poudelrc@appstate.edu

Published by Yıldız Technical University Press, İstanbul, Turkey

one dipole has an effect on the energy of the other dipole within this field. If these two dipoles constitute two separate systems, one may be able to see an effect similar to the organizational force, where the whole becomes not only more than but also very different than the sum of the parts (Anderson, 1972).

We are proposing the existence of a new type of force, one that exists among social beings in particular. Earlier we made the case for social field theory (Poudel, Wood, & Mcgowan, 2015) by generalizing classical field theories. Based on this theory, we define the Hamiltonian of an individual in society. The equation for the evolution of an individual is sketched out here based on the time-dependent Hamiltonian that includes power dynamics (a forcing term). This paper will expand upon Navier-Stokes' approach to studying non-equilibrium dynamics in a field that evolves over time and establish how Lotka-Volterra-type equations can be derived from the time-dependent equations in the social field.

This article is organized in sections. In Section 2, we start with background information followed by a short review of the available literature on energetics. Social field theory is summarized in Section 4, and the subsequent sections present some properties of the social field. Using the groundwork spanning Sections 6 through 9, we propose the equations for the motions of an individual and a society in Section 10. A quick summary of the implications for physics and economic science are documented in Section 11. We conclude following a brief discussion in Section 12.

2. BACKGROUND

Measurement and logic are general methods in all sciences. In natural science, measurements are based on concepts like space, time, and energy (or force as energy's derivative). Social scientists have identified many similar forces but has yet to quantify social forces and social energy. Many examples occur in science where a proper quantification in a mathematical language of the relationship among variables of interest opened up a structured reasoning that has eventually contributed to the advancement of science. The social science can't be an exception.

Does a fundamental difference exist between the natural and social sciences? No doubt they are two cultures (Snow, 1961) existing within the limits of human observation. One part of social sciences is exploratory, revolving around the development of noble concepts or theories. Social theorization involves a richness and freedom beyond the structured line of reasoning exercised in many physical theories. One needs to cut to the core of the issues beyond human observation. Along Riemann's line of thinking, we argue that an attempt connecting these two sciences should not be hindered by overly narrow views, and progress should not be obstructed by traditional prejudices such as the laws of conservation or principles of invariance. An open system like human society may also be inferred based on many other open systems, which we will analyze using thermodynamic principles.

How can one communicate the traditions of knowledge and wisdom between the social and physical sciences? Does a language exist that is able to cross these man-made boundaries? Based on our partial experience with natural science and encounters with colleagues across this divide, we believe various concepts exist that may be able to cross these boundaries. Energy is the simplest of all such concepts. We argue that energetics can provide a viewpoint from which the subject appears not necessarily in its most fundamental form but in its simplest. Even human beings as the most complex creation of nature must adhere to the correspondence principle and the laws of nature. To assume that Mother Nature has a set of different laws for human beings would be a misapprehension.

2.1 Dynamics: Kinematics and Kinetics

The dynamics of an open system such as a human being can be described under various approaches. These may include subjective and objective approaches utilizing some measurable properties. The subjective method may include a multiplicity of theories involving the principles of natural selection. Objective methods normally try to codify the dynamics utilizing physical concepts. Some of these concepts are energy, entropy, and information. As these three concepts are mathematically related to one another (Machta, 1999) , to approach the problem using either of these threads doesn't make much difference theoretically. Following Schrodinger (Schrodinger, 1944) and Prigogine (Prigogine, 1962), many physicists have approached problems by utilizing the concept of entropy (or negentropy). Georgescu-Roegen (Georgescu-Roegen, 1971) made a seminal attempt to interpret economic processes in terms of entropy. However, characterizing the source term for entropy or information-based formulations for open and evolving human dynamics is not easy. The source term for energy is the power laymen and specialists alike can easily perceive. Even though we may have limited details of the dynamics, a provisional description based on energetics may provide some insights into the dynamics and evolution of human society. As Ostwald noted (Ostwald, 1976), no other general concepts find application in all the domains of science that include both the natural and social sciences.

2.1.1 Kinematics.

This branch of mechanics deals with the movement of an object without reference to the underlying force or the source term in general. In a conservative field, a kinematic description may suffice to characterize the movement if the nature of the force remains the same throughout. However, this is not the case for an open and evolving field like the social field. In an evolving social field, the force and energy may change autonomously over time. We will discuss this topic more in later sections.

As the father of modern economic science, Adam Smith perceived a so-called invisible hand back in the 18^{th} century; however, we have yet to decipher the term. It could be the reason why many theories in economic science are based on the kinematic description. Authors such as us are equally likely to have misunderstood or misapprehended the term. A source term like invisible hand is a key to understanding even the simplest concepts of supply and demand that may lead to the rationalization of the price of a product.

2.1.2 Kinetics

The dynamics of a system can also be described in the language of kinetics. Kinetics considers movement in tandem with the underlying forces or the source term in general. What is the source term in social dynamics? According to Bertrand Russell, it is power (Russell, 1948) : "The fundamental concept in social science is Power, in the same sense in which Energy is the fundamental concept in physics." This observation is in accordance with one of the fundamental equations governing an open system – the rate of change of energy (E) is equal to power (P), or $dE / dt = P$. Human beings and societies are open systems in which matter, energy, entropy, and information flow in and out of the system's boundaries.

How would one characterize system dynamics from the perspective of natural science? A few different types of methods are found. At the end of the day, essentially all methods are based one way or another on the Hamiltonian of the system. If one follows the suggestions of Anthony J. Leggett, a 2003 Noble Laureate in physics, first distinguishing the various levels of the problems encountered in any discipline becomes important. As is the case with condensed matter physics (Leggett, 2018), the open problems in social science may also be classified under the following three categories (Poudel & McGowan, 2019):

i. Hamiltonian, known and tractable
ii. Hamiltonian, partially known but intractable
iii. Hamiltonian, not even known.

One goal of this paper is to develop provisional equations of motion for social systems in the way Wolfgang Weidlich (Weidlich, 2002) had long sought. We quantify the Hamiltonian in the social field in natural units and make use of the Hamiltonian in order to propose equations of motion for social systems. The equations we have developed for the social system are based on kinetics. The equations involve energetic descriptions of the social system that takes the source term (i.e., social power) into account. In the following section, we briefly review the science of energetics in terms of its relevance to this study.

3. LITERATURE REVIEW

3.1 Energetics

Energy is a concept that appears in every science. The ontology of energy had not been as well established as it is perceived today until the handiwork of Scot William Macquorn Rankine in 1850. Rankine proposed a new science of energetics in 1855. Energetics is the science of studying energy and its transformations. In a modern sense, energetics may include the production, distribution, and dissipation of energy, such as those that occur in a biological cell being sometimes referred to as bioenergetics. No other general concept finds application in all the domains of science (Ostwald, 1976). This science received its currency on the foundation of the first law of thermodynamics, also known as the principle of the conservation of energy.

In the case of an open and evolving human social system, to search for equivalent concepts such as mass, inertia, or momentum may not be that meaningful. Such an inherent challenge inhibits the classical Newtonian mechanics from being extended to social systems. This challenge led curious minds like Alfred J. Lotka to rely on energetics to understand evolution (Lotka, 1922). In energetics, Lotka saw a physical principle competent that was sufficient for extending our systematic knowledge to natural selection. This remains unfinished business as something that never took off the ground (Deltete, 1983), a history of which was documented briefly by Richard Adams (Adams, 1988). Evolution through the lens of thermodynamics has been a topic of various studies (Annila & Salthe, 2010; Fox, 1988; Roddier, 2017; Chaisson, 2004). Prigogine advanced the thermodynamics of evolution formulation based on entropy dynamics (Prigogine, Nicolis, & Babloyantz, 1972). In order to expand the concept of natural selection, Weber et al. (Weber, et al., 1989) proposed a thermodynamic approach that is more appropriate to biological systems. The approach considers a biological system as embedded in the web of energetic-information relations. Recently, Adrian Bejan's Constructal Law has been gaining some momentum in interpreting evolution both in animate and inanimate systems (Bejan, Gunes, Errera, & Sahin, 2018; Bejan & Zane, 2013; Bejan A. , 2016).

Can energy flow alone create forms and structures? Or is structure/organization the basis of energy flowing through the system? Should such questions have a universal answer? Does the answer depend on whether one is talking about the living or non-living world (Swenson, 2012)? Regardless of where one starts regarding this chicken-and-egg question, one basic question remains: What is the physical reason that natural processes move in a direction of the origin and evolution of life?

Ronald Fox (Fox, 1988; Fox, 2015) argued biological organization and evolution to be a consequence of the flow of energy through matter. The motion of inanimate beads in the electric field (Kondepudi, Kay, & Dixon, 2015) appears to evolve over time to form structures. The structures formed in this way also show a self-healing mechanism. Why does life exist (Thornton, 2017)? Contrary to common observations, Morowitz and Smith (Morowitz & Smith, 2007) argued that the continuous generation of sources of free energy through abiotic processes may have forced life to have emerged into existence. This argument may also support Peter Mitchell's argument that life is a general mechanism for energy transduction. Multiple viewpoints may exist for looking at a complex adaptive system such as human society.

Regardless of where one looks from, energy flow is at the core of human life and evolution. As such, this must also be true for human society. Not only does human society evolve and develop by utilizing energy that is known in the domain of natural science, human society itself may also be a field of energy. Accordingly, we have proposed a social field theory that quantifies the energy of an individual in the social field. Regarding its structure and organization, we rely on facts created by earlier scientific research, in particular the postulates from Niels Bohr (Bohr, 1913) that state energy levels to also be quantized in the social field. His postulates accompany our efforts at understanding the first principles and causes in the Aristotelian sense. The laws of nature may have to fit together seamlessly across the living and non-living world.

3.2 Classical Field Theory: Generalization

Let x be a parameter characterizing property such as mass or charge or the (di)pole strength of matter. According to classical field theory, the potential energy PE of an object x at distance r in the field of object X is:

$$PE = -k\frac{X_i x_j}{r_{ij}^a} \tag{1}$$

For simplicity, assume · = 1. The force field F can then be expressed as

$$F = k\frac{X_i x_j}{r_{ij}^2} \tag{2}$$

Table 1 summarizes the classical gravitational, electrostatic, and magnetic fields in terms of the generalized Equations 1 and 2.

Parallel to the development of classical field theories (C. Truesdell, 1960) in natural science, many social scientists have attempted to utilize these same concepts. Harald Mey (Mey, 1972) put together such efforts in a monograph in German and translated by Douglas Scott. However, none of these attempts has yet to succeed. John Martin (Martin, 2003) reviewed isomorphic attempts in the realm of social science, and more examples are found in spatial science (Rich, 1980) and economics (Tinbergen, 1962). Recently, Neil Fligstein and Doug McAdam (Fligstein & McAdam, 2012) made an attempt to invigorate field theory into social science. They interpreted large-scale social dynamics by means of an interconnected *strategic action field* that anchors interaction and meaningful membership to the field.

None of these field theories uses the language of energy. Social force and social energy have yet to be quantified in the literature on theoretical sociology (Turner, 2012). In order to quantify an individual's social energy, we will first need to characterize humans and human society. We will review these subtle concepts in the following section.

4. SOCIAL FIELD THEORY

Many types of field theories are found in the social sciences (N.Kluttz & Fligstein, 2016). The social field theory (SFT) summarized here was born out of one of the author's efforts to understand the link between energy access and poverty dynamics (Poudel, Zheng, Wood, & McGowan, 2014). Each person may have a unique view of the world around them. In order to support this author's views on the

Table 1. Parameter and Equation of Classical Field Theories

Fields	Parameter	Two Objects		Potential Energy (*PE*)	Force (*F*)	Constant *k*
		X	*x*			
Gravitational	Mass	M	m	$\frac{Mm}{r}$	$k\frac{Mm}{r^2}$	G
Electrostatic	Charge	Q	q	$\frac{Qq}{r}$	$k\frac{Qq}{r^2}$	$k\frac{1}{4\pi \in_0}$
Magnetic	Pole strength	m_1	m_2	$\frac{m_1 m_2}{r}$	$k\frac{m_1 m_2}{r^2}$	$\frac{\mu_0}{4\pi}$

nexus between energy and poverty, we have derived a rationale from the accepted field theories in classical mechanics. SFT was particularly inspired by Bohr's postulates for the hydrogen atom, which connects classical and quantum mechanics in a way many engineering students find easy to understand.

The Earth's magnetic field deflects high energy ions, thus making the biosphere habitable. This is a fundamental property of the blue planet Earth that sets it apart from many other planets. This magnetic field may have something to do with what humans do. With regard to this epistemology, we have modeled the social field to be analogous to the magnetic field. The social field is thus characterized in terms of social strength (*S*), individual strength (*I*), and social distance (*r*). We characterize the entire spectrum of human beings at different levels of experience and understanding using the single variable *I*. This variable has a bearing in relation to the idea of pole strength in a magnetic field. According to Wright (Wright, 1942), social distance is the relation social entities have to others and is measured through the degree of their contact or isolation.

Our characterization of society is in accordance with sociologist Paul F. Lazarsfeld (Lazarsfeld, 1958), who came up with the following three key societal variables:

- Global Properties: These are not based on information individual members have regarding society,
- Analytical Properties: These are based on information individual members have about society, and
- Structural Properties: These are based on data about the relations among members.

In line with classical field theory, we have mapped these properties onto the SFT variables as presented in Table 2.

In accordance with Lazarsfeld's nomenclature, social strength (*S*) compares to the global properties, individual strength (*I*) to the analytical properties, and social distance (*r*) to the structural properties of society.

By following Lazarsfeld, we can circumvent one of the complex problems in physics: multi-body systems. Even characterizing the dynamics of the nucleons of the helium atom is a non-trivial task. *S* represents an outcome of all such known and unknown dynamics that may exist among members of a human society. According to Joseph Needham (Needham, 1942), this holistic organizational parameter can be very different from the sum of the parts. Our hope is that this macroscale variable may be inferred based on the big data that is available nowadays.

Table 2. Characteristic variables of Social Field

Lazarsfeld	Social Field Theory
Global Properties	social strength (*S*)
Analytical Properties	individual strength (*I*)
Structural Properties	social distance (*r*)

As anthropologist Clifford Geertz (Geertz, 1973) stated reiterating Nietzsche's view, human beings seem to be an incomplete or unfinished animal. *Homo sapiens* may be physically weak and incomplete, but they possess an open-ended mind that can transcend its current state. Even if all humans may have been created equal, the human mind may be able to construe various dimensions of its own reality, some real and others imaginary. Addressing all the idiosyncratic dimensions that characterize a human being may not be possible. To surmount our ignorance of a complex human being, we simply postulate that individual strength (*I*) to be a parameter in an *n*-dimensional space. Individual strength (*I*) describes a sum total of all dimensions that may be meaningful to an individual. Along the same vein, social strength (S) also has an *n*-dimensional space. However, not all dimensions of *S* may matter to an individual in question.

This characterization of the social field led us to codify field theories in a language of energetics. The potential energy (*PE*) of an individual in the social field is:

$$PE = -k\frac{S_i I_j}{r_{ij}} \qquad (3)$$

This equation suggests that *PE* of an individual is not absolute but depends on the underlying society. Equation 3 provides a conceptual framework for understanding poverty (Poudel, Zheng, Wood, & McGowan, 2014). Lee Smolin previously suggested that the property of an object is not absolute but instead depends on the environment from which the property is accessed. According to us, his assertion seems more obvious in the social field.

Here we follow natural units such that $k = 1$ and introduce a change of variable. We define the reciprocal of the social distance as the trust vector *S* where $r_{ij} = 1$. Accordingly, the *PE* of an individual is $S_i I_j$r. A force is equal to the change of potential energy per unit distance, sometimes also referred to as a potential gradient. Based on Equation 3, the social force *F* on an individual is as follows:

$$F = \frac{S_i I_j}{r_{ij}^2} = S_i I_j r_{ij}^2 \qquad (4)$$

The two hypotheses of the social field are as follows (Poudel, Wood, & Mcgowan, A Quest For Development Metrology, 2015; Poudel, Zheng, Wood, & McGowan, 2014):

HP01: The social field is a quasi-conservative field defined as a field whose total energy is a monotonic function of time.

HP02: The energy levels in the social field are quantized in similar notations as in the established models of the atom, Bohr's theory (Bohr, 1913) of the hydrogen atom, and Schrödinger's equation.

What are the justifications for these hypotheses? The first hypothesis (HP01) was inspired by our hands-on experience with certain developing societies around the world. This hypothesis is supported in part by a correlation that exists between the Energy Development Index and the Human Development Index. Energy access is a prerequisite for human development as well as wealth creation. A recent study (Garrett, 2014) quantitatively related the global rates of energy consumption to a very general metric of global economic wealth. The second hypothesis [HP02] assumes continuity of living and non-living worlds. Human society at large must be governed by the same laws of nature that have been witnessed, such as in the hydrogen atom. These two hypotheses provide a rationale to the social field in accordance with which many consequences can be deduced.

4.1 Rationale for the Concept of Fields and the Social Field

Consider the energy of an apple *A* at the surface of the Earth *E*. An apple may be characterized by a multidimensional variable where $A = A$[size, mass, color, sweetness, etc.], with the terms in brackets being certain dimensions relevant to the apple and obviously not an exhaustive list. In the same way, the Earth may also be characterized by E[size, mass, magnetic moment, density/charge distribution, etc.]. Let us simplify this energetics interactions by focusing on one of the dimensions common to both an apple and the Earth. If the dimension under study is mass (m), then we are dealing with an interaction between the apple and the earth in the gravitational field.

The potential energy of an apple in the gravitational field of the earth is $PE_1 = \frac{Gm_M m_A}{r_M}$, with r being the radius of the Earth. Consider the same apple *A* now in the field of the moon *M* at its surface. The potential energy of the same apple now becomes, $PE_2 = \frac{Gm_M m_A}{r_M}$. One may show $PE_1 \cdot 22.15 \cdot PE_2$. The apple is the same here; nothing has changed in the apple. Just moving the apple to the moon's field gives it a different absolute potential energy. We argue in the paper that this relationship is true also for a human being and human society.

Our argument is aimed at supporting the social field here. Consider two individuals who are identical in all respects and in each of the dimensions that may define the individual strength *I* of an individual. Please note that *I* is a multidimensional variable, just as *A* was above for the apple. Assume the first individual to be in Nepal and the other to be in the USA. These two human beings can have different potential energies because they are in two different societies, or to be more specific, two different social fields. Obviously, the strength of American society (S_A) is much higher than that of the strength of Nepalese society (S_N). This difference in societal strength may be attributed to an individual's migration tendency.

Let us consider one of the individuals above that got a Diversity Visa and migrated to a developed country in the West, say America. The life trajectories of these two identical individuals could be entirely different in the economic dimension. This may not be explainable without taking into account the difference between the social strengths of America and Nepal (S). In the future, some of these insights could be compared to the facts that may appear based on some empirical method. We don't yet have clear insight into any empirical method to be utilized.

5. PROPERTIES OF A SOCIAL FIELD

A social field is an open system that evolves over time. The evolution of parameters defining the social field makes it a non-inertial frame. In a subsequent section, we will provide a reason as to why a social field consisting of living beings tends to be an autonomous system.

5.1 Open System

In the case of an open system mass, energy (including entropy and information) can flow in and out of the system's boundaries. Human beings are an open system, and so is human society. A governing equation for such a system as in Figure 1 can be expressed in terms of power following the usual notations from thermodynamics.

$$\frac{dE_{in}}{dt} - \frac{dE_{out}}{dt} - \frac{dU}{dt} = P_{net} = P_{generation} - P_{dissipation} \qquad (5)$$

In Equation 5, U is internal energy, and P_{net} is net power generation internal to the system.

5.2 Evolving Field

An evolving field is a field for which the parameters characterizing the field may change over time. Suppose the Earth's mass (M) changes over time. The gravitational field around

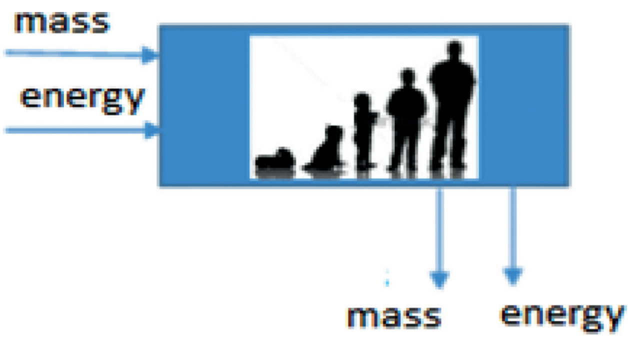

Figure 1. Open human system.

us, which Newton quantified as GM / r^2, can then be considered an example of an evolving field.

The social field is an evolutionary field in which variables characterizing the field can be expressed mathematically such that $S = S(t)$ and $I = I(t)$. These variables not only change with time but also follow a gradual sequence or direction for a reason.

5.3 Non-Inertial Frame

A non-inertial field is defined as a field in which acceleration like term may vary with time. Mathematically, this would be $\frac{d^n x}{dt^n} \neq 0$ for $n > 2$ (i.e., acceleration is not a constant). Let us compare Equation 4 with Newton's law of motion $F(\text{net}) = ma$. The acceleration term a S x^2. This term is a function of time that implies that a social field is generally a non-inertial field.

We know from classical mechanics that a pseudo force that is a function of acceleration and other parameters comes into play in the analysis of a non-inertial frame. Many people may have a feel for such pseudo forces in various experiences such as weightlessness in an elevator moving down with some acceleration.

5.4 Autonomous System

An autonomous system can generate spontaneous force and a resultant motion by itself. An external force is not mandatory for such a motion. A human being is an example of an autonomous system, and so is its ensemble: a human society. A human can utilize somatic and exosomatic energy sources to generate movements of various types. In general, an autonomous motion is a property of a living organism. The collective action of biological cells results in motions of various kinds at various scales. Likewise, the collective action of an ensemble of humans in the form of a society results in motion of various kinds, some of which may entail social evolution. A physical explanation for the autonomous motion of human society is presented in a subsequent section.

5.5 Energy: Hierarchical Field

Hierarchy is an important concept in science. An object in a hierarchical structure can be arranged by rank in terms of its properties. This concept extends from the periodic table to the food chain in the ecosystem. In a modern periodic table, elements are arranged by their atomic number. The tropic levels in the food chain are ranked in terms of their relation to the primary source of energy. These levels describe how energy may cascade in an ecosystem. Hierarchical structure is a basic fact for both biotic and abiotic worlds (Weber, et al., 1989).

Following HP02, we postulate the social field to be hierarchical in reference to the total energy of an individual. In other words, human beings can be ranked in terms of the total energy in the social field. Just like many other classical fields, the total energy is composed of two forms of energy:

$$\text{Potential Energy: } PE = -\frac{SI}{r} \quad (6)$$

$$\text{and Kinetic Energy: } KE = \frac{1}{2}\frac{SI}{r} \quad (7)$$

$$\therefore \text{ Total Energy: } TE = \text{KE} + \text{PE} = -\frac{1}{2}\frac{SI}{r} \quad (8)$$

In the social field, we equate the kinetic energy to capital (C_1), and potential energy to the capabilities (C_2) of an individual. This capital in the social field is a different term than is commonly used. Unlike the case in economic science (Nitzan & Bichler, 2009; Dobija, 2004), capital in the social field is a well-defined term that has the unit of Joules equivalent to natural units. The total energy in the social field is the Hamiltonian of an individual where $H = H(C_1, C_1, t)$. Alternatively, $H = H(S,I,r,t) = H(S,I,\Gamma,t)$.

Figure 2 depicts the energy levels quantized in relative scales of $E_n = E_1/n^2$, where n is the principle quantum number. This example is taken from the hydrogen atom. Our postulate HP02 is that energy in the social field is also quantized in some similar fashion. A difference in energy levels (E) is pronounced at the ground state but is not so apparent at higher quantum states.

5.6 Entropy

Entropy is a physical quantity with multiple interpretations. Following the analogy from thermodynamics, entropy can be written as:

$$ds = \frac{dQ}{T} = \frac{d(SI/r)}{s/\bar{r}} = \frac{d(SI\Gamma)}{S\bar{\Gamma}} \text{ or } = dI = \frac{\Gamma}{\bar{\Gamma}} + I\frac{d\Gamma}{\bar{\Gamma}} + I\frac{\Gamma}{\bar{\Gamma}}\frac{dS}{S} \quad (9)$$

For an open system, the source of entropy could be internal and external. Prigogine has broken entropy change (ds) into two components: i) the transfer of entropy across the boundary of the system ($d_e s$) and ii) the entropy produced within the system ($d_i s$). Equation 9 provides three sources of the change in entropy in the social field.

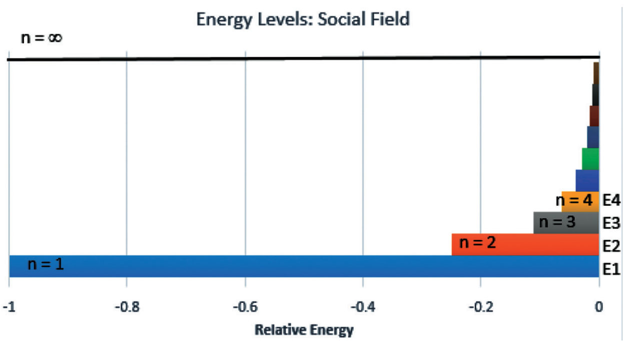

Figure 2. Relative energy levels.

If we ignore the change in Γ, Equation 9 reduces to $s = \bar{I}$ *log(SI)*. This equation is similar to the Boltzmann equation $s = k\ ln\ W$, where $= R / N_A$ is the Boltzmann constant and W is the thermodynamic probability of a macrostate.

5.7 Social Field and Social System

A social field is a field of energy, a natural physical foundation characterizing a field. It is composed of an ensemble of units defining a society. In the case of human beings, a society may be defined as an ensemble of individuals interacting and influencing one another. In his Chapter 'Clocks and Steam-engine' (Charbonnier, 1969), Claude Levi-Strauss touched upon the social field and entropy in society. Arthur de Gobineau has been credited as the first person to perceive the presence of entropy as a concomitant factor of progress and essential feature of human society.

Meanwhile, a social system is composed of both a human system and a natural system. An analysis of social systems is much more complex (Ball, 2012) than a social field and is beyond the scope of this paper. A human system may involve such things as the etiquettes, laws, and hierarchy that humans have developed for the orderly functioning of human society. Inheritance, patent system, and geopolitical economic boundaries may not be in the domain of the natural social field upon which we enumerate here in the language of energetics. social scientists may provide important insight into how one can superimpose the human system with an underlying social field to make any analysis complete and meaningful.

6. MEASUREMENT SPACE: HYPERSPACE

A phase space is a multidimensional space in which each axis corresponds to one of the coordinates required to specify the state of a physical system. A measurement space for the social field is an n-dimensional phase space of class C_2, where n is the total number of dimensions that matter to society. Note that C_2 has a different meaning than C_2. For each dimension, we have two sub-dimensions: potential energy (capabilities) and kinetic energy (capital). The class C_2 represents these two sub dimensions. Figure 3 presents a measurement space for one of the dimensions of the social field. A point in the phase space corresponds to the state of a human being at a given point in time. The measurement space of the social field is thus an n-dimensional phase space of class C2 that evolves over time. We call this hyperspace $e_2^n(t)$-space for the sake of brevity.

Let O be the origin of $e_2^n(t)$-space with respect to some point of reference. The social field is an evolving field, and hence the reference point also changes position in relation to some absolute scale. Along the x-axis, we have capital, and along y-axis, we have capabilities on a normalized scale. A human being is represented by a dot, with an ordered-pair expressed in terms of capital and capabilities. The ensemble of dots enclosed by the triangle represents the society that is under study.

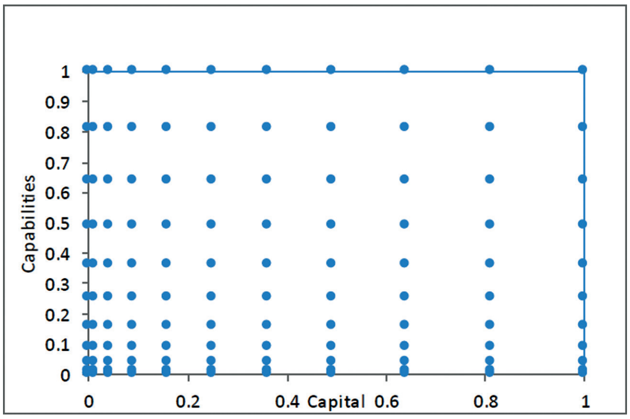

Figure 3. Measurement space for a social field.

7. SOCIAL POTENTIALS

Pierre Duhem introduced the concept of thermodynamic potentials in 1886. A thermodynamic potential is a scalar quantity used to characterize the thermodynamic state of a system. Thermodynamics consists of two types of variables: extensive and intensive. E (energy), s (entropy), V (volume) and N (number of particles) are extensive variables, whereas T (temperature), p (pressure), and C (chemical potential) are intensive variables. In thermodynamics, the functional dependence of entropy $s(E, N, V)$ on E, N, and V is called the fundamental equation (Haase, 1969), with Equation 10 relating these variables as follows:

$$dE = Tds - pdV + pdN \tag{10}$$

An equivalent version of the fundamental equation of social field in terms of energy is $H = H$ (s, N). The change in the Hamiltonian can be characterized by some change in s and N. Hence, based on multivariate calculus, we can write:

$$dH = \frac{\partial H}{\partial s} ds + \frac{\partial H}{\partial \Gamma} d\Gamma + \frac{\partial H}{\partial N} dN \tag{11}$$

Based on social field theory and following in the footsteps of Duhem and Gibbs, we have come up with social potentials (i.e., social temperature, entropy strength, and social potential). These potentials are defined as follows:

$$\left(\frac{\partial H}{\partial s}\right)_{\Gamma,N} = S\Gamma = Social\ \ Temperature \tag{12}$$

$$\left(\frac{\partial H}{\partial \Gamma}\right)_{S,N} = SI = Entropy\ \ Strength \tag{13}$$

$$\left(\frac{\partial H}{\partial N}\right)_{s,\Gamma} = \sigma = Social\ \ Potential \tag{14}$$

Expressed in terms of these social potentials, a fundamental equation in the social field thus will have the form:

$$dH = S\Gamma ds + SI\, d\Gamma + sdN \tag{15}$$

Schwarz's theorem for thermodynamic potential ∂ (*xi*, *xj*) can be written as:

$$\frac{\partial}{\partial xi}\left(\frac{\partial \phi}{\partial xj}\right) = \frac{\partial}{\partial xj}\left(\frac{\partial \phi}{\partial xi}\right) \tag{16}$$

In an attempt to extend analogies between thermodynamics and economics, John von Neumann (Neumann, 1945) had previously come up with the function (*X*, *Y*) whose role appears to be similar to that of thermodynamic potentials in phenomenological thermodynamics. economics has similar sets of equations known as Slutsky conditions (Barten, 1967). The social field, however, is a non-inertial frame, and interaction between individuals in the field tends to be non-reciprocal. For these reasons, Schwarz's theorem may not hold true in the social field. Mathematically, this is the equivalent of saying the Hamiltonian *H* is an inexact differential, such that:

$$\frac{\partial}{\partial x_i}\left(\frac{\partial H}{\partial x_j}\right) \neq \frac{\partial}{\partial x_j}\left(\frac{\partial H}{\partial x_i}\right) \tag{17}$$

The social potentials as represented by Equations 14-16 are parameters relevant to the development metrology (Poudel, Wood, & Mcgowan, 2015) and may play an important role in economic growth, development, and evolutionary process. The dynamics of the evolution of human society can also be expressed in terms of these metrics. Nevertheless, we choose to adopt an approach similar to that of classical mechanics in the subsequent sections in order to keep it simple for our readers and ourselves.

8. LIVING VERSUS NON-LIVING

Living beings respond to external stimuli, whereas non-living objects react. Objects react only to influences acting upon them at the instant that those influences act, which is a concept also known in physics as object egotism (Biology Education Research Group at University of Maryland College Park, 2011). Here we define the reaction as a subset of the response. Our first approximation is that a living creature has the ability to go beyond local action-reaction symmetry as described by Newton's third law ($R_{AB} = - R_{BA}$). Multiple reasons may exist for this asymmetry. Object egotism is a fundamental concept underlying Newtonian physics. We human beings are more than that. As a living creature, humans can scale, lead, or lag behind reaction forces. Hence a human being's general response to the external stimulus R may be expressed as:

$$R(t) = -R(t)\, R(t \pm r) \tag{18}$$

The response depends on the current time, history, and future projections (i.e., memory and foresight). Here is a scale factor and is lead/lag time.

This demarcation of living and non-living may create more questions than it may answer. This preliminary definition, however, is inspired partly by the conventional approaches of physics that aim for tracing the phenomena of nature back to the simple laws of mechanics (Hertz, 1899). This definition, even if it is primitive, may resonate with many observations encountered in the hierarchical social field. People may respond differently depending on whether an action being imposed upon them is by their peers, subordinates, or superiors in terms of power. We propose this formalism to build a base with mainstream classical physics and to move up the ladder to understand complex human life better. This approach may strengthen the wisdom of many scholars who believe in the continuity of the living and non-living world.

Consider an ensemble of human beings chosen arbitrarily from Figure 2; we may call this physical ensemble society. In Figure 4, *i* and *j* are indices counting the human beings *Mi* in the multi-body social field, with *G* being a centroid of some kind and *R* being a reaction force. In the social field, *H* is generally an inexact differential as defined in Equation 17.

The reaction force relates to the Hamiltonian following Equation 19 based on Green's theorem. If the *KE* and *PE* functions of *H* are independent of each other, the reaction force may reduce to zero.

$$\oint R(r,t)dr = \iint \left(\frac{\partial H_2}{\partial C_1} - \frac{\partial H_1}{\partial C_2}\right) dC_1 dC_2 \tag{19}$$

Figure 4 portrays an interaction of a system of particles *Mi* for living and non-living systems. As shown in Figure 4(a), the internal forces $\boldsymbol{R}_{ij}$ and $\boldsymbol{R}_{ji}$ in many non-living systems are equal and opposite and have the same line of action. Hence, their sum $\boldsymbol{R}_{ij} + \boldsymbol{R}_{ji} = 0$. This is not the general case for living systems. For a living system as in Figure 4(b), $\boldsymbol{R}_{ij} + \boldsymbol{R}_{ji} = 0$. The internal forces may not always be balanced between conscious human beings. Hence, a multi-body physical ensemble (society as marked in Figure 3) will have a net force plus a moment around *O*. This net force/moment renders the social field autonomous. In addition, a living system also possesses an intrinsic force $\boldsymbol{R}_{ii}$ of various degrees. Consciousness is the ability of a living creature to sense its environment plus itself. A human being can utilize its consciousness to move alone and/or with society up the energy ladder (see Figure 2) by also utilizing the intrinsic force $\boldsymbol{R}_{ii}$. D'Alembert's principle (Beer, Jr., Cornwell, & Self, 2015) may not hold true in the social field. In other words, the system of external forces acting on human beings *Mi* and the system of these human beings' effective forces are not equipollent. D'Alembert's principle is normally valid for a system where $\boldsymbol{R}_{ij} + \boldsymbol{Rji} = 0$, and $\boldsymbol{R}_{ii}$ is absent.

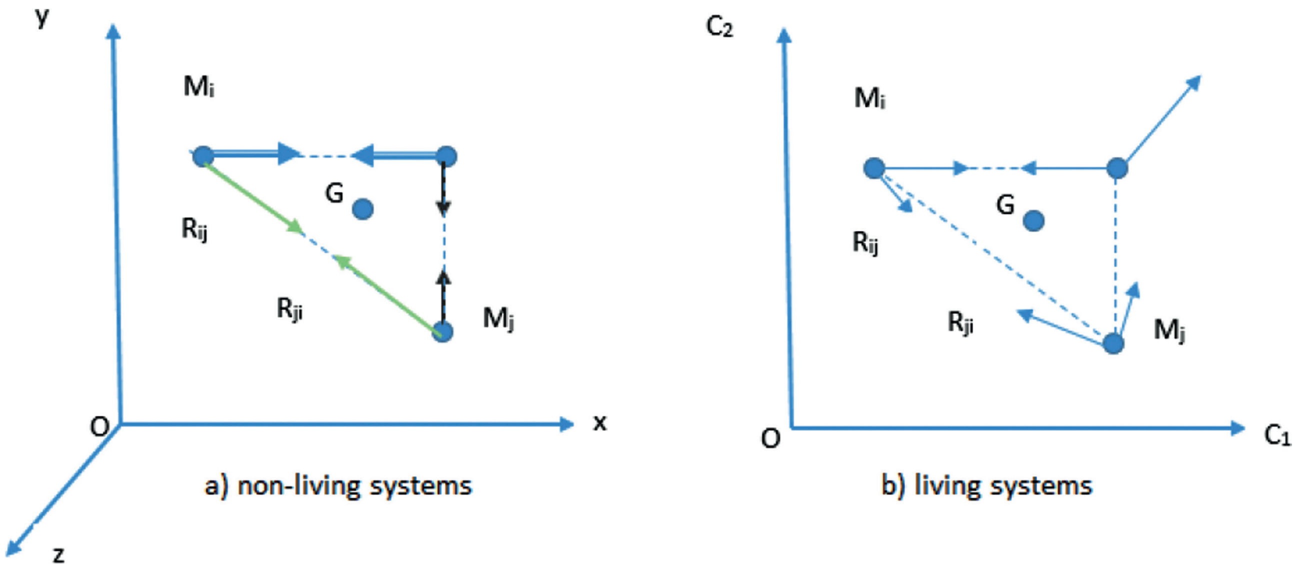

Figure 4. Non-reciprocal interaction in a social field.

9. AUTONOMOUS SYSTEM

As explained above, an ensemble of human beings can generate a force plus moment by its own mechanism, mainly because the internal forces ***Rij*** may generally not balance out one another. Such a system does not require an external intervention in order to change the current state of the system. This is a feature of the living world that is not often seen in the non-living world. In the case of most of the rigid body systems, the internal forces balance each other. The system reacts mostly to an external force and other induced dynamic forces. In the case of human beings, humans also possess intrinsic force *Rii*. Even if repressible at times, this force is the very reason a social system is an autonomous system. An autonomous system is generally composed of units (sub-systems) that can pump energy in and out the system. In other words, the subsystem (or constituents) of an autonomous system must consume energy in order to transform energy into work of some kind.

10. EQUATION OF MOTION

The equations of motion (EOM) describe a general time evolution of a state of systems. We want to reiterate at the outset that we are proposing the EOM in the social field, not for the social system. A social system is a complex amalgam of human-made and natural systems. Hence, these EOMs would not be able to account completely for the complex dynamics we witness in human society. Nonetheless, a concept of the social field may provide a new canvas upon which the complex EOMs of social systems can be sketched.

Many EOMs are based on Newton's second law (i.e., $F = ma$). The EOM of the human social system, however, is expressed in terms of power for a reason. In fact, the equation we propose for the social field is the power equation $P = F\,v$, where power (P) is defined as the rate of change of energy. The change of energy is expressed in terms of the total derivative of the Hamiltonian $H = H(S, I, r, t)$ in the framework of the Navier-Stokes' equations. In short, we present an expression for the dynamics of human evolution in the language of energetics.

10.1 Why Navier-Stokes?

The Navier-Stokes' equations are the cornerstone of fluid dynamics at various lengths and time scales. These equations belong to a class of fundamental equations in non-equilibrium statistical physics (XiuSan, 2010). The momentum and energy equations can handle source and sink terms. These terms may represent energy generation and dissipation influencing the autonomous social field. Hence, this class of equations makes perfect sense for a quasi-conservative field (HP01).

10.2. Equation of Motion: Individual

A society has been characterized by a set of variables: social strength (S), individual strength (I), trust vector ($H = 1 / r$) and time (t). Based on SFT, the Hamiltonian $H = H(S, I, r, t)$ corresponds to the total energy of the social field under analysis. Its time evolution can be written in total derivative form as

$$\frac{dH}{dt} = \frac{\partial H}{\partial t} + \frac{\partial H}{\partial S}\frac{dS}{dt} + \frac{\partial H}{\partial I}\frac{dI}{dt} + \frac{\partial H}{\partial r}\frac{dr}{dt} \tag{20}$$

The three macro variables (S, I and r) of society are not yet developed enough in social science to be able to define or measure. Hence, the equations of the social field shall be presented here based on the Hamiltonian comprised of the composite variables and capital (C_1) and capabilities (C_2) of individuals in the society as:

$$\frac{dH}{dt}=\frac{\partial H}{\partial t}+\frac{\partial H}{\partial C_1}\frac{dC_1}{dt}+\frac{\partial H}{\partial C_2}\frac{dC_2}{dt} \quad (21)$$

The reaction forces among human beings give rise to forces of various kinds resulting ultimately in power dynamics. Following the discussion in Section 8, these forces can be grouped into extrinsic (F_{ex}) surface force and intrinsic (F_{en}) body forces. The surface force results mainly from interactions among individuals (i.e., $j \neq i$), whereas the body force is intrinsic to an individual.

$Ri = \sum_{j=1}^{n}(r)R_{ji}(t \pm \tau)$ for $j \neq i$ Surface Force | Extrinsic

R_{ii} Systematic force Body Force | Intrinsic (22)

These forces drive the change $\delta H/dt$ of the Hamiltonian in the autonomous social field and vice versa. By including the source/sink terms $\dot{Q}$ to account for other generation and dissipation, we get:

$$\underbrace{\frac{dH}{dt}}_{\text{Local Derivative}}+\underbrace{\frac{\partial H}{\partial C_1}\frac{dC_1}{dt}+\frac{\partial H}{\partial C_2}\frac{dC_2}{dt}}_{\text{Convective Derivative}}=\underbrace{(F_{en}+F_{ex})\frac{dr}{dt}\pm\dot{\mathbb{Q}}}_{\text{Forcing or Power Terms}} \quad (23)$$

In terms of the trust vector, the right hand side of the equation gets modified as:

$$\frac{dH}{dt}+\frac{\partial H}{\partial C_1}\frac{dC_1}{dt}+\frac{\partial H}{\partial C_2}\frac{dC_2}{dt}=(F_{en}+F_{ex})\frac{1}{\Gamma^2}\frac{dr}{dt}\pm\dot{\mathbb{Q}} \quad (24)$$

Many people may care more about a relative change in the Hamiltonian with reference to some datum D or the amount of change accumulated over a time window dt. The relative change $\Pi(r,t)$ may be expressed in several ways, some of which are presented below as:

$$\left.\begin{array}{l} H(r,t)-H_D(r,t);\quad \text{where } D \text{ stands for datum} \\ H_f(r,t)-H_i(r,t) \\ \dfrac{H_f(r,t)}{H_i(r,t)} \\ \text{Log return } r(\log)=\text{in}\left(\dfrac{H_f(r,t)}{H_i(r,t)}\right) \end{array}\right] \quad (25)$$

The nature of the equation of motion for an individual or society would not be affected by a change in variables. Equations 23 and 24 describe the dynamics of the evolution of an individual in the social field. The following section presents equations governing the dynamics of the social field itself.

10.3 Equation of Motion: Society

A human society is an ensemble of individuals influencing one another in the social field. Members of a society can influence each other in various ways, mainly in terms of energy, entropy, and information as well as through an exchange of matter. Suppose a society has N individuals. The Hamiltonian (H_s) of a society can be aggregated as the sum total of the Hamiltonian in the ensemble. Hence:

$$H_s(n, t) = \sum_{k=1}^{N} H_k(n, t) \quad (26)$$

We can also represent H_s in terms of the probability distribution function in the $e_2^n(t)$-space.

Normalize $\int H(n, t)dr = 1$, and $H(n, t) \geq 0$ (27)

On the same basis as Equation 27, an equation of motion for a human society will take the form:

$$\frac{\partial}{\partial t}H_s(n,t)=-\sum_{\substack{i=1,2\\n}}\frac{\partial H_s(n,t)}{\partial C_i}$$
$$\dot{C}_i+(F_s(n,t)+F_b(n,t))\dot{r}_n\pm\dot{\mathbb{Q}}_s \quad (28)$$

The summation on the *RHS* covers all dimensions and the class C_2 over the $e_2^n(t)$-space. An aggregated multi-body equation in a society leads to an implicit Fokker-Planck equation.

Equation 28 is a multivariate Fokker-Planck equation describing the time evolution of H_s in the absolute scale. Following a different approach and characterization, Dirk Helbing (Helbing, 1993) has previously introduced social field/forces on the basis of Boltzmann-Fokker-Planck equations.

10.4 Coarse-Graining: Reduced Order Model

What are the major dimensions that are important for a society? We depend on social scientists to help us on this coarse-graining. One of the field theorists in sociology, Pierre Bourdieu has implied three major forms of capital (Bourdieu, 1986). Accordingly, we propose to contract the n-dimensional social field to $\boldsymbol{R}^3$ to make it manageable. These three reduced dimensions of the social field are: i) economic b) cultural, and c) social. Following the SFT, some logical consequences can be drawn to interpret trends in social capital as brought forward by Putnam (Putnam, 2001). We will leave it to social scientists to evaluate if an assertion based on energetics may make sense to interpret the declining trends in social capital across many societies. In the following section, we present how Lotka-Volterra-type equations can be derived from Equation 28 by simplifying the assumptions of the social field.

10.5 Lotka-Volterra Equation

Lotka-Volterra (LV) equations are coupled first-order nonlinear equations that describe the evolution of two interdependent quantities. This simplified model was developed independently by Lotka and Volterra around the first-quarter of the 20th century. These deterministic equations are easy to explain in order to demonstrate a nonlinear dependency of a pair of variables of interest, and hence became popular as a standard example for hands-on modeling exercises in many academic disciplines. Interesting dynamical concepts such as the attractor, limit-cycles, and others can be illustrated utilizing LV equations. These equations are extended to real-world applications in various ways.

For two interdependent variables x and y, the LV equation (Lotka, 1910) can be expressed as:

$$\frac{dx}{dt} = k_1 x - k_2 xy; \frac{dy}{dt} = -k_3 y + k_4 xy \tag{29}$$

We can multiply the first equation by y and the second by x, then add them together to get a simplified version (with $k_4 = k_2$) as:

$$xy + yx = (k_1 - k_3)\, xy + k_2 xy(x - y) \tag{30}$$

Next, we establish that the time-dependent Hamiltonian equation (i.e., Equation 28) reduces to the LV equation (i.e., Equation 30) under special conditions. Let's assume the following form of the Hamiltonian to illustrate the concept:

$$H(C_1, C_2, t) = C_1 + C_2 + k\frac{C_1 C_2}{C_1 + C_2} \tag{31}$$

where $k = k\ (t)$ and is a parameter that describes the symbiotic relationship between capabilities and capital (Poudel, Wood, & Mcgowan, 2015). The third term in the *RHS* from Equation 31 represents an effect of the positive (or negative) feedback loop (see Figure 5) between these two variables that are interdependent in the social field. If these variables are independent (i.e., coupled but with no feedback loop), this translates to $k = 0$, which reduces Equation 31 to the common definition of total energy.

The special conditions are:

- Normalized energy scale, $C_1 + C_2 = 1$ and k = 1;
- No explicit dependence of H on time (i.e., $\frac{\partial}{\partial t} H_s$(n, t) = 0);
- Linear or constant body force $F_b\ (n,t)$ on H_s
- Neglecting the dissipation term (i.e., $\dot{Q}_s = 0$
- Under these above conditions, we may write:

$$H \cdot (C_1, C_2, t) = 1 + C_1 \times C_2) \tag{32}$$

Change of variables: $y = C_1$, $x = C_2$, $\dot{y} = \frac{dC_1}{dt}$ and $\dot{x} = \frac{dC_2}{dt}$

Substituting H in Equation 19, the *RHS* terms $F_s(n,t)\dot{\mathrm{r}}_{\mathrm{n}}$ from Equation 28 reduce to the surface integral:

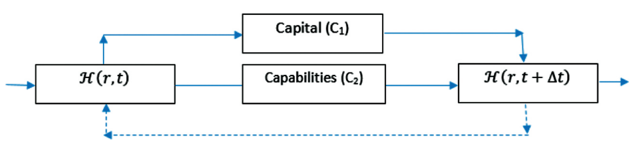

Figure 5. Feedback loop between capital and capabilities.

$$\iint (x - y)dx\,dy = a_1 x + a_2 + \frac{1}{2}(x^2 y - xy^2)$$

The first term in the *RHS* from Equation 28 can be expressed as:

$$\sum_{\substack{i=1,2\\ n}} \frac{\partial H_s(n,t)}{\partial C_i} \dot{C}_1 = x\dot{y} + y\dot{x}$$

Substituting these values into Equation 28 while also including a linear body force, we can get a form of the LV equation as follows:

$$x\dot{y} + y\dot{x} = a_1 x + a_2' + a_3 xy + \frac{1}{2} xy(x - y) \tag{33}$$

Equation 33 is one form of the LV equation. In other words, the LV-type equations can be derived from the time-dependent Hamiltonian equation in the social field.

11. IMPLICATIONS: PHYSICS AND ECONOMICS

Social field theory claims to formalize a new form of energy and hence may help break the glass ceiling of utilizing thermodynamics to study social dynamics. Many scholars (Muller, 1998; Jaynes, 1991; Ayres & Nair, 1984; Richmond, Mimkes, & Hutzler, 2013; Glucina & Mayumi, 2010) including ET Jaynes trusted thermodynamics to bridge the well-lit roads on each side of the natural and social science divide. A good theory can inform what is actually available to measure for a research question. This paper may provide what to look for in the sea of big data for some testable hypothesis in relation to the dynamics of human society. The ideas embedded here may provide a clue to understanding turbulence in fluid dynamics as well as the chaos in social dynamics that takes place in some parts of the world. We will address these issues in the future, and as we do so, we will develop further confidence in this under-explored territory of social energetics. For the time being, here are some implications for physics and economics.

11.1 Physics

Is a social field plausible? Or is it just another fantasy? Physicists are probably in the best position to evaluate these questions. An analysis of open systems may have to go beyond a narrow lens of the conservation laws. An overarching assumption such as the conservation of money takes us nowhere in our efforts to deepen our understanding of what money is. The SFT is expressed here in natural units, hence it demands a Cavendish experiment, this time in the social science domain. Such an experiment may pave the way for quantifying the capabilities (*PE*) of an individual in a given social field. How can these ideas, if plausible, inform policy decisions, especially in terms of helping catalyze development under real circumstances on the ground?

The social field theory is accompanied by two fundamental postulates. One is an extension of Bohr's postulates, and the other is based on the review of the repository of knowledge developed by progenitors. These postulates need to go through rigorous experimental testing in order to prove their ability to stand on their own. Our hope is that these postulates will survive because convergence is the ultimate nature of science. One measure of progress in the development of any science is its ability to make close contact with other sciences (Weber, et al., 1989; Mirowski, 1990). We need to discover a generally acceptable conceptual framework and a language that will facilitate communication and stimulate further coherent research across the natural and social sciences beyond econophysics (McCauley, Roehner, Stanley, & Schinckus, 2016) as it exists today. Economic science may benefit most from such a framework, and the ongoing synergy of physicists and economists may escalate to another level of cooperation in order to better understand the issues challenging humanity.

1.2 Economics

Money is a concept of paramount significance to economic science. The energetics framework conceives of money in accordance with the original insights of Howard Odum (see Chapter 4: Energy and Money (Odum & Odum, 1976)). Money flows in circles, but energy flows through a system and ultimately out in a degraded form. To sum up, energy and money flow hand in hand but in opposite directions. For further details, we refer readers to Howard Odum (Odum, 1971) and Frederick Soddy (Soddy, 1921); we decided not to duplicate their original insights in this short paper.

Another hope of ours is that SFT may provide a new physically-oriented underpinning of economic science. Economics through the lens of energetics is a science up in the air and above an abstraction layer. Economic science tends to abstract many things human beings value in pecuniary terms. Such an abstraction facilitates exchanges and efficiency but obscures a lot of the dynamics that are important for comprehending a social system. Spolsky said (Spolsky, 2002), "All non-trivial abstractions to some degree are leaky." Abstraction facilitates the buildup of complex systems such as the global economic system. A system based on abstraction, however, is bound to fail sooner or later to some extent. A recession may be an instance of the abstraction's failure. Let's not go too far out of our comfort zone. We acknowledge economic science to be much more complex than physics because it has dealt mostly with the non-living world and only very recently with active matters.

The SFT may provide a clue toward a non-overlapping definition of capital and capabilities (Poudel, Wood, & Mcgowan, 2015) . A credit is a stake in the capabilities. Poverty relates to the energy state of an individual in a society. An individual who migrates to a new society may well be at another energy level than had they stayed in their native society. The business cycles result from an interplay between capital and capabilities in an autonomous society that is able to generate a source term of its own. We have witnessed inequality in a modern society as a possible consequence of pseudo-forces in the non-inertial social field. Alternative physical reasons exist for wealth inequality (Bejan & Errera, Wealth inequality: The physics basis, 2017). A recession like the one in 2008 may be a by-product of some sort of polarization. Equally so, it could trigger a bandwagon effect that influences trust vectors among various peoples in the global economic society. We have established here a logical explanation as to why the social field is an autonomous field. The social field neither requires an external intervention to break symmetry nor does it necessitate Adam Smith's invisible hand to prescribe a function.

12. DISCUSSION

This research is an outgrowth of our efforts to better understand the energy-poverty nexus. Energetics can pave the way for the integration of knowledge across two cultures and in time perhaps furnish an expression for the dynamics of human society. We may have come up with a viewpoint that is not visible from the natural or social science perspective alone. Equally possible, this blue-sky thinking may be considered a lax analogy by some; we admit this probable nexus portends that we have gone beyond our comfort zones. An academic discipline is like a valley in the mountain. One may be better off focusing on cultivating one's own valley. Nonetheless, we believe it is worth the effort. Our inspiration distills in the words of Churchill: "It is not enough that we do our best; sometimes we must do what is required." Energetics provides a map of roads over the mountains connecting these academic valleys designated as natural and social sciences. This roadmap may not be enough; we may need to pave the way for these roads at a more fundamental level. Eventually, we will also need to build and illuminate tunnels between these academic valleys for which we will rely on the further study of physicists and social scientists. This can't be another case of a fish being oblivious to water, similar to the flat earth and geocentric models. We believe this is another problem we face by utilizing the human knowledge that has not been given to anyone in its totality (Hayek, 1945). The social field cannot be a no man's land between the natural and social sciences.

Social science relies on concepts based on the intuition of its forefathers who raised many important questions that are even interesting to natural scientists. The postulates based on SFT may provide deductive reasoning for some of the dynamics we've witnessed in the hierarchical social field. We don't claim that the normative question in the social sciences can be inferred entirely based on scientific reasoning.

Instead, SFT may provide a foundation upon which some common universal principles may be extended for studying both the natural and social sciences. The common principle we suggest is based on an energetics approach that acknowledges the hierarchical structure of the social field and its underlying power dynamics. A most important element of any inquiry is the foundation upon which we search for answers to many research questions. A superficial and inadequate foundation may not provide an adequate answer to a question, even if we apply the most rigorous methods at a later stage of investigation (Northrop, 1947). SFT may catalyze our efforts to complement our understanding of evolution and provide an alternative line of reasoning for some of the dynamics we've witnessed in our society. Evolution is not just a biological process (Chaisson, 2004), it applies equally well to human society.

Chemiosmosis (Mitchell, 1962) is a mechanism by which a biological cell extracts energy from its environment. As an aggregate of biological cells, human life can't possibly be an exception. Human beings generate and dissipate energy in the social field, and its evolution is bounded by the same universal principles of energetics. We expand the energetic approach to connect the dots of knowledge in order to theorize human evolution at the macroscale. Upon the logical foundation of the SFT, we have explained how the dynamics of human life are rooted in physics and thermodynamics. The same universal principles of physics manifest at scales ranging from the atomic to the human as well as planetary scales and beyond. We propose SFT as a bridge connecting disciplines (Hall, Lindenberger, Kümmel, Kroeger, & Eichhorn, 2001) such as physics and economics and one that may also add to the knowledge of the life sciences. Not only does SFT provide a new perspective on evolution based on the laws of physics, it also provides a logical foundation for understanding cooperative behavior (Pennisi, 2005) among human beings and human societies.

Hopefully, one day we will have a better sense of the molecular roots of evolution (Ball, 2013) and the principles underlying human life, as Frederick Soddy, Bertrand Russell, Manfred Eigen, and many others have suggested. To fill in this gap, we must rely on something beyond a firsthand knowledge of the subject. We submit the SFT and underlying energetics-based equations as a stopgap for our knowledge about equations of motion for social systems. These equations may be valid in the social field but not completely valid for the social system, as the latter is made up of human-made and natural systems.

13. CONCLUSION

In an effort to understand human life through physics, we have presented a theoretical model of human beings by generalizing classical field theories. The social field theory formalizes the energy of an individual in the social field. Upon the logical foundation of the field theory, we have developed a provisional version of equations of motion for social systems, which Wolfgang Weidlich had claimed were non-existent in the literature. The Lotka-Volterra-type equations can be derived from the time-dependent Hamiltonian equations in the social field. A model based on the social field theory that we present here may complement the existing exploratory causal mechanisms of the evolution of human society. This model may contribute to an understanding of why evolution works and open up some new perspectives. Energetics makes evolution possible. All models are wrong, but some are useful for some time as humans develop knowledge. We anticipate that an energetics model based on social field theory be useful for bridging the *terra incognito* between the natural and social sciences.

ACKNOWLEDGMENTS

We benefited from the inputs of participants at multiple conferences. We would especially like to mention participants of the 7th BioPhysical Economics meeting (BPE-2016) (Poudel & McGowan, 2016; Poudel R. C., 2016); the 9th Biennial Conference of the United States Society for Ecological Economics (USSEE); the 11th American Society of Nepalese Engineers (ASNEngr) Annual Conference 2018; and the Complex Systems Group Meeting (2018) at Worcester Polytechnic Institute. We owe a long list of scholars and progenitors for their direct and indirect intellectual contributions to this paper. We did not seek any funding for this research. RP acknowledges a sabbatical granted by the Institute of Engineering, Tribhuvan University.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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